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Revised Multicolour Edition Based on CCE Pattern

As per NCERT/CBSE Syllabus

Science for Ninth Class

Part - 2

Chemistry

Containing answers to NCERT book questions and value-based questions

LAKHMIR SINGH
MANJIT KAUR

S. CHAND School

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This book has been revised according to the CCE pattern of school education based on NCERT syllabus prescribed by the Central Board of Secondary Education (CBSE) for Class IX

Science for Ninth Class

(PART – 2)

CHEMISTRY

As per NCERT/CBSE Syllabus
(Based on CCE Pattern of School Education)

Containing answers to NCERT book questions and value-based questions

Lakhmir Singh

And

Manjit Kaur

This Book Belongs to :

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MANJIT KAUR did her B.Sc., B.Ed. from Delhi University in 1970. Since then she has been teaching in a reputed school of Directorate of Education, Delhi. Manjit Kaur is such a popular science teacher that all the students want to join those classes which she teaches in the school. She has a vast experience of teaching science to school children, and she knows the problems faced by the children in the study of science. Manjit Kaur has put all her teaching experience into the writing of science books. She has co-authored more than 15 books alongwith her husband, Lakhmir Singh.

It is the team-work of Lakhmir Singh and Manjit Kaur which has given some of the most popular books in the history of science education in India. Lakhmir Singh and Manjit Kaur both write exclusively for the most reputed, respected and largest publishing house of India : S.Chand and Company Pvt. Ltd.

An Open Letter

Dear Friend,

We would like to talk to you for a few minutes, just to give you an idea of some of the special features of this book. Before we go further, let us tell you that this book has been revised according to the NCERT syllabus prescribed by the Central Board of Secondary Education (CBSE) based on new "Continuous and Comprehensive Evaluation" (CCE) pattern of school education. Just like our earlier books, we have written this book in such a simple style that even the weak students will be able to understand chemistry very easily. Believe us, while writing this book, we have considered ourselves to be the students of Class IX and tried to make things as simple as possible.

The most important feature of this revised edition of the book is that we have included a large variety of different types of questions as required by CCE for assessing the learning abilities of the students. This book contains :

(*i*) Very short answer type questions (including true-false type questions and fill in the blanks type questions),

(*ii*) Short answer type questions,

(*iii*) Long answer type questions (or Essay type questions),

(*iv*) Multiple choice questions (MCQs) based on theory,

(*v*) Questions based on high order thinking skills (HOTS),

(*vi*) Multiple choice questions (MCQs) based on practical skills in science,

(*vii*) NCERT book questions and exercises (with answers), and

(*viii*) Value based questions (with answers).

Please note that answers have also been given for the various types of questions, wherever required. All these features will make this book even more useful to the students as well as the teachers. "A picture can say a thousand words". Keeping this in mind, a large number of coloured pictures and sketches of various scientific processes, procedures, appliances, manufacturing plants and everyday situations involving principles of chemistry have been given in this revised edition of the book. This will help the students to understand the various concepts of chemistry clearly. It will also tell them how chemistry is applied in the real situations in homes, transport and industry.

Other Books by Lakhmir Singh and Manjit Kaur

1. Awareness Science for Sixth Class
2. Awareness Science for Seventh Class
3. Awareness Science for Eighth Class
4. Science for Ninth Class (Part 1) PHYSICS
5. Science for Tenth Class (Part 1) PHYSICS
6. Science for Tenth Class (Part 2) CHEMISTRY
7. Science for Tenth Class (Part 3) BIOLOGY
8. Rapid Revision in Science
   (A Question-Answer Book for Class X)
9. Science for Ninth Class (J & K Edition)
10. Science for Tenth Class (J & K Edition)
11. Science for Ninth Class (Hindi Edition) :
    PHYSICS and CHEMISTRY
12. Science for Tenth Class (Hindi Edition) :
    PHYSICS, CHEMISTRY and BIOLOGY
13. Saral Vigyan (A Question-Answer Science
    Book in Hindi for Class X)

We are sure you will agree with us that the facts and formulae of chemistry are just the same in all the books, the difference lies in the method of presenting these facts to the students. In this book, the various topics of chemistry have been explained in such a simple way that while reading this book, a student will feel as if a teacher is sitting by his side and explaining the various things to him. We are sure that after reading this book, the students will develop a special interest in chemistry and they would like to study chemistry in higher classes as well.

We think that the real judges of a book are the teachers concerned and the students for whom it is meant. So, we request our teacher friends as well as the students to point out our mistakes, if any, and send their comments and suggestions for the further improvement of this book.

Wishing you a great success,

Yours sincerely,

Lakhmir Singh
Manjit Kaur

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Alaknanda, New Delhi-110019
E-mail : singhlakhmir@hotmail.com

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FIRST TERM

SECOND TERM

LATEST CBSE SYLLABUS, CLASS 9 SCIENCE

(CHEMISTRY PART)

FIRST TERM
(April to September)

Matter : Definition of matter ; Solid, liquid and gas ; Characteristics–shape, volume, density ; Change of state – melting (absorption of heat), freezing, evaporation (cooling by evaporation), condensation, sublimation

Nature of matter : Elements, compounds and mixtures ; Heterogeneous and homogeneous mixtures ; Colloids and suspensions

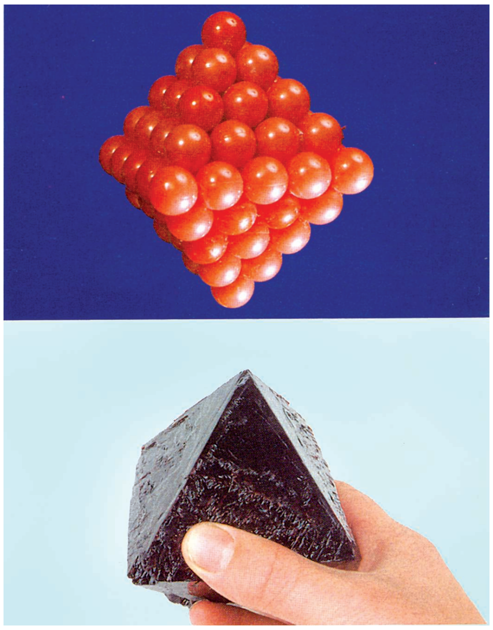
SECOND TERM
(October to March)

Particle nature, basic units : Atoms and molecules, Law of conservation of mass and law of constant proportions ; Atomic and molecular masses

Mole concept: Relationship of mole to mass of the particles and numbers ; Valency ; Chemical formulae of common compounds

Structure of atom : Electrons, protons and neutrons ; Isotopes and isobars

1



MATTER IN OUR SURROUNDINGS

Anything which occupies space and has mass is called matter. Air and water ; hydrogen and oxygen ; sugar and sand ; silver and steel ; copper and coal ; iron and wood ; ice and alcohol ; milk and oil ; kerosene and petrol ; carbon dioxide and steam ; carbon and sulphur ; rocks and minerals ; are all different kinds of matter, because all of them occupy space (that is, they have volume), and mass.

If we look around us, we can see a large number of things of different shapes, sizes and textures. Many of these things are used by us in our everyday life. For example, we eat food, drink water, breathe in air and wear clothes. We use table and chair for studying and bed for sleeping. We also see other human beings, various animals, plants, and trees around us. The things like food, water, air, clothes, table, chair, human beings, animals, plants and trees, etc., are all examples of matter.

The only conditions for 'something' to be 'matter' are that it should *'occupy space' and 'have mass'*. Now, the things like friendship, love, affection, hatred, good manners, thoughts, ideas, taste and smell, etc., do not occupy space and do not have mass. So, from the point of view of chemistry, things like friendship, love, affection, hatred, good manners, thoughts, ideas, taste and smell are not considered 'matter' (though all these things matter a lot in our everyday life !).

Matter can be classified in a number of ways. Ancient Indian philosophers said that all the matter (*padarth*), living or non-living, was made up of five basic elements (*panch tatva*) : air, earth, fire, sky and water (*vayu, prithvi, agni, akash* and *jal*). Modern day scientists classify matter in two ways : on the basis of its **physical properties** and on the basis of its **chemical properties.** On the basis of physical properties, matter is classified as solids, liquids and gases. And on the basis of chemical properties, matter is classified as elements, compounds and mixtures. In this chapter, we will study the classification of matter on the basis of its physical properties. The classification of matter on the basis of its chemical properties will be described in the next chapter.

MATTER IS MADE OF PARTICLES

Everything around us is made of tiny pieces or *particles.* Our body is made of particles, our chair is made of particles, our table is made of particles and this book is also made of particles. The number of particles in everything is, however, very, very large. For example, a small rain drop (water drop) contains about 10^{21} particles of water in it ! The particles which make up matter are so small that we cannot see them even with a high power microscope. Even without seeing them, we have certain evidence which tells us that all the things (or all the matter) is made of tiny particles. We will now give some of the evidence which clearly shows that all the matter is made up of tiny particles. This evidence also shows that the particles which make up the matter are constantly 'moving' (they are in motion). Please note that **the particles which make up matter are atoms or molecules.**

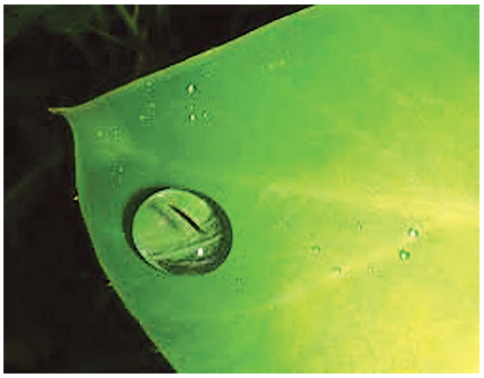


Figure 1. A small rain drop on this leaf of a plant is made up of about 1000,000,000,000,000,000,000 particles !

Evidence for Particles in Matter

Most of **the evidence for the existence of particles in matter and their motion comes from the experiments on diffusion (mixing of different substances on their own), and Brownian motion.** It is easy to explain 'what happens in several experiments' if we believe that matter is made up of tiny particles which are in motion. But without the concept of particles, things become very difficult to explain. We will now describe some simple experiments like 'dissolving of a solid in a liquid', 'mixing of two gases' and 'movement of pollen grains in water' which can only be explained by assuming that all matter is made up of tiny particles which are constantly moving.

Figure 2. This picture shows the diffusion of potassium permanganate in water.

1. Dissolving a Solid in a Liquid

Potassium permanganate is a purple coloured solid substance and water is a colourless liquid, so **we will first study the dissolving of potassium permanganate in water**. When a crystal of potassium permanganate is placed in a beaker of water, the water slowly turns purple on its own, even without stirring (see Figure 3). The spreading of purple colour of potassium permanganate in the whole water of beaker can be explained as follows.

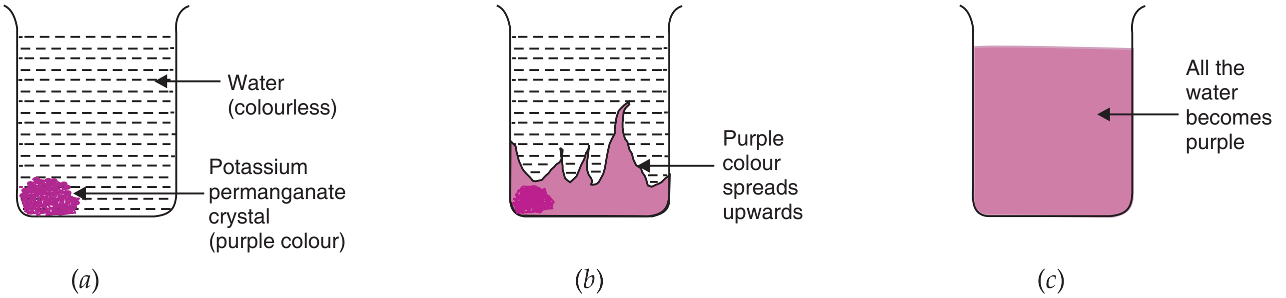


Figure 3. The colour of potassium permanganate spreads in the whole beaker of water on its own.

Both, potassium permanganate crystal and water are made up of tiny particles. The particles of potassium permanganate are purple coloured whereas the particles of water are colourless. When the potassium permanganate crystal is put in water, its particles separate from one another. These purple coloured particles of potassium permanganate spread throughout water making the whole water look purple (see Figure 4). Actually, on dissolving, the particles of potassium permanganate get into the spaces between the particles of the water.

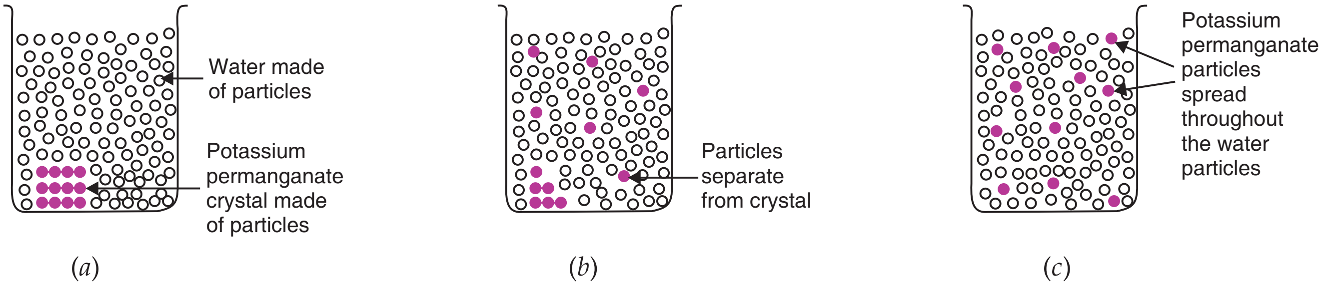


Figure 4. The particles of potassium permanganate crystal spread into the particles of water, making the whole water purple.

In this experiment, the particles of potassium permanganate and those of water mix on their own, without any external stirring. Since the particles of potassium permanganate and particles of water spread into each other and mix up on their own, it is concluded that 'they are moving' or 'they are in motion' [we can see this as the spreading of purple colour upwards in the beaker of water as shown in Figure 3(*b*)]. If the particles were not moving, the colour could not spread throughout the beaker on its own. This movement of different particles among each other (on their own), so that they become mixed uniformly, is called *diffusion*.

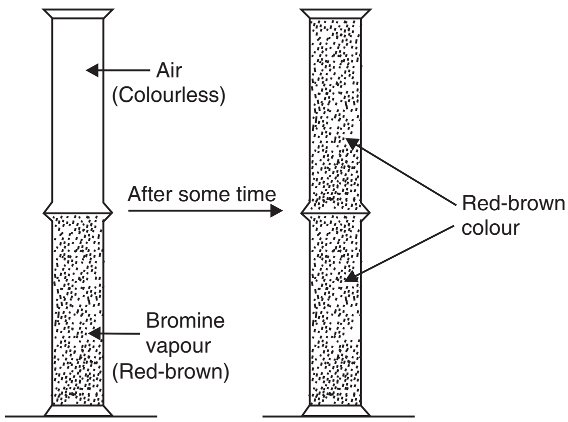
We will now discuss the case of sugar dissolving in water. When sugar is added to water and stirred, it dissolves quickly. The sugar seems to disappear. What happens to the sugar when it dissolves ? Where does the sugar go ? We can explain how the sugar dissolves and disappears in water by using the idea of particles.

Both sugar and water are made up of very small particles. These particles are too small to see even under a microscope. When sugar dissolves, tiny sugar particles break off from each solid sugar granule. These sugar particles go into the spaces between the particles of water, and mix with them. So, the sugar solution will taste sweet even though we cannot see the sugar in it. Please note that in this experiment we have dissolved sugar in water by 'stirring'. This has been done just to dissolve the sugar quickly. Even if we don't stir, sugar will dissolve in water, but quite slowly.

2. Mixing of Two Gases

Air is a colourless gas (or mixture of gases). When a gas jar is empty, it is actually filled with air. This is because since air is colourless, we cannot see it in the gas jar. Bromine is a red-brown liquid. It forms vapour easily. Bromine vapour (or bromine gas) is red-brown in colour, and it is heavier than air. Let us perform the experiment now.

A gas jar containing air is placed upside down on a gas jar of bromine vapour [see Figure 5(*a*)]. We will see that the red-brown vapours of bromine from the lower gas jar spread up into air in the upper gas jar. And after some time, the gas jar containing air also becomes completely red-brown in colour [see Figure 5(*b*)].



(*a*) Before (*b*) After

Figure 5. The diffusion of bromine vapour into air.

The spreading up of bromine vapour into air can be explained as follows : Both air and bromine vapour are made of tiny moving particles. The moving particles of bromine vapour and air collide with each other and bounce about in all directions, due to which they get mixed uniformly. This is another example of *diffusion*. Please note that though bromine vapour is heavier than air, even then it goes up (against gravity) and mixes with air in the upper jar because its particles are moving with high speeds due to which they have sufficient kinetic energy to overcome the force of gravity and go up into the gas jar containing air. Another point to be noted is that *air present in the upper gas jar also diffuses downwards into bromine vapours in the lower gas jar* but since air is colourless we cannot notice its presence in the lower gas jar.

The process of diffusion gives us two conclusions about the nature of matter :

(*i*) that matter is made up of tiny particles, and

(*ii*) that the particles of matter are constantly moving.

Before we go further, we should know the meaning of terms 'pollen' and 'pollen grain'. Pollen is a powdery substance discharged from the male part of a flower called stamen. Pollen is actually present in the top part of stamen called 'anther'. Pollen contains microscopic particles called pollen grains. Thus, pollen grains are extremely minute and light particles.

3. Movement of Pollen Grains in Water

The best evidence for the existence and movement of particles in liquids was given by Robert Brown in 1827. Robert Brown suspended extremely small pollen grains in water. On looking through the microscope,

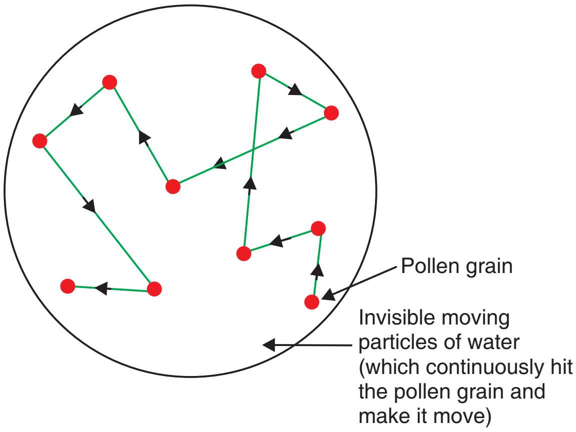


Figure 6. Brownian motion as observed through a microscope. This figure shows the path of a single pollen grain as it is being bombarded by the tiny, invisible particles of water (in which it is placed).

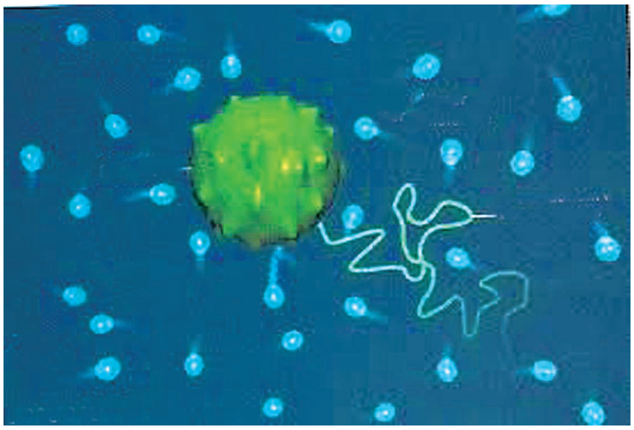


Figure 7. This is a highly enlarged picture to show the phenomenon of Brownian motion. In this picture we can see the fast moving water particles (or water molecules) hitting the pollen grain and causing it to move in a zig-zag path.

it was found that the pollen grains were moving rapidly throughout water in a very irregular way (or zig-zag way) (see Figure 6). It was also observed that warmer the water, faster the pollen grains move on the surface of water.

The movement of pollen grains on the surface of water can be explained as follows : Water is made up of tiny particles which are moving very fast (The water particles or water molecules themselves are invisible under the microscope because they are very, very small). **The pollen grains move on the surface of water because they are constantly being hit by the fast moving particles of water.** So, though the water particles (or water molecules) are too small to be seen, but their effect on the pollen grains can be seen clearly. The random motion of visible particles (pollen grains) caused by the much smaller invisible particles of water is an example of *Brownian motion* (after the name of the scientist Robert Brown who first observed this phenomenon).

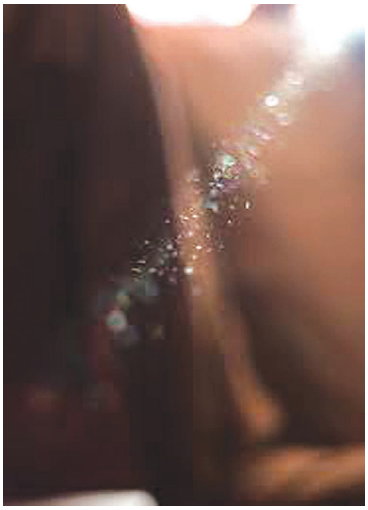


Figure 8. This picture shows a beam of sunlight entering a room. We can see tiny dust particles suspended in air moving rapidly in a haphazard way. This is an example of Brownian motion in gases.

Brownian motion can also be observed in gases. Sometimes, when a beam of sunlight enters a room, we can see tiny dust particles suspended in air which are moving rapidly in a very haphazard way. This is an example of Brownian motion in gases (because air is a gas). **The tiny dust particles move here and there because they are constantly hit by the fast moving particles of air.**

Though we cannot see the particles (or molecules) of air which are extremely small, but we can see the effect produced by their continuous and fast motion. The rapid and random movement of tiny dust particles (or smoke) suspended in air shows that air is made up of particles and that the particles of air are moving constantly. We can now define Brownian motion as follows. **The zig-zag movement of the small particles suspended in a liquid (or gas) is called Brownian motion.** Brownian motion increases on increasing the temperature.

The existence of Brownian motion gives us two conclusions about the nature of matter :

(*i*) that matter is made up of tiny particles, and

(*ii*) that the particles of matter are constantly moving.

Characteristics of Particles of Matter

The important characteristics of particles of matter (like atoms or molecules) are the following :

(*i*) The particles of matter are very, very small

(*ii*) The particles of matter have spaces between them

(*iii*) The particles of matter are constantly moving

(*iv*) The particles of matter attract each other

We will now perform some simple experiments to show all the characteristics of the particles of matter. The samples of matter (or materials) which we will be using for performing these experiments are potassium permanganate, water, sugar, incense stick (*agarbatti*), air, copper sulphate, a piece of chalk, ice and an iron nail.

1. The Particles of Matter are Very, Very Small

The very, very small size of the particles of matter can be shown by performing the following experiment by using potassium permanganate and water. Potassium permanganate is a kind of matter. We take 2 or 3 small crystals of potassium permanganate and dissolve it in 100 millilitres (100 mL) of water in a beaker. We will get a deep purple coloured solution of potassium permanganate in water [see Figure 9(*a*)]. Take 10 mL of deep purple solution of potassium permanganate from the first beaker and mix it with 90 mL of

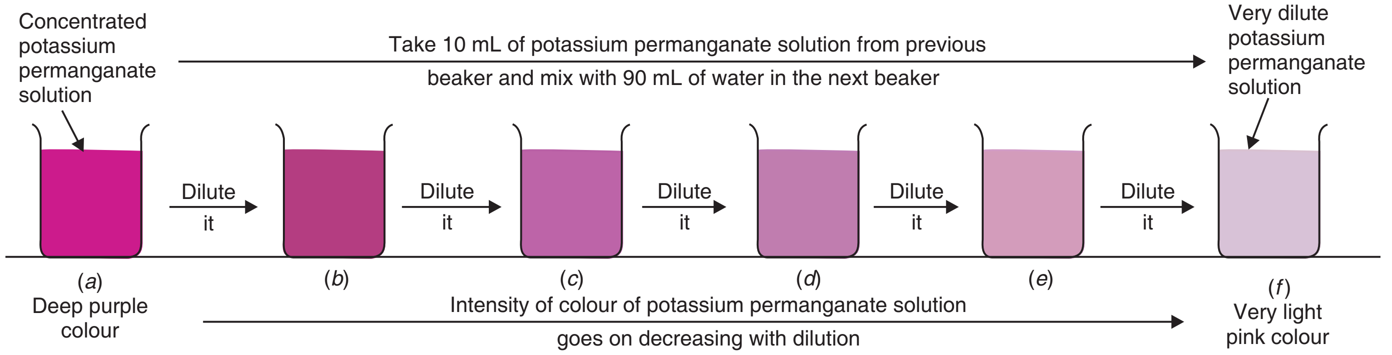


Figure 9. Even after diluting the potassium permanganate solution a number of times, the colour of potassium permanganate persists in the solution.

water present in second beaker, to dilute it [see Figure 9(*b*)]. Due to this dilution, the colour of potassium permanganate solution in the second beaker becomes a bit lighter. Now, take 10 mL of potassium permanganate solution from the second beaker and mix it with 90 mL of water present in the third beaker, to dilute it further [see Figure 9(*c*)]. The colour of solution will become still lighter. We keep on diluting the potassium permanganate solution like this a number of times (say, five times). In this way, we get a very dilute solution of potassium permanganate in water but the water is still coloured (it has a light pink colour now) [see Figure 9(*f*)].

This experiment shows that just 2 or 3 tiny crystals of potassium permanganate can impart colour to a large volume of water. From this observation we conclude that **each potassium permanganate crystal**

itself must be made up of millions of small particles which keep on spreading and imparting colour to more and more of water (on dilution). Since each tiny crystal of potassium permanganate is supposed to be made up of millions of particles, therefore, these particles must by very, very small !.

2. The Particles of Matter have Spaces Between Them

The spaces between the particles of matter can be shown by performing the following experiment by using water and sugar. We take about 100 mL of water in a beaker (Water is a kind of matter). Mark the level of water in the beaker with a marking pen [as shown in Figure 10(*a*)]. Also take 50 grams of sugar. Now add 50 grams of sugar in water in the beaker. Dissolve the sugar by stirring it with a glass rod [see Figure 10(*b*)]. When all the sugar has dissolved, we get a sugar solution. Let us look at the level of sugar

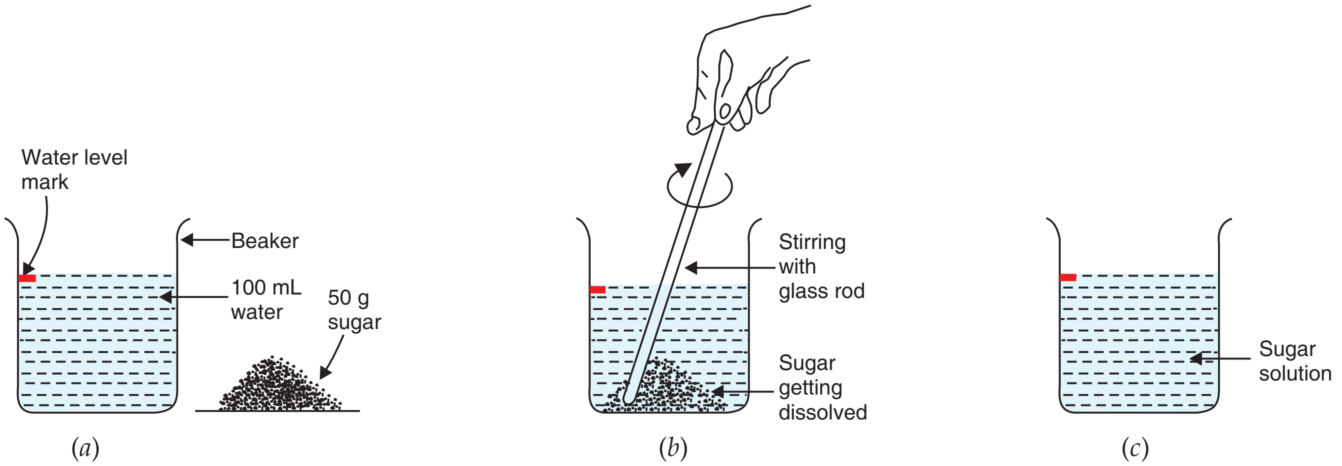


Figure 10. When we dissolve sugar in water, there is no change in the volume of water.

solution in the beaker. We will find that the level of sugar solution in the beaker is at the same mark where water level was initially in the beaker [see Figure 10(*c*)]. This means that **even after dissolving 50 grams of sugar in 100 mL of water, the volume has not increased.** This can be explained by assuming that the particles of water have some spaces between them.

When sugar is dissolved in water, its crystals separate into very fine particles. These particles of sugar go into the spaces between the various particles of water due to which there is no change in the volume of water on dissolving sugar in it. **The fact that there is no change in volume on dissolving sugar in water tells us that there are spaces between the particles of water.** And these spaces accommodate the sugar particles. This also gives us another conclusion that **the particles (or molecules) in water are not tightly packed, they are somewhat loose, having spaces between them.**

3. The Particles of Matter are Constantly Moving

The best evidence that particles of matter are constantly moving comes from the studies of diffusion and Brownian motion (which we have already discussed). We will now describe two more experiments involving diffusion in gases and diffusion in liquids which will show us that the particles of matter (gases and liquids) are constantly moving.

(*a*) **When we light (or burn) an incense stick (*agarbatti*) in one corner of a room, its fragrance (pleasant smell) spreads in the whole room quickly.** This observation can be explained as follows : The burning of incense stick produces gases (or vapours) having pleasant smell. The particles of gases produced by the burning of incense stick move rapidly in all directions, mix with the moving particles of air in

Figure 11. The fragrance of a burning incense stick (*agarbatti*) spreads in the entire room very quickly.

the room, and reach every part of the room quickly (alongwith air). When the gaseous particles from the incense stick reach our nose with air, we can smell the fragrance. If, however, the particles of gases produced by the burning of incense stick and the particles of air were not moving, then the fragrance of incense stick could not spread in the whole room quickly. So, **the observation that the fragrance of a burning incense stick spreads in the entire room very quickly tells us that the particles of matter (here incense gases and air) are constantly moving.**

(*b*) We will now describe the diffusion of copper sulphate into water. Copper sulphate crystals are blue in colour. **When a few crystals of copper sulphate are placed at the bottom of a beaker (or a gas jar) containing water, then water in the whole beaker turns blue slowly.** This can be explained on the basis of motion of copper sulphate particles and water particles as follows. The crystals of copper sulphate dissolve in a little of water around them to form fine particles of copper sulphate in solution. Now, the particles of copper sulphate in solution are in motion and the particles of clear water are also moving. Due to the motion of their particles, the blue copper sulphate particles in solution move upwards in the beaker and the colourless water particles move downwards, and mix with each other. This is called *diffusion.* This diffusion of copper sulphate particles and water particles into each other goes on until the whole water turns blue. Thus, **the spreading of blue colour of copper sulphate crystals in water is due to the movement of both, copper sulphate particles as well as water particles.**

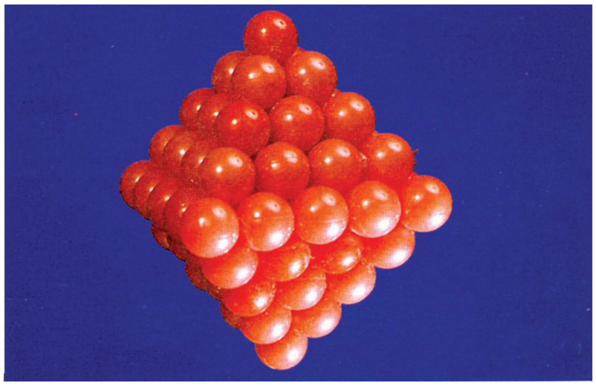
Figure 12. Diffusion of copper sulphate in water.

If we carry out this experiment by using hot water in the beaker (or gas jar), we will find that the water turns blue at a faster rate. This is because, on heating, the particles of water and that of copper sulphate gain kinetic energy and move faster. And due to faster movements, they mix into each other more quickly.

4. The Particles of Matter Attract Each Other

There are some forces of attraction between the particles of matter which bind them together. The force of attraction between the particles of the same substance is known as cohesion. The force of attraction (or cohesion) is different in the particles of different kinds of matter. This will become more clear from the following examples.

(*a*) This is an actual chrome alum crystal. It is a solid. The force of attraction between the particles of chrome alum is large



(*b*) This is the model of chrome alum crystal showing the arrangement of particles in it. These particles attract one another with a large force

Figure 13. The force of attraction between the particles of 'solid matter' is the maximum.

If we take a piece of chalk, a cube of ice and an iron nail, and beat them with a hammer, we will find that it is very easy to break the piece of chalk into smaller particles, it requires more force to break a cube of ice, whereas the iron nail does not break at all even with a large force. This shows that the force of attraction between the particles of chalk is quite weak, the force of attraction between the particles of ice is a bit stronger whereas the force of attraction between the particles of iron nail is very, very strong.

Let us take another example. We can move our hand through air very, very easily because the force of attraction between the particles of air (which is a gas) is very, very small. It is negligible. We can also move our hand through water in a bucket fairly easily because the force of attraction between the particles of water (which is a liquid) is also small. But we cannot move our hand through a plank of wood because the force of attraction between the particles of wood (which is a solid), is very strong. And if we try breaking a plank of wood with a blow of our hand, our hand will get hurt. It needs a karate expert to move his hand through a plank of wood and break it into two. In general, **the force of attraction is maximum in the particles of solid matter and minimum in the particles of gaseous matter.** Let us solve one problem now.

Sample Problem. What happens to the sugar when it dissolves in water ? Where does the sugar go ? What information do you get about the nature of matter from the dissolution of sugar in water ?

Solution. (*a*) When sugar dissolves in water, its tiny particles break off from the solid 'sugar crystals'.

(*b*) The sugar particles go into the spaces between the particles of water and mix with them (to form sugar solution).

(*c*) The dissolution of sugar in water tells us that :

(*i*) the matter (here sugar and water) is made up of small particles.

(*ii*) the particles of matter (here water) have spaces between them.

Figure 14. Stone is a solid. It is rigid (hard or stiff).

Figure 15. Milk is a liquid. It is a fluid.

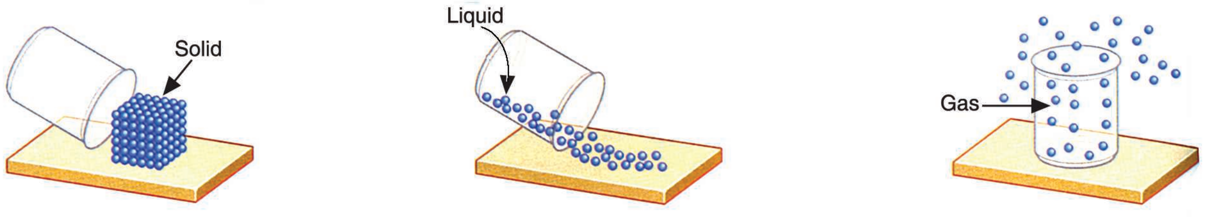
Figure 16. Chlorine (inside the flask) is a gas. It is also a fluid.

Rigid and Fluid

Before we give the definitions of solids, liquids and gases, we should know the meaning of two new terms : rigid and fluid. **Rigid means 'unbending' or 'inflexible'.** A stone is rigid because it is unbending or inflexible. **Fluid means 'a material which can flow easily' and requires a vessel (or container) to keep it.** Water is a fluid because if we pour water on the top of a table, it flows over the surface of the table. Moreover, water requires a vessel to keep it. Milk is a fluid and chlorine gas is also a fluid. Keeping these points in mind, we will now define solids, liquids and gases.

A solid is a rigid form of matter. Due to their rigidity, solids have a tendency to maintain their shape when subjected to outside force. Thus, the main identifying characteristic of solids is their **rigidity.** Solids do not require a container to keep them. A brick and a log of wood are two common solids. **A liquid is a fluid form of matter which occupies the lower part of the container in which it is kept. A liquid does not fill the whole container.** Being fluids, liquids require a container to keep them. A liquid has a well-defined surface, so a liquid can be kept in an open container. The liquid will not escape from the open container by itself. Water and milk are two common liquids around us.

A gas is a fluid form of matter which fills the whole container in which it is kept. Being fluids, gases also require a container to keep them. A gas does not have a free surface, so a gas has to be kept in a closed container. A gas will escape if kept in an open container. This is why gases are usually kept in air-tight gas cylinders. For example, cooking gas (LPG) is kept in air-tight metal cylinders. From this discussion we conclude that both, **liquids and gases are known as fluids.** Please note that the characteristic of liquids and gases of 'flowing' easily is called **'fluidity'.** Due to fluidity, liquids and gases change their shapes readily when subjected to outside force. We will now discuss the classification of matter as solids, liquids and gases in detail.



(*a*) (*b*) (*c*)

Figure 17. Solids cannot flow, so they are not fluids. Liquids and gases can flow, so they are fluids.

CLASSIFICATION OF MATTER AS SOLIDS, LIQUIDS AND GASES

On the basis of physical states, all the matter can be classified into three groups : Solids, Liquids and Gases. For example :

(*i*) Sugar, sand, iron, wood, rocks, minerals and ice are solids,

(*ii*) Water, milk, oil, kerosene, petrol and alcohol are liquids, and

(*iii*) Air, oxygen, hydrogen, carbon dioxide and steam are gases.

Solids, liquids and gases are called the three states of matter. In other words, **matter exists in three physical states : solid, liquid and gas.** The solids, liquids and gaseous forms of matter have different properties. The characteristic properties of solids, liquids and gases are given below. These properties can be used to distinguish between the three states of matter : solid, liquid and gas. Let us start with the properties of solids.

Properties of Solids

Ice, wood, coal, stone, iron, brick, etc., are some of the common solids around us. The solids have the following characteristic properties :

1. Solids have a **fixed shape** and a **fixed volume.**
2. Solids **cannot be compressed** much.
3. Solids have **high densities.** They are heavy.
4. Solids **do not fill their container completely.**
5. Solids **do not flow.**

Figure 18. This brick is a solid. A solid has a definite shape and a definite volume.

Figure 19. This orange juice is a liquid. A liquid has a definite volume but no definite shape.

Figure 20. This balloon is filled with air (which is a gas). A gas has neither a definite volume nor a definite shape.

Properties of Liquids

Water, milk, fruit juice, ink, groundnut oil, kerosene and petrol, etc., are some of the common liquids. The liquids have the following characteristic properties :

1. Liquids have a **fixed volume** but they have **no fixed shape**. Liquids take the shape of the vessel in which they are placed.
2. Like solids, liquids **cannot be compressed** much.
3. Liquids have **moderate to high densities.** They are usually **less dense than solids.**
4. Liquids **do not fill their container completely.**
5. Liquids generally **flow easily.**

Properties of Gases

Air, oxygen, hydrogen, carbon dioxide, nitrogen and steam, etc., are some of the common gases. The gases have the following characteristic properties :

1. Gases have **neither a fixed shape nor a fixed volume.** Gases acquire the shape and volume of the vessel in which they are kept.
2. Gases **can be compressed easily** (into a small volume).
3. Gases have **very low densities.** They are very, very light. A gas is much lighter than the same volume of a solid or a liquid.
4. Gases **fill their container completely.**
5. Gases **flow easily.**

Why Solids, Liquids and Gases Have Different Properties

We will now try to explain why solids, liquids and gases have different properties by using the kinetic theory of matter. This is discussed below.

Matter in all the three states, solid, liquid and gas, is made up of very small particles (atoms and molecules). **According to the kinetic theory of matter, the particles of matter are in continuous motion (and possess kinetic energy).** Some forces of attraction also exist between the particles of matter. These are called interparticle forces. The forces of attraction tend to hold the particles together and control their movements. The interparticle forces of attraction are the maximum when the particles are close together. As the distances (or spaces) between the particles of matter increase, the forces of attraction between them decrease. The movement of particles (or kinetic energy of particles) can be changed by heating the matter (or cooling it). Higher the temperature, greater is the movement of particles. We can now say that the following properties of particles determine the physical state of matter. That is, **the following properties of particles decide whether a given substance will exist as a solid, a liquid or a gas :**

1. **The spaces (or distances) between the particles.** The spaces (or distances) between the particles are the minimum in solids, a little more in liquids, and the maximum in gases.
2. **The force of attraction between particles.** The forces of attraction between the particles (or interparticle forces) are the strongest in solids, less strong in liquids and negligible in gases.
3. **The amount of movement of particles (or kinetic energy of particles).** The movement of particles (or kinetic energy of particles) is the minimum in solids, more in liquids and the maximum in gases.

Keeping these points in mind, we will now describe the structure of solids, liquids and gases, and explain the differences in their properties on the basis of these structures.

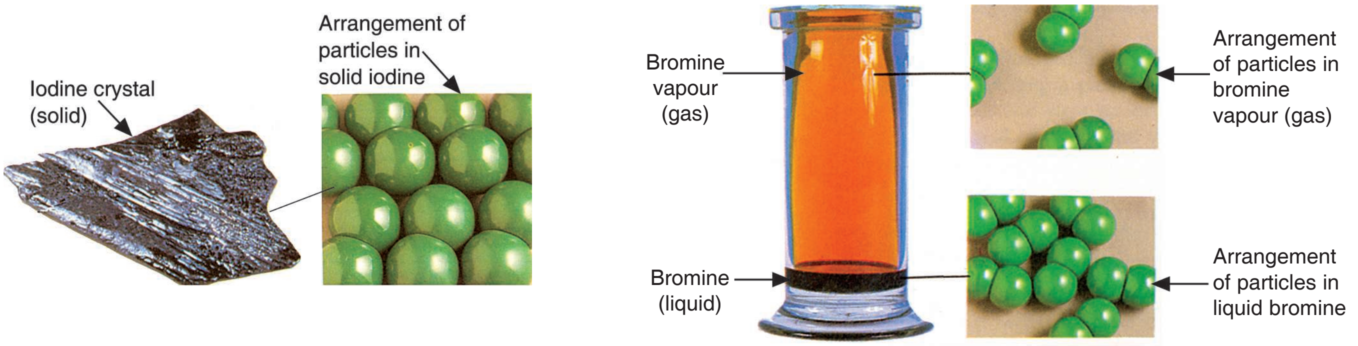
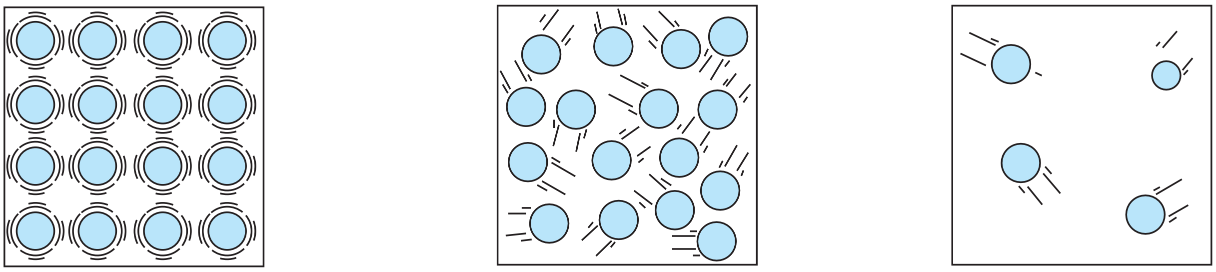


Figure 21. The spaces (or distances) between the particles are the minimum in solids, a little more in liquids, and the maximum in gases.

SOLIDS

In solids, the particles are closely packed [see Figure 22(*a*)]. There is a strong force of attraction between the particles of a solid which holds them together in fixed positions. Thus, the positions of particles in a solid are fixed. The particles of a solid only vibrate about their fixed positions. They cannot move from one position to another. If a solid is heated, its particles start to vibrate faster. The spaces (or distances) between the particles of a solid are very, very small. The particles of a solid have the minimum kinetic energy. Due to this, solids have the most orderly arrangement of particles.

We will now explain the properties of solids. **A solid has a fixed shape** because the particles of a solid are closely packed and their positions are fixed due to the strong forces of attraction between them. **A solid has a fixed volume** because the spaces between its particles are fixed. **A solid cannot be compressed much** because its particles are already very closely packed and there are hardly any spaces between them.



(*a*) Solid (*b*) Liquid (*c*) Gas

Figure 22. Arrangement of particles in solids, liquids and gases.

A solid has a high density because its particles are very close together. **A solid does not fill its container completely** because its particles are held tightly by strong interparticle forces and hence cannot leave their positions to fill the whole container. Similarly, **a solid does not flow (like a liquid does)** because its particles are held very strongly and unable to leave their fixed positions.

We have just learnt that a solid has a fixed shape. Now, **a rubber band changes its shape on stretching, then why do we call it a solid ?** This can be explained as follows : A rubber band is considered a solid because it changes shape under the action of force (which stretches it), and when the force is removed, the rubber band regains its original shape. Like all other solids, if rubber band is stretched with a large force, it breaks.

We will now discuss the case of salt and sugar. When salt and sugar are put in jars of different shapes, they take the shape of the jars, indicating that they do not have a fixed shape. So, **if salt and sugar do not appear to have a fixed shape, then why do we call them solids ?** Actually, this problem arises because salt and sugar have very tiny crystals. Salt and sugar are considered to be solids because the shapes of individual crystals of salt and sugar remain fixed, even when they are put in jars of different shapes.

We have also learnt that solids cannot be compressed much. Now, **a sponge can be compressed easily, so why do we call sponge a solid ?** This can be explained as follows : A sponge is considered to be a solid because its compressibility is due to the presence of minute pores in it which are filled with air. When we press the sponge, air is expelled from its holes making it highly compressible.

LIQUIDS

In liquids, the particles are close together, but they are not as close as in solids. In fact, the particles are somewhat loosely packed in liquids [see Figure 22(*b*)]. The spaces between the particles of a liquid are slightly more than that in a solid but they are still very small. There is a quite strong force of attraction between the particles of a liquid which holds them together but the force is not strong enough to hold the particles in fixed positions. So, due to comparatively less strong interparticle forces, the positions of particles in a liquid are not fixed. The particles of a liquid can move from one position to another within the liquid. The particles of a liquid have more kinetic energy than the particles of a solid. Due to this, the liquids have a more disorderly arrangement of particles than solids. The particles in a liquid are also vibrating. If a liquid is heated, then its particles begin to move faster.

We will now explain the properties of a liquid. **A liquid does not have a fixed shape** because the positions of its particles are not fixed due to comparatively less strong forces of attraction between them. A liquid takes the shape of its container because the particles of a liquid can slide over one another easily. **A liquid has a fixed volume** because, at a given temperature, the spaces between its particles are fixed. **A liquid cannot be compressed much** because its particles are still quite close together and have very small spaces between them. **A liquid has comparatively high density** because its particles are still quite close together. **A liquid does not fill its container completely** because its particles are held fairly strongly by the interparticle forces and hence cannot leave the body of liquid to fill the whole container. **A liquid generally flows easily** because its particles are able to slide over one another due to slightly weaker interparticle forces of attraction.

To Show that Liquids do not have a Fixed Shape but they have a Fixed Volume

Water is a liquid, so we will use water in this experiment. We take some water in a beaker and mark the level of water in it [see Figure 23(*a*)]. We will find that water takes the shape of the beaker. We pour this water from the beaker into other containers (or vessels) of different shapes, one by one.

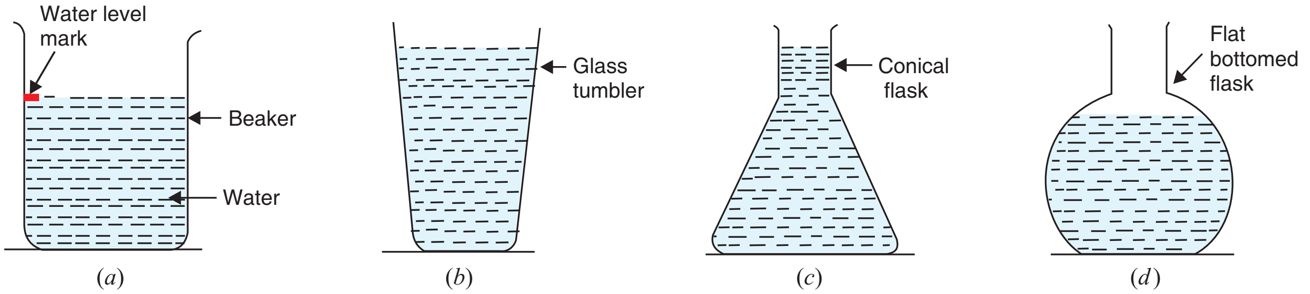


Figure 23. A liquid (here water) takes the shape of its container.

First we pour the water from beaker into a glass tumbler. We will find that water takes the shape of the glass tumbler [see Figure 23(*b*)]. Then we pour this water in a conical flask. We will find that the same water now takes the shape of a conical flask [Figure 23(*c*)]. And finally we pour the water from conical flask into a flat-bottomed flask. The water now takes the shape of a flat-bottomed flask [Figure 23(*d*)]. From this experiment we conclude that water has no fixed shape of its own, it takes the shape of the container (or vessel) in which it is poured. In general, we can say that **"A liquid has no fixed shape. It takes the shape of its container".**

Now, let us pour the water from the flat-bottomed flask back into the original beaker. We will find that water fills the beaker up to the same mark. This means that there is no change in the volume of water when it is poured into different containers. From this we conclude that water has a fixed volume which does not change on changing the container. In general we can say that **"A liquid has a fixed volume".**

GASES

In gases, the particles are much farther apart from one another as compared to solids and liquids [see Figure 22(*c*)]. The spaces (or distances) between the particles of a gas are very large. The force of attraction between the particles of a gas is negligible. So, the particles of a gas are free to move in any direction. The positions of particles of a gas as well as the spaces between the particles of a gas are not fixed. The particles of a gas have the maximum movement (or maximum kinetic energy). Due to this, the gases have the most disorderly arrangement of particles. Because of high kinetic energy and negligible forces of attraction, the particles of a gas move with high speeds in all directions. When the fast moving gas particles hit the walls of the container, they exert a pressure (called gas pressure). Thus, a gas exerts a pressure on the walls of its container. The pressure exerted by a gas is due to the collisions of the fast moving gas particles against the walls of the container. When a gas is put in an empty container, it quickly spreads throughout the container and fills it completely. If a gas is heated, the particles of gas start moving faster and faster.

Figure 24. When we blow air into a balloon, the air particles (gas particles) push the balloon walls from inside and exert pressure on them. This air pressure causes the balloon to inflate. Thus, a gas exerts pressure on the walls of its container.

We will now explain the properties of gases. **A gas does not have a fixed shape** because the positions of its particles are not fixed. **A gas does not have a fixed volume** because the spaces between its particles are not fixed. Since the particles of a gas are free to move anywhere, it takes the shape and volume of its container. **A gas can be compressed easily** because its particles are far apart and there are large spaces between them (which can be reduced by compression). **A gas has a very low density** because its particles are very far apart from one another. **A gas fills its container completely** because due to high kinetic energy and negligible forces of attraction, the particles of a gas are moving with high speeds in all directions. **A gas flows easily** because its particles are completely free to move anywhere.

To Show that Gases do not have a Fixed Shape or a Fixed Volume

Air is a gas, so we will use air in this experiment. We take two balloons of different shapes and sizes. Let us fill equal amount of air in both the balloons. We will find that the air takes the shape of the balloon in which it is filled. For example, in Figure 25(*a*), the balloon has a round shape so the air takes the round shape of the balloon. In Figure 25(*b*), the balloon has a long shape, so the air takes the long shape of this balloon. This shows that air has no fixed shape of its own, it takes the shape of the container (here balloon) in which it is filled. In general we can say that **"A gas has no fixed shape. It takes the shape of its container".** If we look at the round balloon and long balloon shown in Figure 25, we will find that they have different volumes. This shows that the air in the two balloons has different volumes. From this we conclude that the volume of air is not fixed. It takes the volume of the container (here balloon). In general we can say that **"A gas has no fixed volume. It takes the volume of its container".**

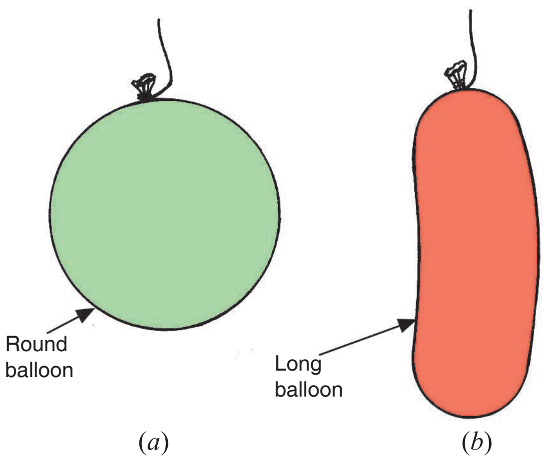


Figure 25. A gas (here air) takes the shape of its container (balloon).

To Show That Solids and Liquids Cannot be Compressed but Gases Can be Compressed Easily

We take three 100 mL glass syringes having frictionless pistons. The nozzles of all the syringes are closed by inserting them in separate rubber corks so as to prevent leakage from them [see Figures 26(*a*), (*b*) and (*c*)]. Remove the pistons from all the syringes.

(*i*) In the first syringe, we fill common salt (which is a solid). Then insert the piston back into the syringe (after applying some vaseline to piston for its smooth movement) [see Figure 26(*a*)].

(*ii*) In the second syringe, we fill water (which is a liquid). Then insert the piston back into the syringe (after applying some vaseline to it) [see Figure 26(*b*)].

(*iii*) In the third syringe, we do not fill anything. It is already filled with air (which is a gas). We just put the piston back in it (after applying some vaseline to it) [see Figure 26(*c*)].

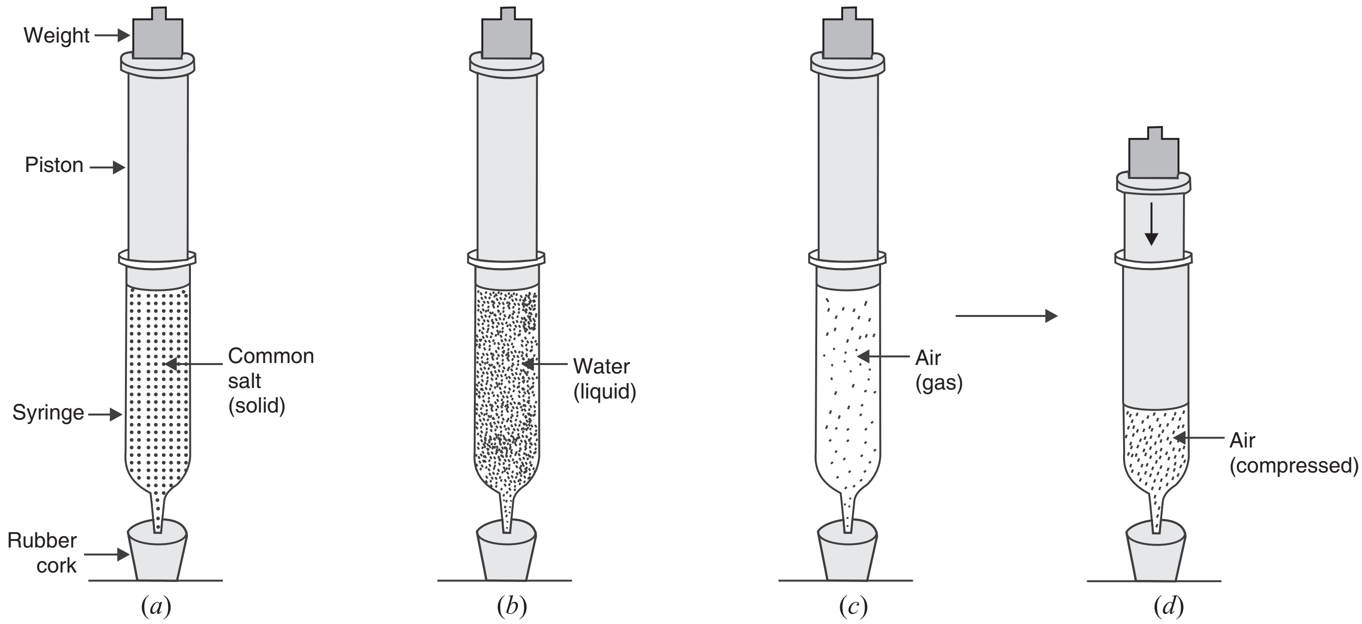


Figure 26. Experiment to study the effect of pressure on solid, liquid and gas.

We now place 50 gram weight on the top of piston of each syringe to put pressure on common salt, water and air filled in them. We will observe that :

(*a*) The piston of first syringe containing common salt does not move down on putting weight [see Figure 26(*a*)]. This shows that on applying pressure, the volume of common salt in the syringe does not get reduced. This means that on applying pressure, the common salt does not get compressed (into a smaller volume). Since common salt is a solid, so in general we can say that **a solid does not get compressed (on applying pressure).**

(*b*) The piston of second syringe containing water also does not move down on putting weight [see Figure 26(*b*)]. This also shows that on applying pressure, the volume of water in the syringe does not get reduced. This means that on applying pressure, the water does not get compressed (into a smaller volume). Since water is a liquid, so in general we can say that **a liquid does not get compressed (on applying pressure).**

(*c*) The piston of third syringe containing air moves down considerably on putting weight [see Figures 26(*c*) and (*d*)]. This shows that on applying pressure, the volume of air in the syringe is reduced. This means that on applying pressure, the air gets compressed (into a smaller volume). Since air is a gas, so in general we can say that **a gas can be compressed easily (by applying pressure).**

Gases have high compressibility. They can be compressed into very small volumes by applying large pressures. Due to its high compressibility, fairly large mass of a gas can be put in a small metal cylinder by compression. Such gas cylinders can be transported conveniently from one place to another. The cooking gas (Liquefied Petroleum Gas, LPG) which we use in our homes is a compressed gas. The oxygen gas supplied to hospitals in cylinders is also in compressed form. And compressed natural gas (CNG) filled in cylinders is being used increasingly as a fuel to run vehicles like cars and buses.

(*a*) This metal cylinder contains compressed cooking gas

(*b*) These metal cylinders contain compressed natural gas.

Figure 27. Due to its high compressibility, a fairly large mass of a gas can be put in a small metal cylinder (called gas cylinder).

DIFFUSION

The spreading out and mixing of a substance with another substance due to the motion of its particles is called diffusion. The diffusion of one substance into another substance goes on until a uniform mixture is formed. Let us take an example of diffusion. If we take a gas jar full of bromine vapours and invert another gas jar containing air over it, then after some time, the red-brown vapours of bromine spread out into the upper gas jar containing air (see Figure 28). In this way, the upper gas jar which contains colourless air in it, also turns red-brown. This mixing is due to the diffusion of bromine vapour (or bromine gas) into air. Air from the upper gas jar also diffuses into the lower gas jar though we cannot see it.

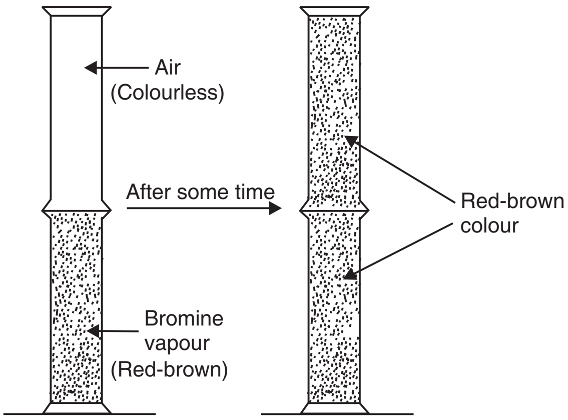


Figure 28. Diffusion of bromine vapour (or bromine gas) into air.

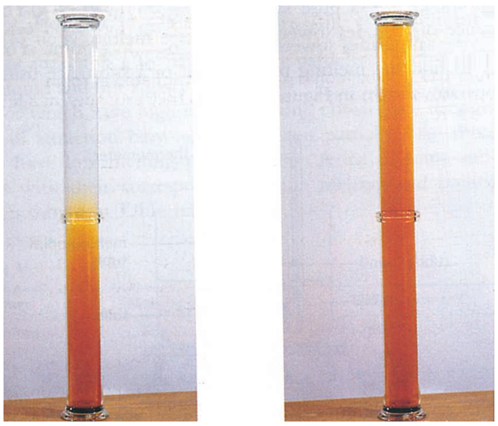


Figure 29. On the left side is a gas jar of air inverted over a gas jar containing red-brown bromine vapour. After 24 hours bromine vapours have diffused throughout the upper gas jar containing air (as shown on the right side).

Diffusion is a property of matter which is based on the motion (or movements) of its particles. Diffusion occurs in gases, liquids and solids. **Diffusion is fastest in gases and slowest in solids**. The diffusion is fastest in gases because the particles in gases move very rapidly. The diffusion is slowest in solids because the particles in solids do not move much. The diffusion in liquids is, however, much faster than that in solids. **The rate of diffusion increases on increasing the temperature of the diffusing substance** (by heating). This is because when the temperature of a substance is increased by heating, its particles gain kinetic energy and move more rapidly. And this increase in the speed of the particles of a substance increases the rate of diffusion. Please note that **the phenomenon of diffusion tells us that the particles of matter are constantly moving**.

Diffusion in Gases

Diffusion in gases is very fast. This is because the particles in gases move very quickly in all directions. The rate of diffusion of a gas, however, depends on its density. **Light gases diffuse faster than heavy gases.** In the laboratory, the diffusion of gases is usually demonstrated by setting up a gas jar of bromine vapours and a gas jar of air as shown in Figure 28. We will now give some **examples of diffusion in gases from our everyday life**.

The smell of food being cooked in the kitchen reaches us even from a considerable distance. This can be explained as follows : When food is cooked, some of the substances in food release gases having the smell of food in them. The particles of these gases move very quickly and mix up with air by diffusion. When the air containing these gases reaches our nose, we get the smell of food being cooked in the kitchen

Figure 30. The smell of food being cooked reaches us by the diffusion of gases released during the cooking of food into air.

Figure 31. The smell of perfume spreads due to the diffusion of perfume vapours into air.

(even without entering the kitchen). Thus, **the smell of food being cooked reaches us even from a considerable distance by the process of diffusion** (of food gases into the air). And if fish is being fried in a home, then its peculiar sharp smell can be detected even when we are quite far off, due to the diffusion of gases (produced during the frying of fish) into air. Another point to be noted is that the smell of hot sizzling food reaches us even when we are at a considerable distance but to get the smell of cold food, we have to go close to it. This is due to the fact that the rate of diffusion of hot gases (released by the hot sizzling food) is much faster than the rate of diffusion of cold gases released by the cold food.

When we light an incense stick (*agarbatti*) in a corner of our room, its fragrance spreads in the whole room very quickly. **The fragrance of burning incense stick (or *agarbatti*) spreads all around due to the diffusion of its smoke into the air**. The particles of gases produced by the burning of incense stick move rapidly in all directions. They collide with the particles of air present in the room, mix with air and reach every part of the room very quickly.

When someone opens a bottle of perfume in one corner of a room, its smell spreads in the whole room quickly. **The smell of perfume spreads due to the diffusion of perfume vapours into air.** When the bottle of perfume is opened, then the liquid perfume quickly changes into vapour (or gas). The perfume vapours move very rapidly in all directions in air, mix with the air particles and hence spread with air in the whole room.The leakage of cooking gas (LPG) in our homes is detected due to the diffusion of a strong smelling substance (ethyl mercaptan) present in the cooking gas, into air.

Diffusion in Liquids

Diffusion in liquids is slower than that in gases. This is because the particles in liquids move slowly as compared to the particles in gases. Here are some examples of diffusion in liquids.

(*i*) If a crystal of potassium permanganate is placed at the bottom of water in a beaker, then the purple colour of potassium permanganate spreads into the whole water, slowly. **The spreading of purple colour of potassium permanganate into water, on its own, is due to the diffusion of potassium permanaganate particles into water**.

(*ii*) If a crystal of copper sulphate is placed at the bottom of water in a beaker, then the blue colour of copper sulphate spreads into the whole water, slowly. **The spreading of blue colour of copper sulphate into water, on its own, is due to the diffusion of copper sulphate particles into water**.

(*iii*) If a drop of ink is put into a beaker of water, then the colour of ink spreads into the whole water of the beaker. **The spreading of ink in water, on its own, is due to the diffusion of ink particles into water**.

The gases like carbon dioxide and oxygen are essential for the survival of aquatic plants and animals. **The carbon dioxide gas and oxygen gas present in air (or atmosphere) diffuse into water (of ponds, lakes, rivers and sea), and dissolve in it**. The aquatic plants use the dissolved carbon dioxide for preparing food by photosynthesis and aquatic animals use the dissolved oxygen of water for breathing. This is an example of diffusion of gases into a liquid. In fact, solids, liquids as well as gases can diffuse into liquids. **The rate of diffusion in liquids is much faster than that in solids** because the particles in a liquid move much more freely, and have greater spaces between them as compared to particles in the solids.

Diffusion in Solids

Diffusion can also take place in solids. **Diffusion in solids is a very, very slow process**. We will now give two examples of diffusion of solids in solids.

(*i*) If we write something on a blackboard and leave it uncleaned for a considerable period of time (say, at least 10 to 15 days), we will find that it becomes quite difficult to clean the blackboard afterwards. This is due to the fact that some of the particles of chalk have diffused into the surface of blackboard.

(*ii*) If two metal blocks are bound together tightly and kept undisturbed for a few *years*, then the particles of one metal are found to have diffused into the other metal.

The diffusion of a solid substance into another solid substance is so slow that many people think that diffusion does not take place in solids at all. The diffusion in solids is very, very slow because the particles in solids do not move from their fixed positions. The particles of a solid only vibrate about their fixed positions. Due to lack of appreciable movements in the particles of solids, the diffusion of solids in solids is rare. Before we go further and discuss the units of temperature, **please answer the following questions :**

Very Short Answer Type Questions

1. What are the conditions for 'something' to be called 'matter' ?
2. Name two processes which provide the best evidence for the motion of particles in matter.
3. Which single term is used to describe the mixing of copper sulphate and water kept in a beaker, on its own ?
4. When sugar is dissolved in water, there is no increase in the volume. Which characteristic of matter is illustrated by this observation ?
5. Even two or three crystals of potassium permanganate can impart colour to a very large volume of water. Which characteristic of particles of matter is illustrated by this observation ?
6. When an incense stick (*agarbatti*) is lighted in one corner of a room, its fragrance spreads in the whole room quickly. Which characteristic of the particles of matter is illustrated by this observation ?
7. A piece of chalk can be broken into small particles by hammering but a piece of iron cannot be broken into small particles by hammering. Which characteristic of the particles of matter is illustrated by these observations ?

8. What is the scientific name of particles which make up matter ?

9. Name the process by which a drop of ink spreads in a beaker of water.

At start After an hour After a day

These pictures show black ink diffusing through a beaker of water.

10. What is the general name of :
(*a*) rigid form of matter ?
(*b*) fluid forms of matter ?

11. Out of solids, liquids and gases, which one has :
(*a*) maximum movement of particles ?
(*b*) maximum interparticle attractions ?
(*c*) minimum spaces between particles ?

12. 'A substance has a definite volume but no definite shape'. State whether this substance is a solid, a liquid or a gas.

13. Name the physical state of matter which can be easily compressed.

14. 'A substance has a definite shape as well as a definite volume'. Which physical state is represented by this statement ?

15. A substance has neither a fixed shape nor a fixed volume. State whether it is a solid, a liquid or a gas.

16. Name two gases which are supplied in compressed form in homes and hospitals.

17. Write the full forms of the following :
(*a*) LPG (*b*) CNG

18. Which of the two diffuses faster : a liquid or a gas ?

19. Which of the two diffuses slower : bromine vapour into air or copper sulphate into water ?

20. State whether the following statement is true or false :
Red-brown bromine vapour diffuse into air in a gas jar but the colourless air molecules do not diffuse into bromine vapour.

21. A bottle of perfume was opened in a room. The smell of its vapours spread in the entire room. Name the property of gases which is responsible for this behaviour of perfume vapours.

22. If the fish is being fried in a neighbouring home, we can smell it sitting in our own home. Name the process which brings this smell to us.

23. Name one property of liquids and gases which tells us that their molecules are moving constantly.

24. Fill in the following blanks with suitable words :
(*a*) The best evidence that the particles of matter are constantly moving comes from the studies of .... and ....
(*b*) The smell of perfume gradually spreads across a room due to............
(*c*) Solid, liquid and gas are the three............of matter.
(*d*) At room temperature, the forces of attraction between the particles of solid substances are................than those which exist in the gaseous state.
(*e*) The arrangement of particles is less ordered in the...................state. However, there is no order in the..........state.

Short Answer Type Questions

25. State two characteristics of matter demonstrated by :

(*a*) diffusion.

(*b*) Brownian motion.

26. Name the scientist who studied the movement of pollen grains suspended in water through a microscope. What is this phenomenon known as ?

27. When a crystal of potassium permanganate is placed in a beaker, its purple colour spreads throughout the water. What does this observation tell us about the nature of potassium permanganate and water ?

28. When a gas jar containing air is inverted over a gas jar containing bromine vapour, the red-brown bromine vapour diffuse into air. Explain how bromine vapour diffuse into air.

29. Describe in your own words, what happens to the particles when salt dissolves in water.

30. Explain why, we can easily move our hand in air but to do the same through a plank of wood, we need a karate expert.

31. Give one example of the diffusion of a solid in another solid.

32. Explain why, the diffusion of a solid in another solid is a very slow process.

33. Which of the following diffuses fastest and which the slowest ?

Solid, Liquid, Gas

Give reasons for your answer.

34. Explain the following :

When an incense stick is lighted in the corner of a room, its fragrance spreads quickly in the entire room.

35. Name the three states of matter. Give one example of each.

36. State two characteristic properties each of :

(*a*) a solid (*b*) a liquid (*c*) a gas

37. Why do gases have neither a fixed shape nor a fixed volume ?

38. How do solids, liquids and gases differ in shape and volume ?

39. Arrange the following substances in increasing order of force of attraction between their particles (keeping the substance having the minimum force of attraction first) :

Water, Sugar, Oxygen

40. Give two reasons to justify that :

(*a*) Water is a liquid at room temperature.

(*b*) An iron almirah is a solid.

41 (*a*) When an incense stick (*agarbatti*) is lighted in one corner of a room, its fragrance quickly spreads in the entire room. Name the process involved in this.

(*b*) A girl is cooking some food in the kitchen. The smell of food being cooked soon reaches her brother's room. Explain how the smell could have reached her brother's room.

42. (*a*) What does the diffusion of gases tell us about their particles ?

(*b*) Give one example of diffusion of gases in a liquid.

43. Give reason for the following observation :

The smell of hot sizzling food reaches us even from a considerable distance but to get the smell from cold food, we have to go close to it.

44. Explain how, the smell of food being cooked in the kitchen reaches us even from a considerable distance.

45. Explain why, when a bottle of perfume is opened in a room, we can smell it even from a considerable distance.

46. When a crystal of copper sulphate is placed at the bottom of a beaker containing water, the water slowly turns blue. Why ?

47. Honey is more viscous than water. Can you suggest why ?

48. Explain why :

(*a*) air is used to inflate tyres.

(*b*) steel is used to make railway lines.

49. Explain why, diffusion occurs more quickly in a gas than in a liquid.

Long Answer Type Questions

50. (*a*) What is meant by 'diffusion' ? Give one example of diffusion in gases.
(*b*) Why do gases diffuse very fast ?
(*c*) Name two gases of air which dissolve in water by diffusion. What is the importance of this process in nature ?

51. (*a*) Compare the properties of solids, liquids and gases in tabular form.
(*b*) Give two reasons for saying that wood is a solid.

During class, the students resemble molecules in a solid (because they are very close to one another)

While going from one classroom to another the students resemble molecules in a liquid (because they are a little more farther apart from one another)

And in the playground students resemble molecules in a gas (because they are very, very far apart from one another)

52. (*a*) Why does a gas exert pressure ?
(*b*) Why does a gas fill a vessel completely ?
(*c*) Why are gases so easily compressible whereas it is almost impossible to compress a solid or a liquid ?

53. (*a*) Define matter. Give four examples of matter.
(*b*) What are the characteristics of matter ?

54. (*a*) What is Brownian motion ? Draw a diagram to show the movement of a particle (like a pollen grain) during Brownian motion.
(*b*) In a beam of sunlight entering a room, we can sometimes see dust particles moving in a haphazard way in the air. Why do these dust particles move ?

Multiple Choice Questions (MCQs)

55. When a crystal of potassium permanganate is placed at the bottom of water in a beaker, the water in the whole beaker turns purple on its own, even without stirring. This is an example of :
(*a*) distribution (*b*) intrusion (*c*) diffusion (*d*) effusion

56. Which one of the following statement is correct in respect of fluids ?
(*a*) only gases behave as fluids (*b*) gases and solids behave as fluids
(*c*) gases and liquids behave as fluids (*d*) only liquids are fluids

57. A few substances are arranged in the increasing order of 'forces of attraction' between their particles. Which one of the following represents the correct arrangement ?
(*a*) water, air, wind (*b*) air, sugar, oil (*c*) oxygen, water, sugar (*d*) salt, juice, air

58. In which of the following conditions, the distance between the molecules of hydrogen gas would increase ?
(*i*) increasing pressure on hydrogen contained in a closed container
(*ii*) some hydrogen gas leaking out of the container
(*iii*) increasing the volume of the container of hydrogen gas
(*iv*) adding more hydrogen gas to the container without increasing the volume of the container
(*a*) (*i*) and (*iii*) (*b*) (*i*) and (*iv*) (*c*) (*ii*) and (*iii*) (*d*) (*ii*) and (*iv*)

59. Out of the following, an example of matter which can be termed as fluid is :
(*a*) carbon (*b*) sulphur (*c*) oxygen (*d*) phosphorus

60. The best evidence for the existence and movement of particles in liquids was provided by :
(*a*) John Dalton (*b*) Ernest Rutherford (*c*) J.J. Thomson (*d*) Robert Brown

61. A form of matter has no fixed shape but it has a fixed volume. An example of this form of matter is :
(*a*) krypton (*b*) kerosene (*c*) carbon steel (*d*) carbon dioxide

62. Which of the following statement is incorrect ?
(*a*) the particles of matter are very, very small
(*b*) the particles of matter attract one another
(*c*) the particles of some of the matter are moving constantly
(*d*) the particles of all the matter have spaces between them

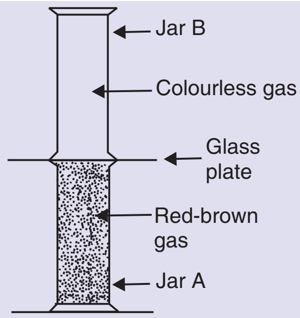
63. When a gas jar full of air is placed upside down on a gas jar full of bromine vapours, the red-brown vapours of bromine from the lower jar go upward into the jar containing air. In this experiment :
(*a*) air is heavier than bromine
(*b*) both air and bromine have the same density
(*c*) bromine is heavier than air
(*d*) bromine cannot be heavier than air because it is going upwards against gravity

64. When a gas jar containing colourless air is kept upside down over a gas jar full of brown-coloured bromine vapour, then after some time, the brown colour of bromine vapour spreads into the upper gas jar making both the gas jars appear brown in colour. Which of the following conclusion obtained from these observations is incorrect ?
(*a*) bromine vapour is made of tiny particles which are moving
(*b*) air is made up of tiny particles which are moving
(*c*) the particles of bromine are moving but those of air are not moving
(*d*) even though bromine vapour is heavier than air, it can move up against gravity

65. Which one of the following statements is not true ?
(*a*) the molecules in a solid vibrate about a fixed position
(*b*) the molecules in a liquid are arranged in a regular pattern
(*c*) the molecules in a gas exert negligibly small forces on each other, except during collisions
(*d*) the molecules of a gas occupy all the space available

Questions Based on High Order Thinking Skills (HOTS)

66. Look at the diagram on the right side. Jar A contains a red-brown gas whereas jar B contains a colourless gas. The two gas jars are separated by a glass plate placed between them



(*a*) What will happen when the glass plate between the two jars is pulled away ?
(*b*) What name is given to the phenomenon which takes place ?
(*c*) Name the brown gas which could be in jar A.
(*d*) Which is the colourless gas most likely to be present in jar B ?
(*e*) Name one coloured solid and one colourless liquid which can show the same phenomenon.

67. Bromine and air take about 15 minutes to diffuse completely but bromine diffuses into a vacuum very rapidly. Why is this so ?

68. Bromine particles are almost twice as heavy as chlorine particles. Which gas will diffuse faster ; bromine (vapour) or chlorine ? Explain your answer.

69. Why is a liquid (the hydraulic fluid) used to operate the brakes in a car ?

70. Explain why, a small volume of water in a kettle can fill a kitchen with steam.

71. Explain why, osmosis can be considered to be a special kind of diffusion. Classify the following into (*i*) osmosis, and (*ii*) diffusion :
(*a*) swelling up of a raisin on keeping in water
(*b*) spreading of virus on sneezing

(*c*) earthworm dying on coming in contact with common salt

(*d*) shrinking of grapes kept in thick sugar syrup

(*e*) preserving of pickles in salt

(*f*) spreading of smell of cake being baked in the kitchen

(*g*) aquatic animals using oxygen dissolved in water during respiration

72. A student placed a gas jar containing air in the upside down position over a gas jar full of red-brown bromine vapours. He observed that the red-brown colour spread upwards into the jar containing air. Based on this observation, the student concluded that it is only the bromine vapour which moves up and diffuses into air in the upper jar, the air from the upper jar does not move down by diffusion into the lower jar containing bromine vapours. Do you agree with this conclusion of the student ? Give reason for your answer.

73. An inflated balloon full of air goes down slowly (becomes smaller and smaller slowly) even though the knot at the mouth of the balloon is airtight. And after a week all the air has escaped from the balloon. Explain how the air particles got out of the balloon.

74. When extremely small particles X derived from the anther of a flower were suspended in a liquid Y and observed through a microscope, it was found that the particles X were moving throughout the liquid Y in a very zig-zag way. It was also observed that warmer the liquid Y, faster the particles X moved on its surface.

(*a*) What could particles X be ?

(*b*) What do you think liquid Y is ?

(*c*) What is the zig-zag movement of X known as ?

(*d*) What is causing the zig-zag movement of particles X ?

(*e*) Name the scientist who discovered this phenomenon.

(*f*) What does this experiment tell us about the nature of liquid Y ?

75. When a beam of sunlight enters a room through a window, we can see tiny particles X suspended in a gas (or rather a mixture of gases) Y which are moving rapidly in a very haphazard manner.

(*a*) What could particles X be ?

(*b*) Name the gas (or mixture of gases) Y.

(*c*) What is the phenomenon exhibited by particles X known as ?

(*d*) What is causing the movement of particles X ?

(*e*) What conclusion does the existence of this phenomenon give us about the nature of matter ?

ANSWERS

2. Diffusion and Brownian motion **3.** Diffusion **4.** The particles of a liquid (here water) have spaces between them **5.** Each crystal of potassium permanganate must be made up of millions of small particles **6.** The particles of matter are constantly moving in all the directions **7.** The particles of matter attract one another (some attract less as in the case of chalk but some attract much more as in the case of iron) **8.** Atoms or Molecules **9.** Diffusion **10.** (*a*) Solid (*b*) Liquid and Gas **19.** Copper sulphate into water **20.** False **21.** Diffusion **22.** Diffusion **23.** Diffusion **24.** (*a*) diffusion ; Brownian motion (*b*) diffusion (*c*) states (*d*) much more (*e*) liquid ; gaseous **39.** Oxygen < Water < Sugar **47.** The force of attraction between the particles of honey is much more than the force of attraction between the particles of water **55.** (*c*) **56.** (*c*) **57.** (*c*) **58.** (*c*) **59.** (*c*) **60.** (*d*) **61.** (*b*) **62.** (*c*) **63.** (*c*) **64.** (*c*) **65.** (*b*) **66.** (*a*) The red-brown gas will diffuse from jar A into colourless gas in jar B due to which its red-brown colour will also spread into jar B (*b*) Diffusion (in gases) (*c*) Bromine vapour (*d*) Air (*e*) Potassium permanganate and Water **67.** Bromine diffuses slowly into air because the motion of bromine molecules is obstructed due to the collisions with the moving molecules of air. Bromine diffuses very rapidly into vacuum because there is 'nothing' in the vacuum to oppose the motion of bromine molecules **68.** Chlorine will diffuse faster than bromine vapour. This is because light molecules diffuse faster than heavy molecules **69.** The particles in a liquid (the brake oil) can move freely without being compressed much and hence transmit the pressure applied on brake pedal to the brake drum (on moving wheel) efficiently **70.** The steam is gaseous form of water. The molecules of water in steam move very rapidly in all directions and fill the whole kitchen space with steam. Gases (including steam) fill their container completely **71.** In both, diffusion as well as osmosis, there is movement of particles from a region of higher concentration to a region of lower concentration. Diffusion can take place without there being a membrane or through a permeable membrane (which allows both solvent particles as well as solute particles to pass through it). Osmosis takes place only through a semi-permeable membrane (which allows only solvent particles to pass through it) (*i*) Osmosis : (*a*), (*c*), (*d*) and (*e*) (*ii*) Diffusion : (*b*), (*f*) and (*g*) **72.** No, the student's conclusion is wrong. The air from upper gas jar also diffuses down into the lower gas jar containing bromine vapour. But since air is colourless, it cannot be noticed by the student **73.** The fast moving molecules of air trapped in the inflated balloon exert continuous pressure on the thin, stretched rubber sheet of balloon and keep on diffusing out gradually through it. **74.** (*a*) Pollen grains (*b*) Water (*c*) Brownian motion (*d*) The fast moving water molecules are constantly hitting particles X (pollen grains) causing them to move in a zig-zag path (*e*) Robert Brown (*f*) The liquid Y is made up of extremely small particles which are constantly moving **75.** (*a*) Dust particles (*b*) Air (*c*) Brownian motion (*d*) The fast moving air molecules are constantly hitting the tiny dust particles causing them to move rapidly in a very haphazard manner (*e*) The gaseous matter 'air' is made up of very tiny particles which are constantly moving

THE COMMON UNIT OF TEMPERATURE AND SI UNIT OF TEMPERATURE

We use **Celsius scale of temperature** for measuring temperatures in our everyday life. So, **the common unit of measuring temperatures (like melting points, boiling points, etc.) is 'degrees Celsius'** which is written in short form as **°C** (read as degrees C). The laboratory thermometers which we use for performing science experiments are all calibrated in 'degrees Celsius'. Even the clinical thermometer which we use for measuring human body temperature is calibrated on Celsius scale of temperature. **The melting point of ice on Celsius scale of temperature is 0°C** (zero degree Celsius). And **the boiling point of water on Celsius scale is 100°C**.

Figure 32. Anders Celsius : The scientist who invented Celsius scale of temperature.

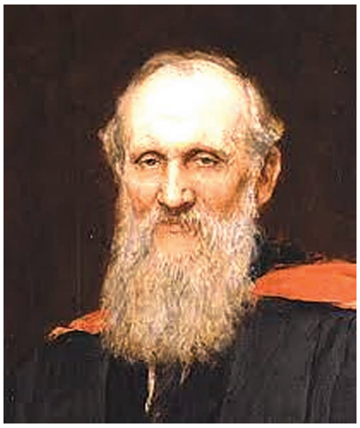


Figure 33. Lord William Thomson Kelvin : The scientist who invented Kelvin scale of temperature.

There is another scale of temperature called **Kelvin scale of temperature** which is used by the scientists mainly for research work. **The SI unit of measuring temperature is Kelvin**, which is denoted by the symbol **K**. Please note that the word 'degree' or its sign (°) is not written with the Kelvin scale temperatures. An advantage of the Kelvin scale of temperature is that all the temperatures on this scale are positive. **The melting point of ice on Kelvin scale is 273 K**. And **the boiling point of water on Kelvin scale is 373 K**.

We have just learnt that the melting point of ice on the Celsius scale is 0°C and on the Kelvin scale is 273 K. This means that a temperature of 0° on Celsius scale is equal to 273 on the Kelvin scale. So,

0°C = 273 K

The relation between Kelvin scale and Celsius scale of temperature can be written as :

Temp. on Kelvin scale = Temp. on Celsius scale + 273

This relation can be used to convert a Celsius temperature into Kelvin temperature or a Kelvin temperature into Celsius temperature. We should remember the above relation because it will be used to solve numerical problems as shown below.

Sample Problem 1. Convert the temperature of 25°C to the Kelvin scale. **(NCERT Book Question)**

Solution. We know that :

Temp. on Kelvin scale = Temp. on Celsius scale + 273
= 25 + 273
= 298 K

Thus, a temperature of 25°C on Celsius scale is equal to 298 K on the Kelvin scale.

Sample Problem 2. Convert the temperature of 300 K to the Celsius scale. **(NCERT Book Question)**

Solution. We know that :

Temp. on Kelvin scale = Temp. on Celsius scale + 273

So, 300 = Temp. on Celsius scale + 273

And, Temp. on Celsius scale = 300 – 273

= 27°C

Thus, a temperature of 300 K on Kelvin scale is equal to 27°C on Celsius scale.

It is clear from the above discussion that :

(*i*) **To convert a temperature on Celsius scale to the Kelvin scale, we have to add 273 to the Celsius temperature.**

(*ii*) **And to convert a temperature on Kelvin scale to the Celsius scale, we have to subtract 273 from the Kelvin temperature.**

CHANGE OF STATE OF MATTER

Matter can exist in three physical states : solid state, liquid state and gaseous state (or vapour state). For example, water exists as a solid in the form of ice ; as a liquid in the form of water ; and as a gas in the form of steam (or water vapour). Water comes as ice out of the freezer of a refrigerator, as water out of a tap, and as steam (or water vapour) out of a kettle of boiling water.

Figure 34. Ice.

Figure 35. Water (in glass).

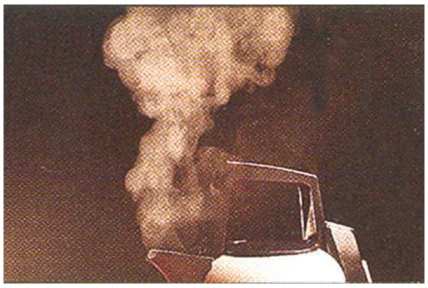


Figure 36. Steam (coming out of kettle).

We can change the physical state of matter in two ways :

1. By changing the temperature, and

2. By changing the pressure.

When we say that we can change the state of matter by changing the temperature, we mean that the state of matter can be changed by heating it or cooling it. And when we say that we can change the state of matter by changing the pressure, we mean that the state of matter can be changed by increasing the pressure on it (compressing it), or by decreasing the pressure on it.

The spaces between the particles, the force of attraction between the particles and the amount of movement (or kinetic energy) of particles can be changed by changing the pressure and (or) temperature of a substance. So, depending on the pressure and temperature, etc., the same substance can exist in all the three physical states : solid, liquid and gas. For example, under normal pressure, water exists as a solid in the form of ice at a temperature of 0°C or below. It exists as a liquid in the form of water at room temperature, and as a gas in the form of steam at a temperature of 100°C or above. From this discussion we conclude that **the two factors which decide whether a given substance would be in a solid, liquid or gaseous state are : temperature and pressure.** We will now discuss the effect of change of temperature and the effect of change of pressure on the physical state of matter in detail, one by one.

EFFECT OF CHANGE OF TEMPERATURE

By increasing the temperature (by heating), a solid can be converted into liquid state ; and the liquid can be converted into gaseous state (or vapour state). And by decreasing the temperature (by cooling), a gas can be converted into liquid state ; and a liquid can be converted into solid state. These points will become more clear from the following discussion.

1. Solid to Liquid Change : Melting

If we heat ice, it changes into water. In this case, solid ice changes into liquid water, so a change of state has taken place. **The process in which a solid substance changes into a liquid on heating, is called melting (or fusion).** So, when ice changes into water on heating, it is called melting of ice (or fusion of ice). A change of state takes place during melting (or fusion). The melting of a solid substance takes place at a fixed temperature. **The temperature at which a solid substance melts and changes into a liquid at atmospheric pressure, is called melting point of the substance.** For example, the ice melts at a temperature of 0°C to form liquid water, so the melting point of ice is 0°C (zero degree Celsius). At melting point, ice changes its state from solid to liquid.

Figure 37. Ice is melting to form water. Here the heat needed to melt ice is being supplied by the surrounding air which is at a higher temperature than ice.

Different solids have different melting points. For example, the melting point of ice is 0°C; the melting point of wax is 63°C; whereas the melting point of iron is 1535°C. **The melting point of a solid is a measure of the force of attraction between its particles (atoms or molecules)**. Higher the melting point of a solid substance, greater will be the force of attraction between its particles. For example, the melting point of iron metal is very high (1535°C) which tells us that the force of attraction between the particles of iron is very strong. We will now describe how a solid changes into a liquid on heating.

When a solid is heated sufficiently, it changes its physical state and becomes a liquid. This happens as follows : When a solid substance is heated, the heat energy makes its particles vibrate more vigorously. At the melting point, the particles of a solid have sufficient kinetic energy to overcome the strong forces of attraction holding them in fixed positions and break to form small groups of particles. And the solid melts to form a liquid.

2. Liquid to Gas Change : Boiling (or Vaporisation)

Water normally exists in the liquid state. If we go on heating water, it ultimately starts boiling and changes rapidly into a gas called steam. In this case, the liquid water changes into a gas, so a change of state has taken place. **The process in which a liquid substance changes into a gas rapidly on heating, is called boiling.** So, when water changes into steam rapidly on heating, it is called boiling of water. A change of state takes place during boiling. The boiling of a liquid takes place at a fixed temperature. **The temperature at which a liquid boils and changes rapidly into a gas at atmospheric pressure, is called boiling point of the liquid.** For example, when water is heated to a temperature of 100°C, it boils rapidly to form a gas called steam, so the boiling point of water is 100°C (hundred degrees Celsius). At boiling point, water changes its state from liquid to gas (or vapour).

Figure 38. Water is boiling to form steam (which is a gas). The heat required for the boiling of water is being supplied by a burner.

Different liquids have different boiling points. For example, the boiling point of alcohol is 78°C, the boiling point of water is 100°C, whereas the boiling point of mercury is 357°C. **The boiling point of a liquid is a measure of the force of attraction between its particles**. Higher the boiling point of a liquid, greater will be the force of attraction between its particles. For example, the boiling point of mercury is very high (357°C) which tells us that the force of attraction between the particles of mercury is very strong. We will now describe how a liquid changes into a gas on heating.

When a liquid is heated, it changes its physical state and becomes a gas. This happens as follows : When a liquid is heated, the heat energy makes its particles move even faster. At the boiling point the particles of a liquid have sufficient kinetic energy to overcome the forces of attraction holding them together and separate into individual particles. And the liquid boils to form a gas.

3. Gas to Liquid Change : Condensation

If we cool steam (or water vapour) by lowering its temperature, it is converted into liquid water. In this case a gas (steam) changes into a liquid, so a change of state has taken place. **The process of changing a gas (or vapour) to a liquid by cooling, is called condensation.** So, when steam (or water vapour) changes into water on cooling, it is called condensation of steam (or condensation of water vapour). A change of state (gas to liquid) takes place during condensation. This happens as follows.

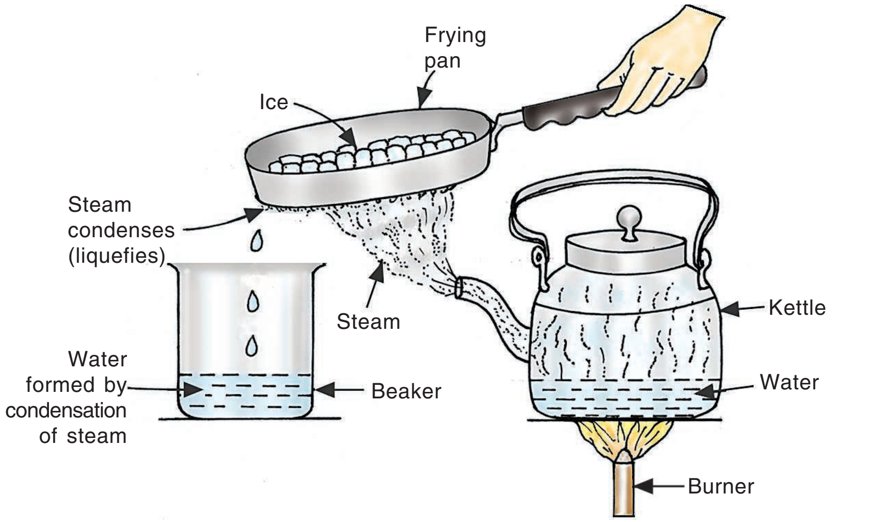


Figure 39. This experimental set-up shows the process of condensation. When we hold a frying pan containing some ice just above the spout of a kettle of boiling water, then the hot steam coming out of the spout comes in contact with the ice-cold bottom of frying pan, gets cooled, and condenses to form drops of liquid water.

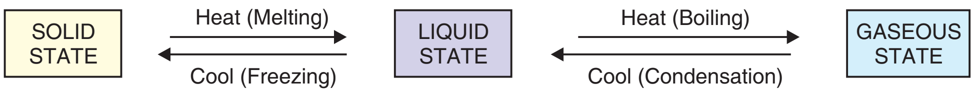
When a gas is cooled enough (by lowering its temperature), then its particles lose so much kinetic energy that they slow down, move closer together until they start being attracted to each other, and form a liquid. Please note that **condensation is the reverse of boiling (or vaporisation).**

4. Liquid to Solid Change : Freezing

When water is cooled (by lowering its temperature by keeping in the freezer compartment of a refrigerator), it changes into solid 'ice'. **The process of changing a liquid into a solid by cooling, is called freezing.** For example, when water is cooled, it gets converted into a solid called 'ice'. This is called freezing of water. **Freezing means solidification.** When water freezes to form ice, then there is a change from liquid state to solid state. Please note that **freezing is the reverse of melting.** So, the freezing point of a liquid is the same as the melting point of its solid form. For example, the melting point of ice is 0°C, so the freezing point of water is also 0°C. A change of state (liquid to solid) occurs during freezing. This happens as follows.

When a liquid is cooled (by lowering its temperature), its particles lose energy due to which they move slowly. If the liquid is cooled enough (up to its freezing point), its each particle stops moving and vibrates about a fixed position. At this stage the liquid freezes and becomes a solid.

From the above discussion we conclude that **the state of matter can be changed by changing the temperature (by heating or cooling)**. For example, when a solid is heated, it melts to form a liquid. And when the liquid is heated further, it boils to form a gas. These changes can be easily reversed. For example, when a gas is cooled, it condenses to form a liquid. And when a liquid is cooled further, it freezes (or solidifies) to form a solid. The conversion of matter from one physical state to another can be shown as follows :



LATENT HEAT

Normally, when heat is given to a substance, then its temperature rises. This, however, is not so when a change of state of a substance takes place. Because when heat is given to change the physical state of a substance (from solid to liquid or liquid to gas), there is no rise in temperature of the substance. **The heat energy which has to be supplied to change the state of a substance is called its latent heat.** *Latent heat does not raise (or increase) the temperature*. But latent heat has always to be supplied to change the state of a substance. The word 'latent' means 'hidden'. It is called latent heat because it becomes hidden in the substance undergoing the change of state, and does not show its presence by raising the temperature. So, the latent heat which is given to change the state of a substance cannot be detected by a thermometer. Let us see **why latent heat does not cause a rise in temperature of the substance.**

Every substance (solid or liquid) has some forces of attraction between its particles which hold them together. Now, if a substance has to change its state, then it is necessary to overcome (or break) these forces of attraction between its particles. **The latent heat which we supply is used up in overcoming the forces of attraction between the particles of a substance during the change of state.** The latent heat does not increase the kinetic energy of the particles of the substance. And since there is no increase in the kinetic energy of the particles, the temperature of a substance does not rise during the change of state.

Latent heat is of two types :

1. **Latent heat of fusion,** and
2. **Latent heat of vaporisation.**

The heat required to convert a *solid* into the *liquid* state is called latent heat of fusion (or latent heat of melting). And the heat required to convert a *liquid* into the *vapour* state (or *gas*) is called latent heat of vaporisation. We will discuss both the types of latent heats in somewhat detail, one by one.

1. Latent Heat of Fusion (Solid to Liquid Change)

The latent heat of fusion can be studied by performing an experiment as follows : We take some crushed ice in a beaker and suspend a thermometer in it (see Figure 40). We note the temperature of ice. It is found to be 0°C. We now heat the ice gently by using a small flame of the burner. On heating, ice starts melting to form water. We keep on recording the temperature of melting ice on the thermometer every minute. As more heat is given, more ice melts to form water but the thermometer reading remains at 0°C. As long as there remains even a little of ice in the beaker, the temperature does not rise, it remains constant at 0°C. This shows that **there is no rise in temperature during the melting of ice.** It is only when all the ice has melted that the temperature of water (formed from ice) starts rising on further heating. **The heat which is going into ice but not increasing its temperature, is the energy**

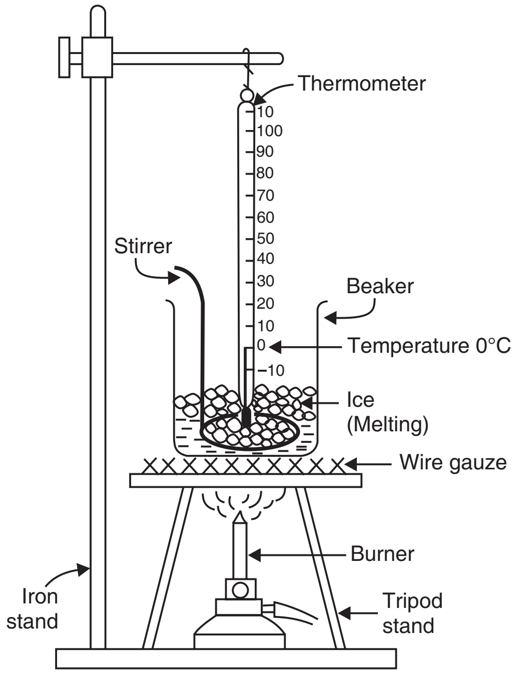


Figure 40. Melting of ice to form water (solid to liquid change).

required to change the state of ice from solid to liquid (water). This is known as the latent heat of fusion of ice (or latent heat of melting of ice). We will now give a definition of the latent heat of fusion of a solid substance.

The latent heat of fusion (or melting) of a solid is the quantity of heat in joules required to convert 1 kilogram of the solid (at its melting point) to liquid, without any change in temperature. It has been found by experiments that 3.34×10^5 joules of heat has to be supplied to change 1 kilogram of ice (at its melting point, 0°C) to water at the same temperature of 0°C. So, **the latent heat of fusion of ice is 3.34×10^5 joules per kilogram** (or 3.34×10^5 J/kg).

We have just seen that when a solid melts (on heating), its temperature remains the same. Now, an important question arises : Where does the heat energy go ? Actually, this **heat energy is used up in changing the state of the solid substance by overcoming the force of attraction between its particles.** This point will become more clear from the following example of melting of ice.

We will now discuss **why the temperature of melting ice does not rise even though heat is being supplied continuously.** This can be explained as follows : Ice is a solid substance, so the particles of ice attract one another with strong forces. These forces of attraction hold the particles closely packed in solid ice. The heat which we supply to ice during melting is all used up to overcome the forces of attraction between ice particles so that they become somewhat loose and form liquid water. This heat does not increase the kinetic energy of particles and hence no rise in temperature takes place during the melting of ice. But when all the ice has melted to form water, further heating increases the kinetic energy of water particles due to which the temperature of water starts rising sharply.

The latent heat of fusion of ice is 3.34×10^5 J/kg. By saying that the latent heat of fusion of ice is 3.34×10^5 joules per kilogram, we mean that 3.34×10^5 joules of heat is required to change 1 kilogram of ice at its melting point of 0°C into water at the same temperature (of 0°C). This means that 1 kilogram of ice at 0°C has 3.34×10^5 joules of less heat than 1 kilogram of water at the same temperature of 0°C. It has been found that **ice at 0°C is more effective in cooling a substance than water at 0°C**. This is due to the fact that for melting, each kilogram of ice takes its latent heat of 3.34×10^5 joules from the substance and hence cools the substance more effectively. On the other hand, water at 0°C cannot take any such latent heat from the substance.

Figure 41. A piece of ice held in our hand feels very cold because it takes latent heat (required for melting) from our hand. Our hand loses heat to ice making us feel cold.

When we hold a piece of ice in our hand, it feels very cold. This can be explained as follows : The piece of ice held in our hand starts melting slowly. This ice takes the latent heat (required for melting) from our hand. Our hand loses heat to ice and hence we feel it to be cold.

When a solid melts, it absorbs heat to form liquid. The reverse of this is also true. That is, **when a liquid freezes to form a solid, an equal amount of heat is given out**. For example, when ice at 0°C melts, it absorbs latent heat of fusion to form water at the same temperature, 0°C. Now, when water at 0°C freezes to form ice at 0°C, then it gives out an equal amount of heat.

2. Latent Heat of Vaporisation (Liquid to Gas Change)

The latent heat of vaporisation can be studied by performing an experiment as follows : We take some water in a beaker and suspend a thermometer in it (see Figure 42). We heat this water by using a burner and note its temperature after every minute. As heat is given, the temperature of water rises gradually until 100°C is reached. At the temperature of 100°C, water boils and starts changing into steam (which is a gas). As more heat is given to water, more steam is formed but the thermometer reading remains at 100°C showing that there is no rise in temperature during the boiling of water. Thus, **once the water has begun to**

boil, the temperature remains constant at 100°C until all the water has changed into steam. The heat which is going into boiling water but not increasing its temperature is the energy required to change the state of water from liquid to gas (or vapour). This is known as the latent heat of vaporisation of water. We will now give a definition of the latent heat of vaporisation of a liquid substance.

The latent heat of vaporisation of a liquid is the quantity of heat in joules required to convert 1 kilogram of the liquid (at its boiling point) to vapour or gas, without any change in temperature. It has been found by experiments that 22.5×10^5 joules of heat is required to change 1 kilogram of water (at its boiling point, 100°C) to steam at the same temperature of 100°C. So, **the latent heat of vaporisation of water is 22.5×10^5 joules per kilogram** (or 22.5×10^5 J/kg).

We have just seen that when a liquid boils (on heating), its temperature remains the same. **The heat energy supplied to a boiling liquid is used up in changing the state of the liquid substance by overcoming the force of attraction between its particles**. This point will become more clear from the following example of vaporisation of water.

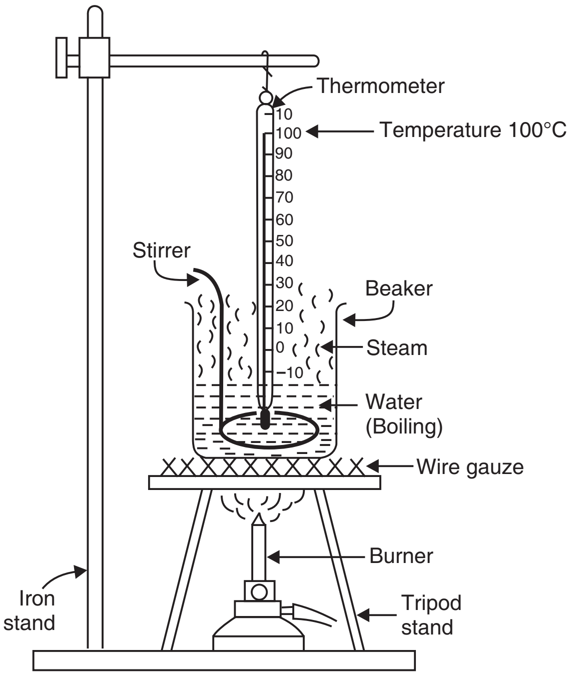


Figure 42. Boiling of water to form steam (liquid to gas change).

We will now discuss **why the temperature of boiling water does not rise even though heat is being given continuously.** This can be explained as follows : Water is a liquid substance. The particles of water attract one another with certain forces. These forces of attraction hold the water particles together in the liquid state. The heat which we supply to water during boiling is used to overcome (or break) the forces of attraction between water particles so that they become totally free and change into a gas (steam). This latent heat does not increase the kinetic energy of water particles and hence no rise in temperature takes place during the boiling of water.

If we put a little of spirit at the back of our hand and wave it around, the spirit evaporates rapidly and our hand feels very cold. This is due to the fact that spirit needs latent heat of vaporisation to change from liquid to vapour state (gas state). The spirit takes the latent heat of vaporisation from our hand. So, our hand loses heat and gets cooled.

When water changes into steam, it absorbs latent heat, but when steam condenses to form water, an equal amount of latent heat is given out. It has been found that **the burns caused by steam are much more severe than those caused by boiling water** though both of them are at the same temperature of 100°C. **This is due to the fact that steam contains more heat, in the form of latent heat, than boiling water.** So, when steam falls on our skin and condenses to produce water it gives out 22.5×10^5 joules per kilogram more heat than boiling water at the same temperature. Since steam gives out more heat than boiling water, it causes more severe burns. This also explains why steam is better than boiling water for heating purposes.

Figure 43. These burns have been caused by steam.

SUBLIMATION

Most of the solid substances, when heated, first change into a liquid and then into vapours (or gas). This vapour, on cooling, first forms a liquid and then a solid. But there are a few solid substances which change directly into vapours (or gas) on heating and the vapours give back solid substance on cooling (without passing through the liquid state). **The changing of a solid directly into vapours on heating, and of vapours into solid on cooling, is known as sublimation**. Sublimation can be represented as :

$$\text{Solid} \underset{\text{Cooling}}{\overset{\text{Heating}}{\rightleftharpoons}} \text{Vapour (or Gas)}$$

Please note that :

(*i*) **the changing of a solid directly into vapour (or gas) is called sublimation,** and

(*ii*) **the changing of vapour (or gas) directly into solid is also called sublimation.**

The solid substance which undergoes sublimation is said to '*sublime*'. The solid obtained by cooling the vapours of the solid is called a '*sublimate*'. We will now give an example of sublimation.

Ammonium chloride undergoes sublimation. When solid ammonium chloride is heated, it directly changes into ammonium chloride vapour (without passing through liquid state). And when hot ammonium chloride vapour is cooled, it directly changes into solid ammonium chloride (without passing through the liquid state). Sublimation occurs in only a few substances. So, it is a rare process. **The common substances which undergo sublimation are : Ammonium chloride, Iodine, Camphor, Naphthalene and Anthracene.** When these solids are heated, their particles move so quickly that they separate completely to form vapour (or gas). And when these vapour (or gas) is cooled, these particles slow down so quickly that they become fixed and form a solid. Another example of sublimation is provided by solid carbon dioxide (which is commonly known as dry ice). **Solid carbon dioxide (or dry ice) sublimes to form carbon dioxide gas**. We will now perform an experiment to demonstrate the sublimation of ammonium chloride.

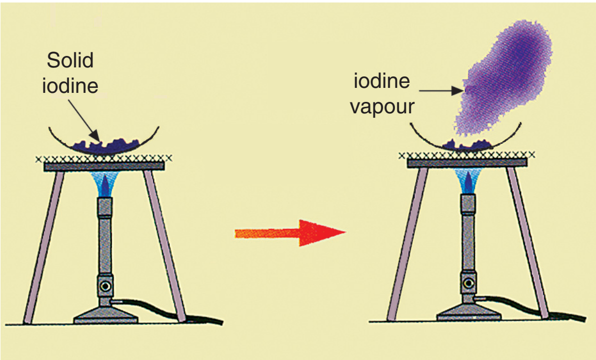


Figure 44. Solid iodine sublimes on heating. This means that solid iodine gets converted directly into vapours (or gas) on heating.

Figure 45. Dry ice (solid carbon dioxide) sublimes on heating and can be used to create special effects on stage (as shown in the above photograph).

We take some ammonium chloride in a china dish and place the china dish on a tripod stand (see Figure 46). The china dish is covered with an inverted glass funnel. A loose cotton plug is put in the upper, open end of the funnel to prevent the ammonium chloride vapours from escaping into the atmosphere. The china dish is heated by using a burner. On heating, ammonium chloride changes into white vapours. These vapours rise up and get converted into solid ammonium chloride on coming in contact with the cold, inner walls of the funnel (see Figure 46). In this way, ammonium chloride collects on the inner sides of the funnel in the form of a sublimate and can be removed.

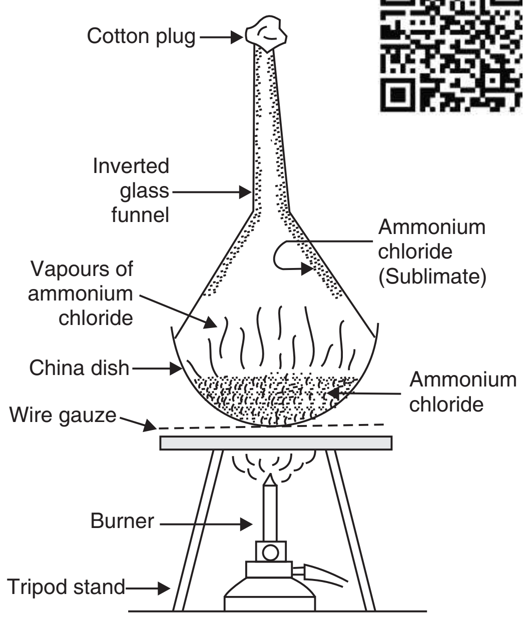


Figure 46. Sublimation of ammonium chloride.

In many households, small naphthalene balls are kept in stored woollen and silk clothes, etc., to protect them from the attack of moths and other insects. It is noticed that these **naphthalene balls disappear with time without leaving behind any residue**. This is because naphthalene balls undergo sublimation. The naphthalene balls keep on forming naphthalene vapours slowly which disappear into the air. We can now show the interconversion between the three states of matter : solid, liquid and gas, with the help of 'states of matter triangle' shown in Figure 48.

Figure 47. These are naphthalene balls. Naphthalene is an organic compound which undergoes sublimation.

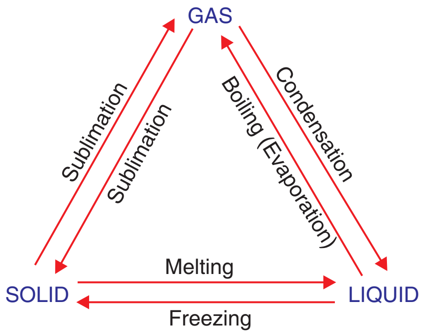


Figure 48. States of matter triangle. It shows the interconversion of the three states of matter.

EFFECT OF CHANGE OF PRESSURE

The physical state of matter can also be changed by changing the pressure. In other words, the physical state of matter can also be changed by increasing the pressure or decreasing the pressure. For example, gases can be changed into liquids by increasing the pressure (accompanied by lowering of temperature). And some solids (like solid carbon dioxide) can change into gases on decreasing the pressure. Let us discuss it in a little more detail.

Gases Can be Liquefied by Applying Pressure and Lowering Temperature

When a high pressure is applied to a gas, it gets compressed (into a small volume), and when we also lower its temperature, it gets liquefied. So, we can also say that gases can be liquefied (turned into liquids) by compression and cooling. This happens as follows.

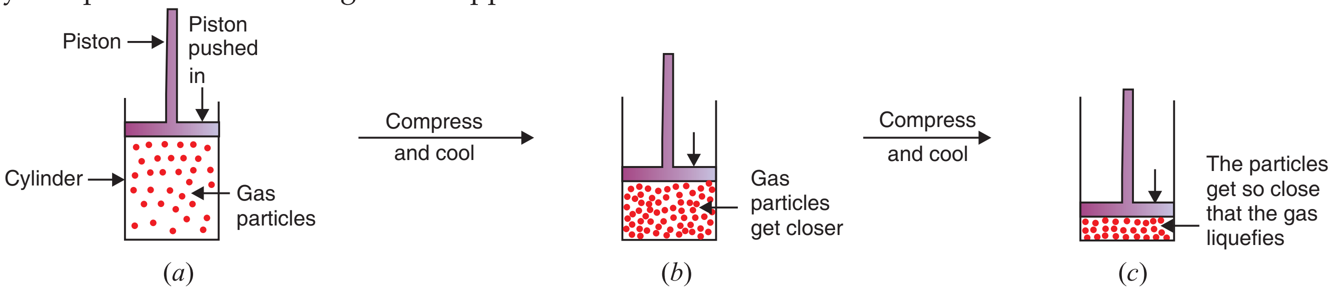


Figure 49. By applying high pressure, the particles of a gas can be brought so close together that it liquefies (turns into a liquid).

There is a lot of space between the particles of a gas. We can reduce the spaces (or distances) between the particles of a gas by enclosing it in a cylinder and compressing it by pushing in the piston [see Figures 49(*a*) and (*b*)]. If enough force (or pressure) is applied to the piston, the gas is highly compressed (into a small volume). The particles of gas get so close together that they start attracting each other sufficiently to form a liquid [see Figure 49(*c*)]. And we say that the gas has liquefied. When a gas is compressed too much, then heat is produced due to compression. So, while applying pressure to liquefy gases, it is necessary to cool them to take away the heat produced during compression. Cooling lowers the temperature of compressed gas and helps in liquefying it. From this discussion we conclude that **gases can be liquefied by applying pressure and lowering temperature.** In other words, gases can be liquefied by compression and cooling. A gas must be cooled below a certain temperature before liquefaction by pressure can occur. Cooling is usually done by pouring water

Figure 50. Oxygen gas can be liquefied by applying high pressure and lowering the temperature (cooling). This picture shows liquid oxygen (obtained by the liquefaction of oxygen gas). Liquid oxygen is blue in colour.

over the coils carrying the compressed gas. **Ammonia gas can be liquefied by applying high pressure and lowering the temperature.** That is, ammonia gas can be liquefied by compression and cooling.

We have just studied that increasing the pressure and lowering the temperature can change the state of matter from a gas to a liquid. Even decreasing the pressure and raising the temperature can change the state of matter. This will become clear from the following example. **Solid carbon dioxide (dry ice) is stored under high pressure.** This is because on decreasing the pressure on solid carbon dioxide, it gets converted directly into carbon dioxide gas. For example, when a slab of solid carbon dioxide is kept exposed to air, then the pressure on it is reduced to normal atmospheric pressure (1 atmosphere), its temperature rises, and it starts changing into carbon dioxide gas. Thus, **the conversion of solid carbon dioxide into carbon dioxide gas is a change of state (from solid to gas) which is caused by the decrease in pressure and higher atmospheric temperature.** Solid carbon dioxide is a white solid called dry ice. **Solid carbon dioxide is an extremely cold substance. It is used to 'deep freeze' food and to keep ice-cream cold.** Since solid carbon dioxide directly changes into carbon dioxide gas (or sublimes), and does not melt to produce a liquid (like ordinary ice), it is called dry ice. Dry ice can produce much lower temperatures than that produced by ordinary ice. So, it is much more effective for cooling purposes than ordinary ice.

Figure 51. Dry ice (solid carbon dioxide) is used to deep-freeze food.

EVAPORATION

When a liquid is left exposed to air, its volume decreases gradually. This is due to evaporation. In this process some of the liquid at the surface turns into vapour (or gas) and mixes with the gases in the air. Thus, when a liquid turns into vapour (or gas), it is said to evaporate. We can now define evaporation as follows : **The process of a liquid changing into vapour (or gas) even below its boiling point is called evaporation.** Evaporation of a liquid can take place even at room temperature, though it is faster at higher

Figure 52. This picture shows the evaporation of water from the surface of a pond. This evaporation is caused by the heat of the sun.

Figure 53. Common salt is obtained by the evaporation of sea-water collected in shallow lagoons by the heat of the sun.

temperatures. **Whatever be the temperature at which evaporation takes place, the latent heat of vaporisation must be supplied whenever a liquid changes into vapour (or gas).** The wet clothes dry due to evaporation of water present in them. And rain water puddles also dry up because of evaporation of water. Common salt is also recovered from sea-water by the process of evaporation.

The process of evaporation can be explained as follows. Some particles in a liquid always have more kinetic energy than the others. So, even when a liquid is well below its boiling point, some of its particles have enough energy to break the forces of attraction between the particles and escape from the surface of the liquid in the form of vapour (or gas). Thus, the fast moving particles (or molecules) of a liquid are constantly escaping from the liquid to form vapour (or gas).

Factors Affecting Evaporation

The evaporation of a liquid depends mainly on the following factors :

(*i*) Temperature
(*ii*) Surface area
(*iii*) Humidity
(*iv*) Wind speed

We will discuss all these factors in detail, one by one.

1. Temperature

The rate of evaporation increases on increasing the temperature of the liquid. In other words, the rate of evaporation of a liquid increases on heating. When the temperature of a liquid is increased by heating it, more particles of the liquid get enough kinetic energy to go into the vapour state (or gaseous state). This increases the rate of evaporation. Thus, **the rate of evaporation of a liquid can be increased by heating it.** The rate of evaporation of a liquid becomes maximum at its boiling point.

2. Surface Area of the Liquid

The rate of evaporation increases on increasing the surface area of the liquid. So, if the surface area of a liquid exposed to the air is increased, the rate of evaporation of the liquid increases. For example, if the same liquid (say, water) is kept in a test-tube and in a china dish, then the liquid kept in the china dish will evaporate more rapidly (because more of its surface area is exposed to air). In our daily life, we spread out the washed wet clothes while drying to increase their surface area for the rapid evaporation of water present in them (which leads to quicker drying of wet clothes). After rain, the wet roads dry quickly because the rain water is spread over a large area of road. This gives the particles of water a greater chance of escaping from the liquid. From this discussion we conclude that **the rate of evaporation of a liquid can be increased by increasing the surface area of the liquid.**

Figure 54. Wet clothes are spread for drying. The spread wet clothes have large surface area. This makes the evaporation of water faster. Due to this, clothes dry up more quickly.

3. Humidity of Air

The amount of water vapours present in air is represented by a term called humidity. When the amount of water vapours present in the air is small, the air appears to be 'dry' and we say that the humidity is low. On the other hand, when the amount of water vapours in the air is large, the air appears to be 'damp' and we say that the humidity is high. So, **humidity of air tells us the degree of 'dampness' of air.**

When the humidity of air is low, then the rate of evaporation is high, and water evaporates more readily. Under these conditions, sweat from our body evaporates readily and we feel cool and comfortable. The wet clothes dry quickly under the conditions of low humidity of air. **When the humidity of air is high, then the rate of evaporation is low, and water evaporates very slowly.** In the later part of summer, the humidity of air increases. People sweat a lot in such weather. But the sweat from our bodies does not evaporate readily due to high humidity of air. Such weather becomes muggy (damp) and we feel hot and uncomfortable. This type of weather is experienced during cloudy days in the rainy season and in areas close to the sea (coastal areas). The wet clothes take a long time to dry when the humidity of air is high.

4. Wind Speed

The rate of evaporation of a liquid increases with increasing wind speed. When the speed of wind increases, the particles of water vapour move away with the wind, decreasing the amount of water vapour in the surroundings. This increases the rate of evaporation of water. The washed wet clothes dry more quickly on a windy day because evaporation is faster due to the high speed of the wind.

Cooling Caused by Evaporation

We have already studied that whenever a liquid evaporates, it must be supplied the latent heat of vaporisation. **The cooling caused by evaporation is based on the fact that when a liquid evaporates, it draws (or takes) the latent heat of vaporisation from 'anything' which it touches.** By losing heat, this 'anything' gets cooled. Keeping these points in mind, we will now give some examples of the cooling caused by evaporation.

If we put a little of spirit (ether or petrol) at the back of our hand and wave it around, the spirit evaporates rapidly and our hand feels very cold. This is due to the fact that to change from the liquid to the vapour state, spirit requires latent heat of vaporisation. The spirit takes this heat of vaporisation from our hand. The hand loses heat and gets cooled. This is an example of **cooling caused by evaporation.**

During hot summer days, water is usually kept in an earthen pot (called pitcher or *matka*) to keep it cool. Let us see how it gets cooled. The earthen pot has a large number of extremely small pores (or holes) in its walls. Some of the water continuously keeps seeping through these pores to the outside of the pot. This water evaporates (changes into vapour) continuously and takes the latent heat required for vaporisation from the earthen pot and the remaining water. In this way, the remaining water loses heat and gets cooled. This is also an example of the **cooling caused by evaporation.** It should be noted that *all the water on the earth does not get evaporated due to the high value of the latent heat of vaporisation of water.* **At many places, especially in villages, people often sprinkle water on the ground in front of their homes during the hot summer evenings.** This water evaporates by taking the large latent heat of vaporisation from the ground and surrounding air. By losing heat, the place becomes cool and comfortable. Please note that **water vaporising from the leaves of trees also cools the surrounding air.**

Figure 55. These earthen pots or pitchers (called *matkas)* keep water cool during hot summer days. This is due to cooling caused by evaporation.

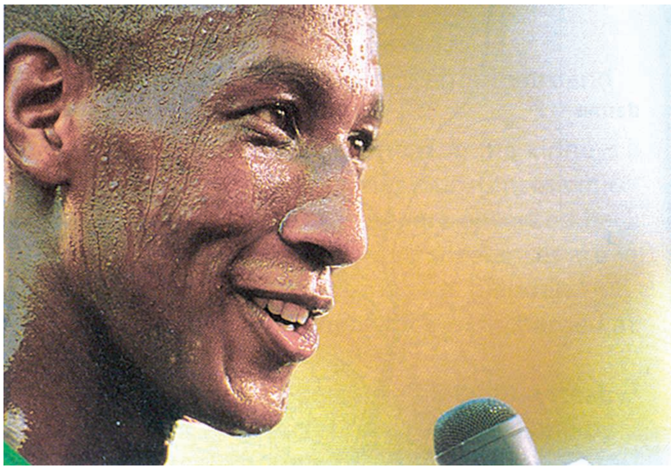


Figure 56. Perspiration (or sweating) is our body's method of maintaining a constant temperature. This also involves cooling caused by evaporation.

Perspiration (or sweating) is our body's method of maintaining a constant temperature. On a hot day or after doing some physical exercise, when our body temperature tends to rise too much, our sweat glands give out moisture (or sweat) on our skin. When this sweat evaporates, it takes the latent heat of vaporisation from our body. This keeps our body cool.

We should wear cotton clothes in hot summer days to keep cool and comfortable. This can be explained as follows. We get a lot of sweat (*pasina*) on our body in hot summer days. Now, cotton is a good absorber of water, so it absorbs the sweat from our body and exposes it to the air (or atmosphere) for evaporation. The evaporation of this sweat cools our body. The synthetic clothes (made of polyester, etc.) do not absorb much of sweat, so they fail to keep our body cool in summer. **A fan increases the rate of evaporation of sweat (or moisture) from our skin and makes us feel cool and comfortable.**

The cooling in a desert room cooler is caused by the evaporation of water. **A desert cooler cools better on a hot and dry day** because the higher temperature on a hot day increases the rate of evaporation of water, and the dryness of air (low humidity of air) also increases the rate of evaporation of water. And due to increased rate of evaporation of water, a desert room cooler cools better on a hot and dry day.

It is a common observation that we are able to sip hot tea (or milk) faster from a saucer than from a cup. This can be explained as follows : Saucer has a large surface area. Due to the large surface area of saucer, the evaporation of hot tea (or milk) from the saucer is faster. And this faster evaporation cools the hot tea (or milk) more quickly making it convenient for us to drink it.

To Show the Presence of Water Vapour in Air

There is always some water vapour in the air around us (which we cannot see). The amount of water vapour in air keeps on changing. **Water vapour comes into the air from the evaporation of water present in ponds, lakes, rivers and oceans.** Water vapour is also given out by plants by the process of transpiration (evaporation from leaves). Animals give out water vapour when they breathe out air. Land also gives water vapour on being warmed by the sun. All this water vapour goes into the air around us. We will now describe an experiment to demonstrate that water vapour is present in air.

The presence of water vapour in air can be shown by the following experiment. We take a steel tumbler and put some well crushed ice into it (see Figure 57). Wipe the tumbler from outside with a piece of clean, dry cloth, so as to make its outer surface completely dry. Allow the ice containing steel tumbler to stand undisturbed for about five minutes. A large number of tiny drops of water appear on the outer surface of steel tumbler (see Figure 57). This happens as follows : The air around the steel tumbler contains water vapour in it. When these water vapour come in contact with the cold, outside surface of steel tumbler, they condense to form tiny drops of liquid water. So, **the formation of drops of water on the outside surface of a tumbler containing crushed ice, shows the presence of water vapour in air.**

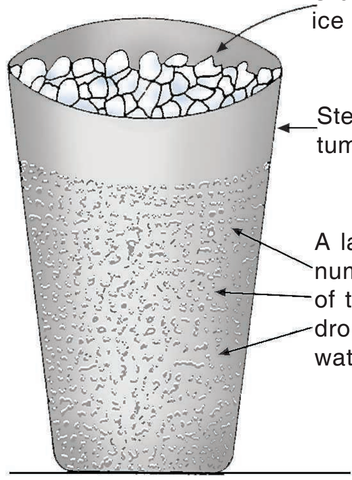


Figure 57. Experiment to show the presence of water vapour in air.

Two More States of Matter : Plasma and Bose-Einstein Condensate

Scientists now say that there are actually five states of matter : **Solid, Liquid, Gas, Plasma** and **Bose-Einstein Condensate**.

Plasma is a mixture of free electrons and ions. Plasma is considered the fourth state of matter. **Plasma occurs naturally in the stars (including the sun)**. Inside the stars, the temperature is so high that the atoms break up. Some of the electrons break away from the atoms converting the rest of atoms into electrically charged particles called ions. This mixture of free electrons and ions in a star is called plasma. **The sun and other stars glow because of the presence of plasma in them**.

Plasma can also be made on the earth by passing electricity through gases at very low pressures taken in a

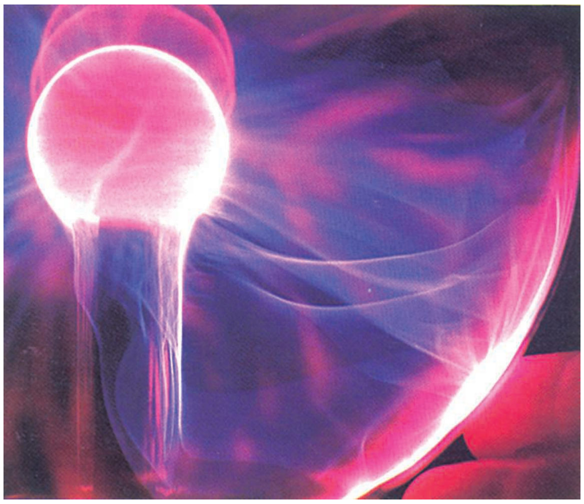


Figure 58. Plasma carrying electricity in a glass container.

glass tube (called discharge tube). The fluorescent tubes and neon sign bulbs form plasma when they are switched on. A fluorescent tube may contain helium gas (or some other gas), and a neon sign bulb contains neon gas. When electricity is passed through a fluorescent tube (or neon sign bulb), the gases present in them get ionised to form plasma. This **plasma makes a fluorescent tube (or neon sign bulb) to glow**.

In 1920, an Indian scientist Satyendra Nath Bose did some calculations for the fifth state of matter. On the basis of these calculations, Albert Einstein predicted the existence of a new state of matter called Bose-Einstein Condensate (BEC). The fifth state of matter called Bose-Einstein Condensate was finally achieved by three scientists, Cornell, Ketterle and Wieman of USA by cooling a gas of extremely low density (about one hundred thousandth the density of normal air) to super low temperatures. We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. The boiling point of water is 100°C. Express this in SI units (Kelvin scale).
2. The Kelvin temperature is 270 K. What is the corresponding Celsius scale temperature ?
3. Convert the temperature of 573 K to the Celsius scale.
4. Convert the temperature of 373°C to the Kelvin scale.
5. The boiling point of alcohol is 78°C. What is this temperature on Kelvin scale ?
6. The Kelvin scale temperature is 0 K. What is the corresponding Celsius scale temperature ?
7. Give the usual name for the following :
Heat required to change the state of a substance without changing the temperature.
8. What is the (*a*) common unit of temperature, and (*b*) SI unit of temperature ?
9. Write the relation between Kelvin scale and Celsius scale of temperature.
10. What should be added to a Celsius scale reading so as to obtain the corresponding Kelvin scale reading ?
11. What is meant by saying that the latent heat of fusion of ice is 3.34×10^5 J/kg ?
12. What is meant by saying that the latent heat of vaporisation of water is 22.5×10^5 J/kg ?
13. Name the temperature at which :
(*a*) a liquid changes into a gas. (*b*) a solid changes into a liquid.
14. Name one common substance which can be easily changed from one state to another by heating or cooling.
15. What is the name of the process in which :
(*a*) a solid turns directly into a gas ? (*b*) a gas turns directly into a solid ?
16. Name one property which is shown by ammonium chloride but not by sodium chloride.
17. What is the name of the process due to which dry ice changes into carbon dioxide gas ?
18. What is the common name of solid carbon dioxide ?
19. Why is solid carbon dioxide known as dry ice ?
20. State one condition necessary to liquefy gases (other than applying high pressure).
21. State whether the following statement is true or false :
Solid carbon dioxide is stored under low pressure.
22. What is the chemical name of dry ice ?
23. Fill in the following blanks with suitable words :
(*a*) Gases can be liquefied by applying .... and lowering ....
(*b*) When steam condenses to form water, heat is............
(*c*) Temp on Kelvin scale = Temp on Celsius scale + ...
(*d*) Scientists say that there are actually five states of matter : solid, liquid, gas, ... and...........
(*e*) The state of matter called............makes a fluorescent tube (or neon sign bulb) to glow..

Short Answer Type Questions

24. What do you understand by the term 'latent heat' ? What are the two types of latent heat ?
25. Why is heat energy needed to melt a solid ? What is this heat energy called ?
26. Under what conditions heat can be given to a substance without raising its temperature ?

27. Why does the temperature remain constant during the melting of ice even though heat is supplied continuously ?

28. Why does the temperature remain constant during the boiling of water even though heat is supplied continuously ?

29. Explain why, ice at 0°C is more effective in cooling than water at the same temperature.

30. Would you cool a bucket of water more quickly by placing it on ice or by placing ice in it ? Give reasons for your answer.

31. Why does steam cause more severe burns than boiling water ?

32. Which contains more heat, 1 kg of ice at 0°C or 1 kg of water at 0°C ? Give reason for your answer.

33. Which contains more heat, 1 kg of water at 100°C or 1 kg of steam at 100°C ? Give reason for your answer.

34. Explain why, steam at 100°C is better for heating purposes than boiling water at 100°C.

35. Which produces more severe burns : boiling water or steam ? Why ?

36. Why does the temperature of a substance remain constant during the change of state ?

37. What is the physical state of water :

(*a*) at 0°C ? (*b*) at 25°C ? (*c*) at 100°C ? (*d*) at 250°C ?

38. Explain why, there is no rise in temperature of a substance when it undergoes a change of state though heat is supplied continuously.

39. Define 'melting point' of a substance ? What is the melting point of ice ?

40. Define 'boiling point' of a substance ? What is the boiling point of water ?

41. Define the following terms :

(*a*) Melting (*b*) Boiling

42. Define the following terms :

(*a*) Condensation (*b*) Freezing

43. Explain why, naphthalene balls kept in stored clothes in our homes disappear over a period of time.

44. Explain briefly, how gases can be liquefied.

45. How is ammonia gas liquefied ?

46. How does applying pressure (or compression) help in the liquefaction of a gas ?

47. How does perspiration or sweating help keep our body cool on a hot day ?

48. Why does all the water of the earth not get evaporated during hot summer days ?

49. If the back of your hand is moistened with alcohol, you will find that it rapidly becomes dry. Why is it that while it is drying, your hand feels cool ?

50. Why does a desert cooler cool better on a hot, dry day ?

51. How does the water kept in an earthen pot (*matka*) become cold during summer ?

52. What type of clothes should we wear in summer ? Why ?

53. Why are we able to sip hot tea or milk faster from a saucer rather than from a cup ?

54. Why does our palm feel cold when we put some acetone (or perfume) on it ?

55. How will you demonstrate that water vapour is present in air ?

Long Answer Type Questions

56. (*a*) Define the term 'latent heat of fusion' of a solid. How much is the latent heat of fusion of ice ?

(*b*) Draw a labelled diagram of the experimental set-up to study the latent heat of fusion of ice.

57. (*a*) Define the term 'latent heat of vaporisation' of a liquid. What is the value of the latent heat of vaporisation of water ?

(*b*) Draw a labelled diagram of the experimental set-up to study the latent heat of vaporisation of water.

58. (*a*) What is sublimation ? Name two substances (other than ammonium chloride) which undergo sublimation.

(*b*) Draw a labelled diagram of the experimental set-up to demonstrate the sublimation of ammonium chloride.

59. (*a*) What are the two ways in which the physical states of matter can be changed ?

(*b*) Draw the 'states of matter triangle' to show the interconversion of states of matter.

(*c*) How can the evaporation of a liquid be made faster ?

60. (*a*) What is evaporation ? State the various factors which affect evaporation.

(*b*) Why does evaporation cool a liquid ?

Multiple Choice Questions (MCQs)

61. Which of the following are also considered to be the states of matter ?
(*i*) Plasma (*ii*) Platelets (*iii*) BEC (*iv*) BHC
(*a*) (*i*) and (*ii*) (*b*) (*ii*) and (*iii*) (*c*) (*i*) and (*iii*) (*d*) (*ii*) and (*iv*)

62. One of the following does not undergo sublimation. This one is :
(*a*) iodine (*b*) sodium chloride (*c*) ammonium chloride (*d*) camphor

63. Which of the following process/processes release heat ?
(*i*) condensation (*ii*) vaporisation (*iii*) freezing (*iv*) melting
(*a*) only (*i*) (*b*) only (*iv*) (*c*) (*i*) and (*iii*) (*d*) (*ii*) and (*iv*)

64. If the temperature of an object is 268 K, it will be equivalent to :
(*a*) – 5°C (*b*) + 5°C (*c*) 368°C (*d*) – 25°C

65. The boiling point of ethane is, – 88°C. This temperature will be equivalent to :
(*a*) 285 K (*b*) 288 K (*c*) 185 K (*d*) 361 K

66. When heat is constantly supplied by a gas burner with small flame to melt ice, then the temperature of ice during melting :
(*a*) increases very slowly (*b*) does not increase at all
(*c*) first remains constant and then increases (*b*) increases to form liquid water

67. When water at 0°C freezes to form ice at the same temperature of 0°C, then it :
(*a*) absorbs some heat (*b*) releases some heat
(*c*) neither absorbs nor releases heat (*d*) absorbs exactly 3.34×10^5 J/kg of heat

68. When heat is constantly supplied by a burner to boiling water, then the temperature of water during vaporisation :
(*a*) rises very slowly (*b*) rises rapidly until steam is produced
(*c*) first rises and then becomes constant (*d*) does not rise at all

69. The latent heat of fusion of ice is :
(*a*) 33.4×10^5 J/kg (*b*) 22.5×10^5 J/kg (*c*) 33.4×10^4 J/kg (*d*) 2.25×10^4 J/kg

70. The latent heat of vaporisation of water is :
(*a*) 2.25×10^6 J/kg (*b*) 3.34×10^6 J/kg (*c*) 22.5×10^4 J/kg (*d*) 33.4×10^5 J/kg

71. Which one of the following set of phenomena would increase on raising the temperature ?
(*a*) diffusion, evaporation, compression of gases
(*b*) evaporation, compression of gases, solubility
(*c*) evaporation, diffusion, expansion of gases
(*d*) evaporation, solubility, diffusion, compression of gases

72. Which of the following represent the suitable conditions for the liquefaction of gases ?
(*a*) low temperature, low pressure (*b*) high temperature, low pressure
(*c*) low temperature, high pressure (*d*) high temperature, high pressure

73. During summer days, water kept in an earthen pot (pitcher) becomes cool because of the phenomenon of :
(*a*) diffusion (*b*) transpiration (*c*) osmosis (*d*) evaporation

74. On converting 25°C, 38°C and 66°C to Kelvin scale, the correct sequence of temperatures will be :
(*a*) 298 K, 311 K and 339 K (*b*) 298 K, 300 K and 338 K
(*c*) 273 K, 278 K and 543 K (*d*) 298 K, 310 K and 338 K

75. The conversion of a solid into vapours without passing through the liquid state is called :
(*a*) vaporisation (*b*) fusion (*c*) sublimation (*d*) freezing

76. The evaporation of water increases under the following conditions :
(*a*) increase in temperature, decrease in surface area
(*b*) increase in surface area, decrease in temperature
(*c*) increase in surface area, rise in temperature
(*d*) increase in temperature, increase in surface area, addition of common salt

77. On converting 308 K, 329 K and 391 K to Celsius scale, the correct sequence of temperatures will be :

(*a*) 33°C, 56°C and 118°C (*b*) 35°C, 56°C and 119°C
(*c*) 35°C, 56°C and 118°C (*d*) 56°, 119°C and 35° C

78. Which of the following energy is absorbed during the change of state of a substance ?

(*a*) specific heat (*b*) latent heat (*c*) heat capacity (*d*) heat of solution

79. Which of the following factors are responsible for the change in state of solid carbon dioxide when kept exposed to air ?

(*i*) increase in pressure (*ii*) increase in temperature
(*iii*) decrease in pressure (*iv*) decrease in temperature

(*a*) (*i*) and (*ii*) (*b*) (*i*) and (*iii*) (*c*) (*ii*) and (*iii*) (*d*) (*ii*) and (*iv*)

80. During respiration, glucose and oxygen enter our body cells and waste products carbon dioxide and water leave the body cells by the process of :

(*a*) effusion (*b*) osmosis (*c*) diffusion (*d*) plasmolysis

Questions Based on High Order Thinking Skills (HOTS)

81. There are four substances W, X, Y and Z. The substance W is a dark violet solid having diatomic molecules. A solution of W in alcohol is used as a common antiseptic C. The substance X is a white solid which is usually recovered from sea water on a large scale. The substance Y is a white solid which is insoluble in water and used in the form of small balls for the safe storage of woollen clothes. The substance Z is a yet another white solid which is used in making commonly used dry cells.

(*a*) Name (*i*) W (*ii*) X (*iii*) Y and (*iv*) Z.
(*b*) Out of W, X, Y and Z, which substance/substances can undergo sublimation ?
(*c*) Which substance is organic in nature ?
(*d*) What is the name of substance C ?
(*e*) Which substance belongs to the halogen family ?

82. The substance X normally exists in a physical state which can flow easily but does not fill its vessel completely. It also turns anhydrous copper sulphate blue. When substance X is cooled excessively, it changes into a substance Y which has a fixed shape as well as a fixed volume. If, however, the substance X is heated strongly, it changes into a substance Z which has neither a fixed shape nor a fixed volume.

(*a*) Name the substances (*i*) X (*ii*) Y and (*iii*) Z.
(*b*) What is the process of conversion of X into Y known as ?
(*c*) At which temperature X gets converted into Y ?
(*d*) What is the process of conversion of X into Z known as ?
(*e*) At which temperature X gets converted into Z ?

83. The scientists now say that there are actually five states of matter A, B, C, D and E. The state A has a fixed volume but no fixed shape. The state B can be compressed very easily by applying pressure and state C has a fixed shape as well as a fixed volume. The state D is a mixture of free electrons and ions whereas state E is named after an Indian scientist and a famous physicist.

(*a*) Name the physical states (*i*) A (*ii*) B (*iii*) C (*iv*) D, and (*v*) E.
(*b*) Name one substance belonging to state C which can directly change into vapours on heating. What is this process known as ?
(*c*) Name one substance which normally belongs to state B but whose solid form changes directly into gaseous state.
(*d*) Name the most common substance belonging to state A.
(*e*) Which state of matter makes the sun and other stars to glow ?

84. When water is cooled to a temperature x, it gets converted into ice at temperature x by a process called P. And when ice at temperature x is warmed, it gets reconverted into water at the same temperature x in a process called Q.

(*a*) What is the value of temperature x in Kelvin ?
(*b*) What is the process P known as ?
(*c*) What is the name of energy released during process P ?

(*d*) What is the process Q known as ?

(*e*) What is the name of energy absorbed during process Q ?

85. When water is heated to a temperature x, it gets converted into steam at temperature x by a process called R. And when steam at temperature x is cooled, it gets reconverted into water at the same temperature x by a process called S.

(*a*) How much is the value of x in Kelvin ?

(*b*) What is the process R called ?

(*c*) What is the name of the energy absorbed during the process R ?

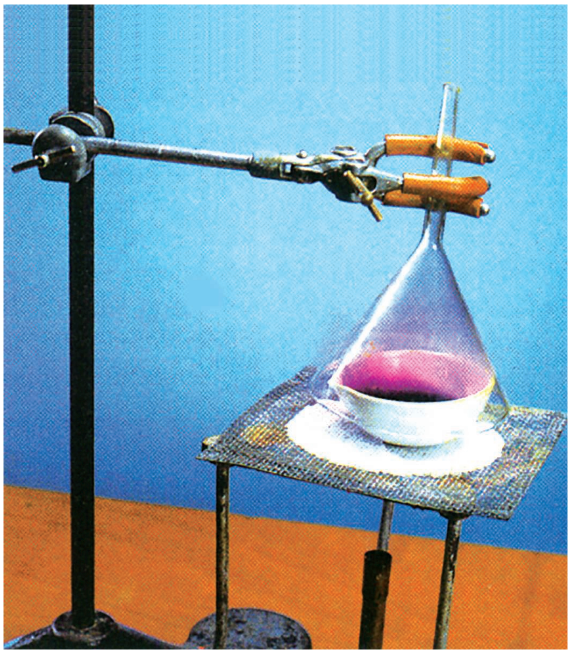
(*d*) What is process S known as ?

(*e*) What is the name of energy released during the process S known as ?

ANSWERS

1. 373 K **2.** –3°C **3.** 300°C **4.** 646 K **5.** 351 K **6.** –273°C **7.** Latent heat **10.** 273 **14.** Water **20.** Lowering temperature (or Cooling) **21.** False **23.** (*a*) pressure ; temperature (*b*) released (*c*) 273 (*d*) plasma ; Bose-Einstein Condensate (BEC) (*e*) plasma **61.** (*c*) **62.** (*b*) **63.** (*c*) **64.** (*a*) **65.**(*c*) **66.** (*b*) **67.** (*b*) **68.** (*d*) **69.** (*c*) **70.** (*a*) **71.** (*c*) **72.** (*c*) **73.** (*d*) **74.** (*a*) **75** (*c*) **76.** (*c*) **77.** (*c*) **78.** (*b*) **79.** (*c*) **80.** (*c*) **81.** (*a*) (*i*) Iodine (*ii*) Sodium chloride (Common salt) (*iii*) Naphthalene (*iv*) Ammonium chloride (*b*) W (iodine), Y (naphthalene) and Z (ammonium chloride) (*c*) Y (naphthalene) (*d*) Tincture iodine (*e*) W (iodine) **82.** (*a*) (*i*) Water (*ii*) Ice (*iii*) Steam (*b*) Freezing (*c*) 0°C (*d*) Boiling (or Vaporisation) (*e*) 100°C **83.** (*a*) (*i*) Liquid (*ii*) Gas (*iii*) Solid (*iv*) Plasma (*v*) Bose-Einstein Condensate (BEC) (*b*) Ammonium chloride ; Sublimation (*c*) Carbon dioxide (*d*) Water (*e*) D (plasma) **84.** (*a*) 273 K (*b*) Freezing (*c*) Latent heat of freezing (*d*) Melting (*e*) Latent heat of fusion **85.** (*a*) 373 K (*b*) Boiling (or Vaporisation) (*c*) Latent heat of vaporisation (*d*) Condensation (*e*) Latent heat of condensation

2



IS MATTER AROUND US PURE

If we observe some sugar and some soil (*mitti*) placed on two different sheets of paper with a magnifying glass, we will find that the colour, shape and size of all the particles of sugar are the same, but the soil contains particles of different colours, shapes and sizes. For example, the soil contains clay particles, some grass particles and even some dead insects, etc. Now, sugar which contains particles of only one kind is called a pure substance whereas soil which contains particles of different kinds is called an impure substance (or mixture). From this we conclude that **all the matter around us is not pure. The matter around us is of two types : pure substances and mixtures**. The mixtures are impure substances. We will now discuss pure substances and mixtures in a little more detail.

(*a*) Sugar is a pure substance (*b*) Soil is an impure substance (or mixture)

Figure 1. The matter around us is of two types : pure substances and mixtures.

Pure Substances : Elements and Compounds

A pure substance is one which is made up of only one kind of particles. These particles may be atoms or molecules. So, we can also say that *a pure substance is one which is made up of only one kind of atoms or* *molecules*. For example, sulphur element is made up of only one kind of particles (called sulphur atoms), therefore, sulphur is a pure substance. Similarly, water is made up of only one kind of particles (called water molecules), therefore, water is a pure substance. **All the elements and compounds are pure substances** because they contain only one kind of particles. Thus, all the elements like **hydrogen, oxygen, nitrogen, chlorine, bromine, iodine, carbon, sulphur, iron, copper, silver, gold, mercury and silicon, are pure substances.** Similarly, all the compounds such as **water (including ice and steam), carbon dioxide, sodium chloride, sugar, copper sulphate, alum (aluminium potassium sulphate), calcium oxide, sodium hydroxide, hydrochloric acid, sulphuric acid, nitric acid, potassium permanganate, camphor, naphthalene and sand (silicon dioxide), are pure substances**. A pure substance is homogeneous throughout its mass. A pure substance cannot be separated into other kinds of matter by any physical process. A pure substance has a fixed composition as well as a fixed melting point and boiling point.

Impure Substances : Mixtures

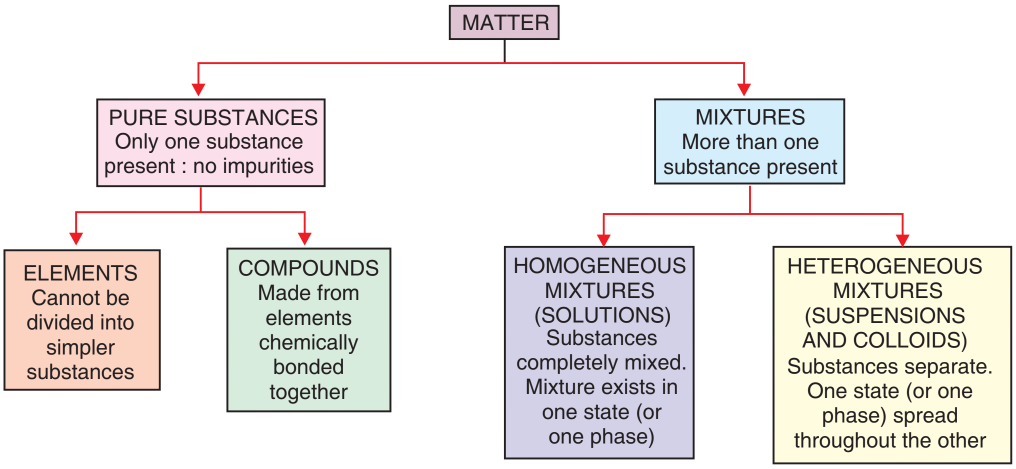
A mixture is one which contains two or more different kinds of particles (atoms or molecules). In other words, **a mixture contains two or more pure substances mixed together**. For example, salt solution is a mixture of two pure substances : salt and water. And milk is a mixture of water, fat and proteins, etc. **All the mixtures are impure substances** because they contain more than one kind of particles. Some of the **examples of the mixtures are : salt solution, sugar solution, milk, sea-water, air, sugarcane juice, soft drinks, *sharbat*, jaggery (*gud*), rocks, minerals, petroleum, LPG, biogas, tap water, tea, coffee, paint, wood, soil and bricks**. A mixture may be homogeneous or heterogeneous. A mixture can be separated into other kinds of matter by physical processes. A mixture does not have a fixed composition or a fixed melting point and boiling point. **Most of the matter around us exists as mixtures of two or more pure substances.**

Figure 2. Gold is an element. It is a pure substance.

Figure 3. Sodium chloride is a compound. It is also a pure substance.

Figure 4. Jaggery (*gud* or Indian raw sugar) is a mixture. It is an impure substance.

From the above discussion we conclude that on the basis of their properties, **all the matter can be divided into three general classes : elements, compounds and mixtures**. A schematic representation of the different types of matter is given below.



We will now discuss the three types of matter, elements, compounds and mixtures, in detail.

Before we discuss elements, we should know the meaning of three terms which are used in distinguishing metal elements from non-metal elements. These are malleability, ductility and brittleness.

(*i*) The property which allows the metals to be hammered (or beaten) into thin sheets (without breaking), is called **malleability**.

(*ii*) The property which allows the metals to be drawn (or stretched) into thin wires (without breaking) is called **ductility**.

(*iii*) The property due to which non-metals break into pieces on hammering, is called **brittleness.** Brittleness is the opposite of malleability and ductility.

ELEMENTS

An element is a substance which cannot be split up into two or more simpler substances by the usual chemical methods of applying heat, light or electric energy. For example, hydrogen is an element because it cannot be split up into two or more simpler substances by the usual methods of carrying out chemical reactions by applying heat, light or electricity. Similarly, oxygen is an element because it cannot be broken down into simpler substances by chemical methods. On the other hand, water is not an element because it can be split up into two simpler substances, hydrogen and oxygen, by electricity.

An element cannot be split up into two (or more) simpler substances because it is made of only one kind of atoms. This gives us another definition of an element which can be stated as follows : **An element is a substance which is made of only one kind of atoms.** For example, copper metal is made of only one

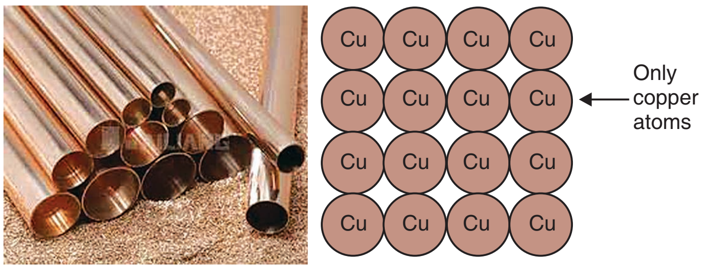


Figure 5. Copper is an element. It is made of only copper atoms.

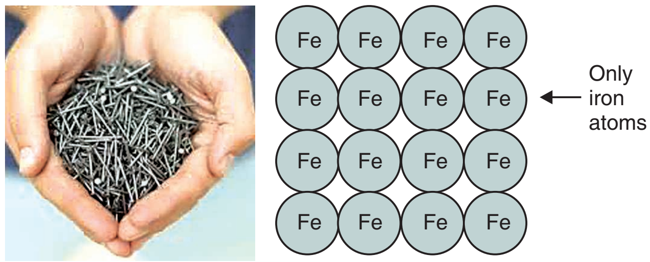
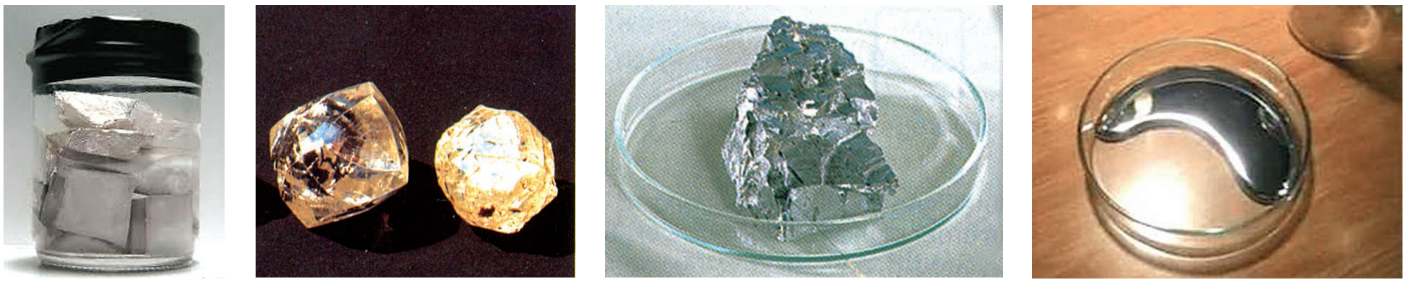


Figure 6. Iron is an element. It is made of only iron atoms.

kind of atoms called 'copper atoms', so copper metal is an element (see Figure 5). Similarly, iron metal is made of only iron atoms, so iron metal is also an element (see Figure 6). It is clear from the above discussion that an element is made of same kind of atoms. In other words, all the atoms of an element are identical. The atoms of different elements differ in size and composition.

There are 115 elements known at present, out of which 92 elements occur in nature, while the remaining 23 elements have been prepared artificially. **Every substance in this world is made up of one or more of these elements.** Some of the common elements are : hydrogen, helium, oxygen, nitrogen, carbon, sulphur,



(*a*) Sodium (*b*) Diamond (a form of carbon element) (*c*) Chromium (*d*) Mercury

Figure 7. These pictures show some of the elements which occur in nature.

phosphorus, chlorine, bromine, iodine, sodium, potassium, magnesium, calcium, aluminium, copper, silver, gold, zinc, iron, silicon, tin and mercury. Diamond and graphite are also elements. They are the allotropic forms of carbon element. Each element is represented by a separate symbol.

Elements can be solids, liquids or gases. Some elements are solids, some elements are liquids whereas other elements are gases at the room temperature. For example, sodium and carbon elements are solids, mercury and bromine elements are liquids, whereas hydrogen and oxygen elements are gases, at the room temperature. In fact, majority of the elements are solids. Eleven elements are gases whereas **only two elements (mercury and bromine) are liquids at the room temperature**.

Most of the materials around us are made up by the combination of two or more elements. For example, water is a common material which is made up of two elements : Hydrogen and Oxygen. Similarly, sugar is a common material which is made up of three elements : Carbon, Hydrogen and Oxygen. **Just as 26 letters of the 'English alphabet' combine in various different ways to make a very large number of words, in the same way, a few elements combine together in various different ways to make an extremely large number of materials and objects.** Even the human body is made up of complex compounds formed by the combination of only certain elements. For example, the human body contains 65% oxygen element, 18% carbon element, 10% hydrogen element, 3% nitrogen element, 2% calcium element and 2% other elements.

Figure 8. Water (H_2O) is a common material which is made up of two elements : Hydrogen (H) and Oxygen (O).

Metals, Non-Metals and Metalloids

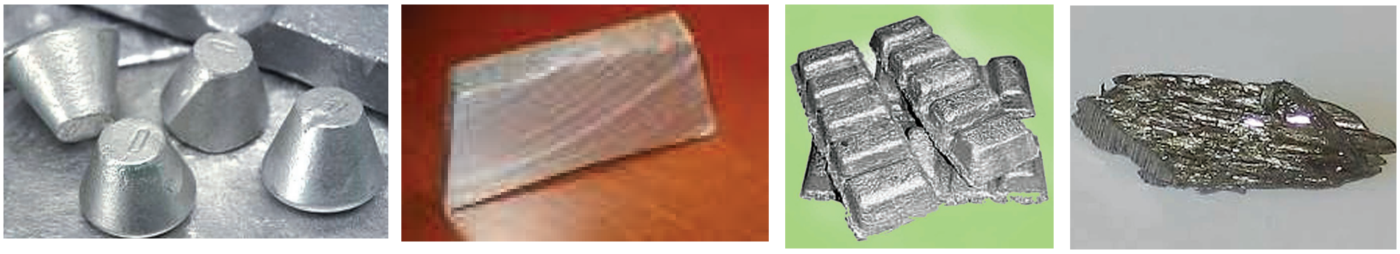
On the basis of their properties, **all the elements can be divided into three groups :**

1. **Metals,**
2. **Non-metals,** and
3. **Metalloids**

We will now discuss these three groups of elements in somewhat detail, one by one. Let us start with metals.

METALS

A metal is an element that is malleable and ductile, and conducts electricity. Some of the examples of metals are : Iron, Copper, Aluminium, Zinc, Silver, Gold, Platinum, Chromium, Sodium, Potassium,



(*a*) Aluminium (*b*) Magnesium (*c*) Zinc (*d*) Silver

Figure 9. Aluminium, magnesium, zinc and silver are all metals.

Magnesium, Nickel, Cobalt, Tin, Lead, Cadmium, Mercury, Antimony, Tungsten, Manganese and Uranium. **All the metals are solids except one metal mercury, which is a liquid**.

Properties of Metals

The important physical properties of metals are given below :

1. Metals are Malleable. This means that metals can be beaten into thin sheets with a hammer (without breaking). Gold and silver metals are some of the best malleable metals. Aluminium and copper metals are also highly malleable metals. All these metals can be beaten with a hammer to form very thin sheets called foils. For example, silver metal can be hammered into thin silver foils because of its high malleability. The silver foils are used for decorating sweets. Similarly, aluminium metal is quite malleable and can be converted into thin sheets called aluminium foils. **Aluminium foils are used for packing food items like biscuits, chocolates, medicines, cigarettes,** etc. Milk bottle caps are also made of aluminium foil. Aluminium sheets are used for making cooking utensils. Copper metal is also highly malleable. So, copper sheets are used to make utensils and other containers. Thus, **malleability is an important characteristic property of metals.**

2. Metals are Ductile. This means that metals can be drawn (or stretched) into thin wires. All the metals are not equally ductile. Some are more ductile than the others. Gold and silver are among the best ductile metals. For example, just 100 milligrams of a highly ductile metal like silver can be drawn into a thin wire about 200 metres long. Copper and aluminium metals are also very ductile and can be drawn into thin wires which are used in electrical wiring. Thus, **ductility is another important characteristic property of metals.** From the above discussion we conclude that **metals are malleable and ductile.** It is due to the properties of malleability and ductility that metals can be given different shapes to make various articles.

3. Metals are Good Conductors of Heat and Electricity. This means that metals allow heat and electricity to pass through them easily. Metals are generally good conductors of heat (The conduction of heat is also called thermal conductivity). **Silver metal is the best conductor of heat.** It has the highest thermal conductivity. Copper and aluminium metals are also very good conductors of heat. **The cooking utensils and water boilers, etc., are usually made of copper or aluminium metals because they are very good conductors of heat.** The poorest conductor of heat among the metals is lead. Mercury metal is also a poor conductor of heat.

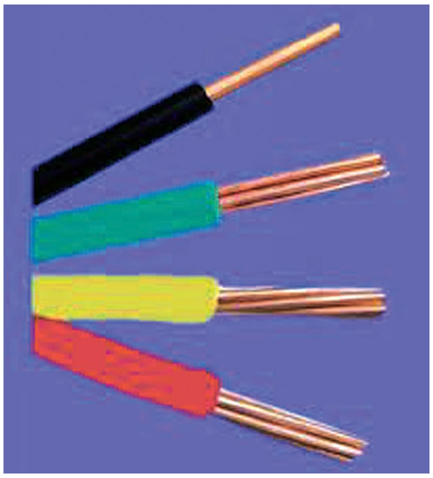


Figure 10. These electric wires are made of copper metal.

Metals are good conductors of electricity. The metals offer very little resistance to the flow of electric current and hence show high electrical conductivity. **Silver metal is the best conductor of electricity.** Copper metal is the next best conductor of electricity followed by gold, aluminium and tungsten. **The electric wires are made of copper and aluminium metals because they are very good conductors of electricity.** The metals like iron and mercury offer comparatively greater resistance to the flow of current, so they have lower electrical conductivity.

4. Metals are Lustrous (or Shiny), and can be Polished. For example, gold, silver and copper are shiny metals and they can be polished. The property of a metal of having a shining surface is called metallic lustre (*chamak*). The shiny appearance of metals makes them useful in making jewellery and decoration pieces. For example, gold and silver are used for making jewellery because they are bright and shiny. The shiny surface of metals makes them good reflectors of light. Silver metal is an excellent reflector of light.

5. Metals are Generally Hard (except sodium and potassium which are soft metals). Most of the metals are hard. But all the metals are not equally hard. The hardness varies from metal to metal. Most of the metals like iron, copper, aluminium, etc., are very hard. They cannot be cut with a knife. There are some exceptions. Sodium and potassium are soft metals which can be easily cut with a knife.

6. Metals are Usually Strong. They Have High Tensile Strength. This means that metals can hold large weights without breaking. For example, iron metal (in the form of steel) is very strong having a high tensile strength. Due to this iron metal is used in the construction of bridges, buildings, railway lines, girders, machines, vehicles and chains, etc. Though most of the metals are strong but some of the metals are not strong. For example, sodium and potassium metals are not strong. They have low tensile strength.

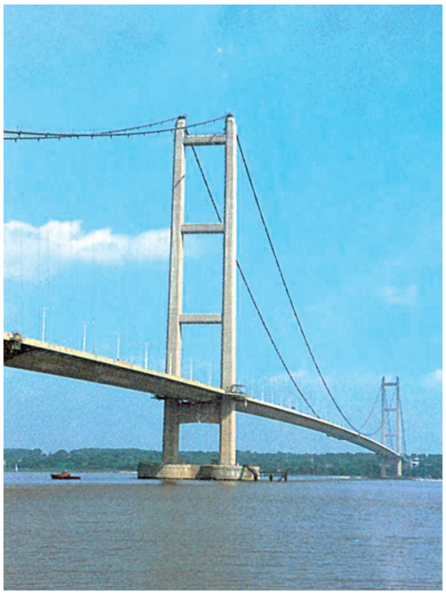


Figure 11. Iron is a very important metal. We use about nine times more iron than all the other metals put together. Iron is made into steel and used for making large things like bridges (see above), as well as small things like needles.

7. Metals are Solids at the Room Temperature (except mercury which is a liquid metal). All the metals like iron, copper, aluminium, silver and gold, etc., are solids at the room temperature. **Only one metal, mercury, is in liquid state at the room temperature.**

8. Metals Generally Have High Melting Points and Boiling Points. This means that most of the metals melt and vaporise at high temperatures. For example, iron is a metal having a high melting point of 1535°C. This means that solid iron melts and turns into liquid iron (or molten iron) on heating to a high temperature of 1535°C. Copper metal has also a high melting point of 1083°C. There are, however, some exceptions. For example, **sodium and potassium metals have low melting points** (of less than 100°C). Another metal gallium has such a low melting point that it starts melting in hand (by the heat of our body).

9. Metals Have High Densities. This means that metals are heavy substances. For example, the density of iron metal is 7.8 g/cm^3 which is quite high. There are, however, some exceptions. **Sodium and potassium metals have low densities.** They are very light metals.

10. Metals are Sonorous. This means that metals make a ringing sound when we strike them. It is due to the property of sonorousness of metals that they are used for making bells, plate type musical instruments like cymbals (*manjira)*, and wires (or strings) for stringed musical instruments such as violin, guitar, *sitar* and *tanpoora*, etc.

11. Metals Usually Have a Silver or Grey Colour (except copper and gold). Copper has a reddish-brown colour whereas gold has a yellow colour.

Metals are widely used in our daily life for a large number of purposes. The cooking utensils, electric fans, sewing machines, cars, buses, trucks, trains, ships and aeroplanes, are all made of metals or mixtures of metals called alloys. In fact, the list of articles made of metals which we use in our daily life is unending.

NON-METALS

A non-metal is an element that is neither malleable nor ductile, and does not conduct electricity. Some of the examples of non-metals are : Carbon, Sulphur, Phosphorus, Hydrogen, Oxygen, Nitrogen, Fluorine, Chlorine, Bromine, Iodine, Helium, Neon, Argon, Krypton, and Xenon. Diamond and Graphite are also non-metals. They are the allotropic forms of carbon. All the non-metals are solids or gases, except bromine which is a liquid non-metal at room temperature.

(*a*) Carbon (*b*) Sulphur (*c*) Bromine (inside the flask) (*d*) Chlorine (inside the gas jar)

Figure 12. Carbon, sulphur, bromine and chlorine are all non-metals.

Properties of Non-Metals

The physical properties of non-metals are just the opposite of the physical properties of metals. The important physical properties of non-metals are given below :

1. Non-Metals are Not Malleable. Non-Metals are Brittle. This means that non-metals cannot be beaten into thin sheets with a hammer. Non-metals break into small pieces when hammered. For example, sulphur and phosphorus are solid non-metals which are not malleable, they cannot be beaten into thin sheets with a hammer. Thus, we cannot get thin sheets from non-metals. Sulphur and phosphorus non-metals are brittle. When beaten with a hammer, they break into small pieces. **Brittleness is a characteristic property of solid non-metals.**

2. Non-Metals are Not Ductile. This means that non-metals cannot be drawn into wires. They are easily snapped on stretching. For example, sulphur and phosphorus are non-metals and they are not ductile. When stretched, sulphur and phosphorus break into pieces and do not form wires. Thus, we cannot get wires from non-metals. From the above discussion we conclude that : **Non-metals are neither malleable nor ductile. Non-metals are brittle.**

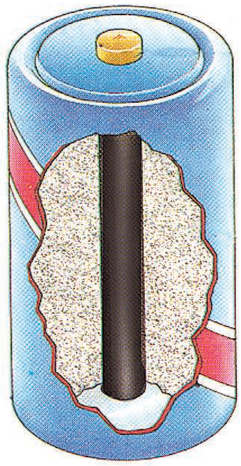


Figure 13. The black electrode in the middle of this dry cell is made of graphite because it is a good conductor of electricity.

3. Non-Metals are Bad Conductors of Heat and Electricity. This means that non-metals do not allow heat and electricity to pass through them. For example, sulphur and phosphorus are non-metals which do not conduct heat or electricity. Many of the non-metals are, in fact, insulators. There are, however, some exceptions. A form of the carbon element, **diamond is a non-metal which is a good conductor of heat.** And another form of carbon element, **graphite is a non-metal which is a good conductor of electricity.** Being a good conductor of electricity, graphite is used for making electrodes (as that in dry cells).

4. Non-Metals are Not Lustrous (Not Shiny). They are Dull in Appearance. Non-metals do not have lustre (*chamak*) which means that non-metals do not have a shining surface. The solid non-metals have a dull appearance. For example, sulphur and phosphorus are non-metals which have no lustre, that is, they do not have a shining surface. They appear to be dull. There is, however, an exception. **Iodine is a non-metal having lustrous appearance.** It has a shining surface (like that of metals).

5. Non-Metals are Generally Soft (except diamond which is extremely hard non-metal). Most of the solid non-metals are quite soft. They can be easily cut with a knife. For example, sulphur and phosphorus are solid non-metals which are quite soft and can be easily cut with a knife. Only one non-metal carbon (in the form of diamond) is very hard. In fact, **diamond (which is an allotropic form of carbon) is the hardest natural substance known.**

6. Non-Metals are Not Strong. They Have Low Tensile Strength. This means that non-metals cannot hold large weights (without breaking). For example, graphite is a non-metal which is not strong. It has a low tensile strength. When a large weight is placed on a graphite sheet, it breaks.

7. Non-Metals may be Solid, Liquid or Gases at the Room Temperature. Non-metals can exist in all the three physical states : solid, liquid and gaseous. For example, carbon, sulphur and phosphorus are solid non-metals; bromine is a liquid non-metal; whereas hydrogen, oxygen, nitrogen and chlorine are gaseous non-metals.

8. Non-Metals Have Comparatively Low Melting Points and Boiling Points (except graphite which is a non-metal having a very high melting point). This means that non-metals melt and vaporise at comparatively low temperatures. For example, sulphur is a non-metal having a low melting point of 119°C. **Only one non-metal graphite has a very high melting point** (of 3700°C). The majority of non-metals have very low boiling points due to which they exist as gases at room temperature.

9. Non-Metals Have Low Densities. This means that non-metals are light substances. For example, sulphur is a solid non-metal having a low density of 2 g/cm^3, which is quite low. The density of gaseous non-metals is very, very low. **One non-metal iodine has, however, high density.**

10. Non-Metals are Not Sonorous. This means that solid non-metals do not make a ringing sound when we strike them.

11. Non-Metals Have Many Different Colours. For example, sulphur is yellow, phosphorus is white or red, graphite is black, chlorine is yellowish-green, bromine is red-brown whereas hydrogen and oxygen are colourless.

Though non-metals are small in number as compared to metals, but they play a very important role in our daily life. In fact, **life would not have been possible without the presence of non-metals on the earth.** For example, carbon is one of the most important non-metals because all the life on this earth is based on carbon compounds. This is because the carbon compounds like proteins, fats, carbohydrates, vitamins and enzymes, etc., are essential for the growth and development of living organisms. Another non-metal oxygen is equally important for the existence of life. This is because the presence of oxygen gas in air is essential for breathing to maintain life. It is also necessary for the combustion (or burning) of fuels which provide us energy for various purposes.

Figure 14. Carbon is a non-metal. Carbon based organic molecules form the basis of all life on earth : animals (including human beings) as well as plants.

We have just studied the characteristic properties of metals and non-metals. We will now compare the properties of metals and non-metals in tabular form by giving the main points of difference between them.

Comparison Among the Properties of Metals and Non-Metals

Metals	*Non-Metals*
1. Metals are malleable and ductile. That is, metals can be hammered into thin sheets and drawn into thin wires.	1. Non-metals are brittle. They are neither malleable nor ductile.
2. Metals are good conductors of heat and electricity.	2. Non-metals are bad conductors of heat and electricity (except diamond which is a good conductor of heat, and graphite which is a good conductor of electricity).
3. Metals are lustrous (shiny) and can be polished.	3. Non-metals are non-lustrous (dull) and cannot be polished (except iodine which is a lustrous non-metal).
4. Metals are solids at room temperature (except mercury which is a liquid metal).	4. Non-metals may be solid, liquid or gases at the room temperature.
5. Metals are strong and tough. They have high tensile strength.	5. Non-metals are not strong. They have low tensile strength.
6. Metals are sonorous. They make a ringing sound when struck.	6. Non-metals are not sonorous.

An element can be identified as being a metal or a non-metal by comparing its properties with the general properties of metals and non-metals. While doing so we should, however, keep the various exceptions to the general properties of metals and non-metals in mind. We will now answer one question based on metals and non-metals.

Sample Problem. State two reasons for believing that copper is a metal and sulphur is a non-metal.

Answer. The two properties which tell us that copper is a metal and sulphur is a non-metal are given below :

Copper	*Sulphur*
1. Copper is malleable and ductile. It can be hammered into thin sheets and drawn into wires. 2. Copper is a good conductor of heat and electricity.	1. Sulphur is neither malleable nor ductile. It is brittle. Sulphur breaks into pieces when hammered or stretched. 2. Sulphur is a bad conductor of heat and electricity.

METALLOIDS

There are a few elements which show some properties of metals and other properties of non-metals. For example, they look like metals but they are brittle like non-metals. They are neither conductors of electricity like metals nor insulators like non-metals, they are semiconductors. **The elements which show**

(*a*) Boron

(*b*) Silicon

(*c*) Germanium

Figure 15. Boron, silicon and germanium elements are metalloids.

some properties of metals and some other properties of non-metals are called metalloids. Their properties are intermediate between the properties of metals and non-metals. Metalloids are also sometimes called semi-metals. **The important examples of metalloids are : Boron (B), Silicon (Si), and Germanium (Ge).**

MIXTURES

A mixture is a substance which consists of two or more elements or compounds not chemically combined together. For example, air is a mixture of gases like oxygen, nitrogen, argon, carbon dioxide and water vapour, etc. The various gases of the air are not chemically combined with one another. Similarly, gunpowder is a mixture of potassium nitrate, sulphur and charcoal (charcoal is a form of carbon), whereas brass is a mixture of copper and zinc. **All the solutions are mixtures.** For example, salt-solution (brine) is

Figure 16. Milk is a mixture of water, fat, proteins, sugar, minerals and vitamins.

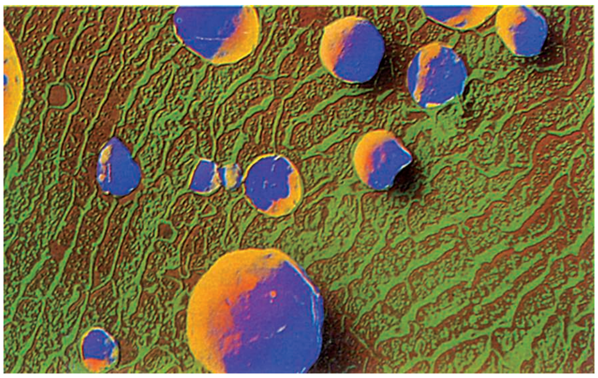


Figure 17. This picture shows fat globules in milk as seen under the high power microscope.

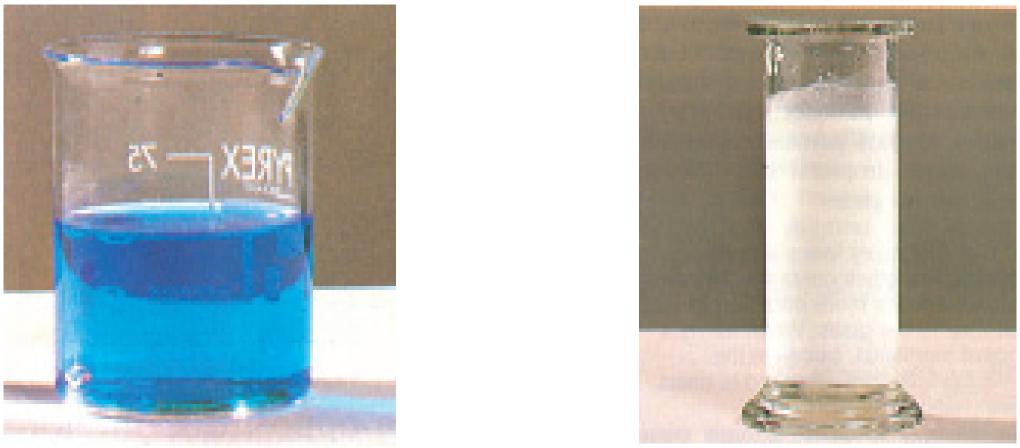
a mixture of common salt (sodium chloride) in water. Please note that **the various substances present in a mixture are known as "constituents of the mixture" or "components of the mixture".** Some of the examples of mixtures are : Air, Gunpowder, Brass, Salt solution, Sugar solution, Milk, Sea-water, Ink, Kerosene oil, Petrol, Petroleum, Lime-water, Paint, Glass, Coal, Soil, Wood, Blood, Starch solution, Soap solution, Iron and sulphur mixture, Dyes, Alcohol and water, Petrol and water, Chalk-water mixture, Soda water, Soft drinks, Lemonade, Vinegar, Muddy river water, Flour in water, Milk of Magnesia, Butter, Cheese, Face cream, Shaving cream, Hair spray, Smoke, Fog and Mist.

Types of Mixtures

Mixtures are of two types :

1. **Homogeneous mixtures,** and
2. **Heterogeneous mixtures.**

Those mixtures in which the substances are completely mixed together and are indistinguishable from one another, are called homogeneous mixtures. A homogeneous mixture has a uniform composition throughout its mass. It has no visible boundaries of separation between the various constituents. A mixture of sugar in water (called sugar solution) is a homogeneous mixture because all the parts of sugar solution have the same sugar-water composition and appear to be equally sweet ! There is no visible boundary of separation between sugar and water particles in a sugar solution. A mixture of two (or more) miscible liquids is also a homogeneous mixture. For example, a mixture of alcohol and water is a homogeneous mixture. Unpolluted air is a homogeneous mixture of gases like oxygen, nitrogen, argon, carbon dioxide and water-vapour, etc. **All the homogeneous mixtures are called solutions.** Some of the **examples of homogeneous mixtures (or solutions)** are : Sugar solution, Salt solution, Copper sulphate solution, Sea-water, Alcohol and water mixture, Petrol and oil mixture, Soda water, Soft drinks, Lemonade, Vinegar, Brass, Air, Kerosene oil, and Petrol. Please note that kerosene and petrol are not single substances, they are mixtures of various compounds of carbon and hydrogen (called hydrocarbons).



(*a*) Copper sulphate solution is a homogeneous mixture

(*b*) Chalk and water mixture is a heterogeneous mixture

Figure 18. Mixtures can be homogeneous or heterogeneous.

Those mixtures in which the substances remain separate and one substance is spread throughout the other substance as small particles, droplets or bubbles, are called heterogeneous mixtures. A heterogeneous mixture does not have a uniform composition throughout its mass. It has visible boundaries of separation between the various constituents. The mixture of sugar and sand is a heterogeneous mixture because different parts of this mixture will have different sugar-sand compositions. Some parts of this mixture will have more of sugar particles whereas other parts will have more of sand particles. There is a visible boundary of separation between sugar and sand particles. **The suspensions of solids in liquids are also heterogeneous**

mixtures. For example, a suspension of chalk in water is a heterogeneous mixture. **A mixture containing two (or more) immiscible liquids is also a heterogeneous mixture**. For example, a mixture of petrol and water is a heterogeneous mixture. As we will learn after a while, **all the suspensions and colloids are heterogeneous mixtures**. Some of the **examples of heterogeneous mixtures** are : Sugar and sand mixture, Salt and sand mixture, Polluted air, Gunpowder, Milk, Ink, Petroleum, Paint, Glass, Coal, Soil, Wood, Blood, Starch solution, Soap solution, Iron filings and sulphur Mixture, Dyes, Petrol and water mixture, Chalk and water mixture, Muddy river water, Flour in water, Milk of Magnesia, Butter, Cheese, Face cream, Shaving cream, Hair spray, Fog and Mist. **Most of the mixtures are heterogeneous, only solutions and alloys are homogeneous mixtures**. We will now take one example to understand the characteristics of mixtures.

To Study the Properties of a Mixture of Iron and Sulphur

When iron filings (or iron powder) and sulphur powder are mixed together, a greyish-yellow mixture is obtained. Let us study the properties of this mixture.

1. If we put a magnet in the mixture of iron filings and sulphur, the iron particles are attracted by the magnet, they stick to the magnet and get separated from sulphur (see Figure 19). Sulphur is not attracted by the magnet, so it is left behind. Thus, a mixture of iron filings and sulphur has been separated into its constituents, iron and sulphur, by the physical method of using a magnet.

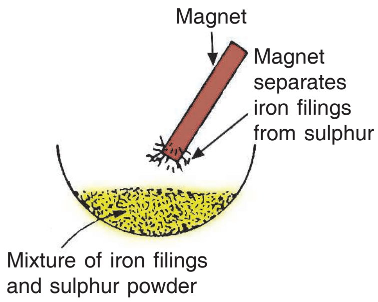


Figure 19. A mixture of iron and sulphur can be separated by using a magnet.

Alternatively, if we shake the mixture of iron filings and sulphur with an organic liquid known as carbon disulphide (CS_2), then sulphur dissolves in it but iron does not dissolve. On filtration, iron is obtained as a residue and sulphur is recovered from the filtrate by evaporating carbon disulphide. Thus, a mixture of iron filings and sulphur has been separated by another physical method of using carbon disulphide solvent (followed by filtration and evaporation). From these two experiments we conclude that **a mixture can be separated into its constituents by physical processes (like filtration, evaporation, sublimation, distillation, solvents, magnet, etc.).**

2. If dilute sulphuric acid is added to the mixture of iron filings and sulphur, the iron part reacts with sulphuric acid and hydrogen gas is produced (which is a colourless and odourless gas). Sulphur remains unchanged. This shows that a mixture of iron and sulphur shows the properties of iron. Now, if this mixture of iron and sulphur is treated with carbon disulphide, the sulphur part dissolves in it leaving the iron unchanged. This means that a mixture of iron filings and sulphur also shows the properties of sulphur. If we combine these two results, we can say that a mixture of iron filings and sulphur shows the properties of both its constituents, iron as well as sulphur. In general we can say that **a mixture shows the properties of all the constituents present in it.**

3. When iron filings are mixed with sulphur powder to prepare the mixture, heat is neither evolved nor absorbed. In general, **energy (in the form of heat, light, etc.) is usually neither given out nor absorbed in the preparation of a mixture.** So, the formation of a mixture is a **physical change**.

4. We can mix any amounts of iron filings and sulphur powder to get mixtures having different compositions. Thus, a mixture of iron filings and sulphur has a variable composition. Since its composition is variable, no definite formula can be given to a mixture of iron filings and sulphur. From this discussion we conclude that **the composition of a mixture is variable, the constituents can be present in any proportion by mass.** Due to its variable composition, a mixture does not have a definite formula.

5. A mixture of iron filings and sulphur does not melt at a single fixed temperature. From this we conclude that **a mixture does not have a definite melting point, boiling point, etc.**

6. If we examine the mixture of iron filings and sulphur powder with a magnifying glass, it is found that though the iron particles are quite close to the sulphur particles, at some places there are more of iron particles whereas at other places there are more of sulphur particles. That is, a mixture of iron filings and sulphur is not homogeneous, it is heterogeneous. Though most of the mixtures are heterogeneous, some mixtures called solutions and alloys are, however, homogeneous. From this we conclude that **a mixture is usually heterogeneous (except solutions and alloys which are homogeneous mixtures).** We will now discuss compounds.

COMPOUNDS

A compound is a substance made up of two or more elements chemically combined in a fixed proportion by mass. For example, water (H_2O) is a compound made up of two elements, hydrogen and oxygen, chemically combined in a fixed proportion of 1 : 8 by mass (Atomic masses : H = 1 u, O = 16 u, so H_2 : O = 2 u : 16 u or 1 : 8). Similarly, common salt (sodium chloride, NaCl) is a compound made up of two elements, sodium and chlorine; ammonium chloride (NH_4Cl) is a compound made up of three elements, nitrogen, hydrogen and chlorine; sand (silicon dioxide, SiO_2) is a compound of silicon and oxygen, and marble (calcium carbonate, $CaCO_3$) is a compound made up of calcium, carbon and oxygen elements.

(*a*) Calcium carbonate (in the form of marble)

(*b*) Sodium hydroxide (in the form of pellets)

(*c*) Copper sulphate

Figure 20. Calcium carbonate, sodium hydroxide and copper sulphate are compounds.

Some more **examples of compounds** are : Ammonia (NH_3), Carbon dioxide (CO_2), Ice (H_2O), Steam (H_2O), Chalk (Calcium carbonate, $CaCO_3$), Limestone (Calcium carbonate, $CaCO_3$), Lime or Quicklime (Calcium oxide, CaO), Slaked lime [Calcium hydroxide, $Ca(OH)_2$], Methane (CH_4), Glucose ($C_6H_{12}O_6$), Sugar or Canesugar ($C_{12}H_{22}O_{11}$), Starch [$(C_6H_{10}O_5)_n$], Baking soda (Sodium hydrogencarbonate, $NaHCO_3$), Washing soda (Sodium carbonate, Na_2CO_3), Potassium nitrate (KNO_3), Potassium sulphate (K_2SO_4), Sodium sulphate (Na_2SO_4), Copper sulphate ($CuSO_4$), Iron sulphide (FeS), Hydrochloric acid (HCl), Sulphuric acid (H_2SO_4), Nitric acid (HNO_3), Hydrogen bromide (HBr) and Sodium hydroxide (NaOH). We have given the formulae of all these compounds so that you may be able to write the names of the elements present in them. **Compounds can be further divided into three classes : acids, bases and salts, on the basis of their properties**. For example, sulphuric acid is an acid, sodium hydroxide is a base whereas sodium sulphate is a salt. We will now take one example to understand the characteristic properties of a compound.

To Study the Properties of a Compound of Iron and Sulphur

When the mixture of iron filings and sulphur powder is heated, a black compound known as iron sulphide (FeS) is formed. Let us examine the properties of this compound to find out the difference between a compound and a mixture.

1. If a magnet is put in the iron sulphide compound, iron does not get separated from sulphur (see Figure 21). Even carbon disulphide solvent cannot separate the sulphur from iron sulphide compound. This means that the iron sulphide compound cannot be separated into its constituents by physical methods. In general we can say that **a compound cannot be separated into its components by physical methods.**

2. When dilute sulphuric acid is added to iron sulphide compound, we get a colourless, foul smelling gas called hydrogen sulphide (having the smell of rotten eggs). No hydrogen gas is formed in this case. This means that iron sulphide does not show the properties of iron present in it. Even the sulphur present in iron sulphide compound cannot be dissolved by carbon disulphide. This means that iron sulphide compound does not show the properties of sulphur. From this we conclude that iron sulphide compound does not show the individual properties of its constituents, iron and sulphur. The properties of iron sulphide compound are entirely different from those of its constituents, iron and sulphur. In general we can say that **the properties of a compound are entirely different from those of its constituent elements.**

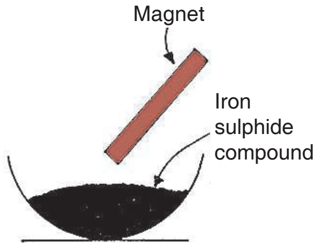


Figure 21. The compound of iron and sulphur (iron sulphide) cannot be separated by using a magnet.

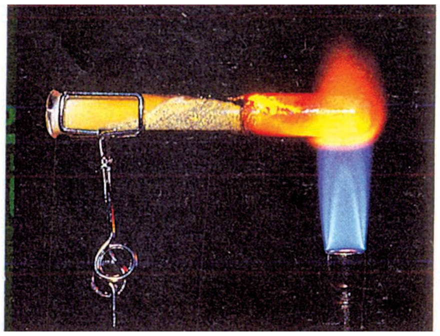
3. Iron sulphide compound is prepared by heating together iron filings and sulphur. Once the reaction starts, a lot of heat and light are produced during the preparation of iron sulphide compound. From this we conclude that **energy (in the form of heat, light, etc.) is usually either given out or absorbed during the preparation of a compound.** The formation of compound is a **chemical change**.

4. Iron sulphide compound (FeS) is prepared by heating together 7 parts by mass of iron and 4 parts by mass of sulphur (Atomic masses : Fe = 56 u, S = 32 u, so Fe : S = 56 u : 32 u or 7 : 4). If we take more of iron or sulphur, the excess part remains unreacted. Thus, iron sulphide compound is always made up of the same elements, iron and sulphur, combined together in a fixed proportion by mass. Since the composition of iron sulphide compound is fixed, it has a definite formula, FeS. From this discussion we conclude that **the composition of a compound is fixed, the constituents are present in a fixed proportion by mass.** A compound has a definite formula.

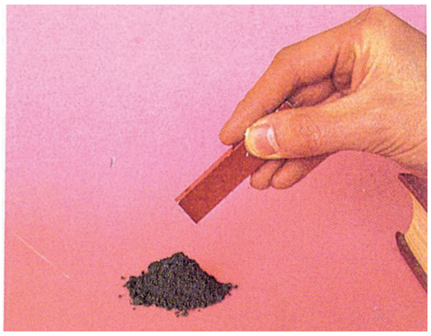
5. Iron sulphide compound melts at a definite temperature. From this we conclude that **a compound has a fixed melting point, boiling point, etc.**

6. If the iron sulphide compound is viewed through a magnifying glass, no separate particles of iron or sulphur are seen and it appears to be just the same throughout its mass. From this we conclude that **a compound is a homogeneous substance.**

(*a*) By mixing iron filings and sulphur powder, we can obtain a mixture (without any chemical reaction taking place). We can still see the yellow sulphur in the mixture and we can pull away iron filings with a magnet



(*b*) But if we heat the mixture of iron filings and sulphur powder (taken in a boiling tube) strongly, with a burner, a chemical reaction takes place and a new chemical compound is formed



(*c*) The new chemical compound formed is iron sulphide (which is black in colour). It contains sulphur but we cannot see any yellow colour of sulphur. It contains iron but we cannot pull away this iron with a magnet

Figure 22. Experiment to study the differences in the properties of a mixture of iron filings and sulphur powder, and iron sulphide compound.

We will now write down the differences between compounds and mixtures in a tabular form.

Differences Between Mixtures and Compounds

In order to decide whether the given substance is a mixture or a compound, the following points of difference between mixtures and compounds should be remembered.

Mixtures	*Compounds*
1. A mixture can be separated into its constituents by the physical processes (like filtration, evaporation, sublimation, distillation, solvents, magnet, etc.).	1. A compound cannot be separated into its constituents by physical processes (It can only be separated into its constituents by chemical processes).
2. A mixture shows the properties of its constituents.	2. The properties of a compound are entirely different from those of its constituents.
3. Energy (in the form of heat, light, etc.) is usually neither given out nor absorbed in the preparation of a mixture.	3. Energy (in the form of heat, light, etc.) is usually given out or absorbed during the preparation of a compound.
4. The composition of a mixture is variable, the constituents can be present in any proportion by mass. A mixture does not have a definite formula.	4. The composition of a compound is fixed, the constituents are present in fixed proportion by mass. A compound has a definite formula.
5. A mixture does not have a fixed melting point, boiling point, etc.	5. A compound has a fixed melting point, boiling point, etc.

Though a compound is always homogeneous, a mixture may be heterogeneous or homogeneous. So, being homogeneous or heterogeneous is usually not helpful in deciding whether a substance is a mixture or a compound and, therefore, this point has not been included in the above table.

In order to find out whether a given substance is a mixture or compound, we should remember that :

1. (*i*) If the substance can be separated into its constituents by physical methods, it is a mixture.
   (*ii*) If the substance cannot be separated into its constituents by physical methods, it is a compound.
2. (*i*) If the substance shows the properties of its constituents, it is a mixture.
   (*ii*) If the properties of the substance are entirely different from those of its constituents, it is a compound.
3. (*i*) If no heat or light, etc., is given out or absorbed during the preparation of the substance, it is a mixture.
   (*ii*) If heat or light, etc., is given out or absorbed during the preparation of the substance, it is a compound.
4. (*i*) If the composition of the substance is variable, it is a mixture.
   (*ii*) If the composition of the substance is fixed, it is a compound.
5. (*i*) If the substance does not have a fixed melting point, boiling point, etc., it is a mixture.
   (*ii*) If the substance has a fixed melting point, boiling point, etc., it is a compound.

Keeping these five points in mind, we will now answer some important questions on mixtures and compounds.

Sample Problem 1. Explain why, air is considered a mixture and not a compound.

Solution. Air is considered a mixture because of the following reasons :

(*i*) Air can be separated into its constituents like oxygen, nitrogen, etc., by the physical process of fractional distillation (of liquid air).

(*ii*) Air shows the properties of all the gases present in it. For example, oxygen supports combustion and air also supports combustion; carbon dioxide turns lime water milky and air also turns lime water milky, though very, very slowly.

(*iii*) Heat and light, etc., are neither given out nor absorbed when air is prepared by mixing the required proportions of oxygen, nitrogen, carbon dioxide, argon, water vapour, etc.

(*iv*) Air has a variable composition because air at different places contains different amounts of the various gases. It does not have a definite formula.

(*v*) Liquid air does not have a fixed boiling point.

Sample Problem 2. Explain why, water is a compound and not a mixture.

Solution. Water is considered a compound because of the following reasons :

(*i*) Water cannot be separated into its constituents, hydrogen and oxygen, by the physical methods (such as filtration, evaporation, distillation, sublimation, magnet, etc.).

(*ii*) The properties of water are entirely different from those of its constituents, hydrogen and oxygen. For example, water is a liquid whereas hydrogen and oxygen are gases; water does not burn whereas hydrogen burns; water does not support combustion whereas oxygen supports combustion.

(*iii*) Heat and light are given out when water is prepared by burning hydrogen in oxygen.

(*iv*) The composition of water is fixed. It contains hydrogen and oxygen combined together in a fixed proportion of 1 : 8 by mass. It has a definite formula, H_2O.

(*v*) Water has a fixed boiling point of 100°C under standard atmospheric pressure.

Sample Problem 3. Classify the following into elements, compounds and mixtures :

Sodium, Soil, Sugar solution, Silver, Calcium carbonate, Tin, Silicon, Coal, Air,
Soap, Methane, Carbon dioxide, Blood **(NCERT Book Question)**

Solution. We can classify the given materials into elements, compounds and mixtures as follows :

Elements	*Compounds*	*Mixtures*
Sodium	Calcium carbonate	Soil
Silver	Soap	Sugar solution
Tin	Methane	Coal
Silicon	Carbon dioxide	Air
		Blood

Sample Problem 4. Give the names of the elements present in the following compounds :

(*a*) Quicklime (*b*) Hydrogen bromide (*c*) Baking soda (*d*) Potassium sulphate

(NCERT Book Question)

Solution. (*a*) Quicklime is calcium oxide, CaO. The elements present in it are : Calcium (Ca) and Oxygen (O).

(*b*) Hydrogen bromide is HBr. The elements present in it are : Hydrogen (H) and Bromine (Br).

(*c*) Baking soda is sodium hydrogencarbonate, $NaHCO_3$. The elements present in it are : Sodium (Na), Hydrogen (H), Carbon (C) and Oxygen (O).

(*d*) Potassium sulphate is K_2SO_4. The elements present in it are : Potassium (K), Sulphur (S) and Oxygen (O).

The Case of Solutions

The solutions are homogeneous substances and heat is also usually evolved or absorbed in the preparation of a solution. Even then **a solution is considered a mixture** because : (*i*) it can be separated into its components by physical methods, (*ii*) it shows the properties of its constituents, (*iii*) it has a variable composition, and (*iv*) it does not have a fixed boiling point.

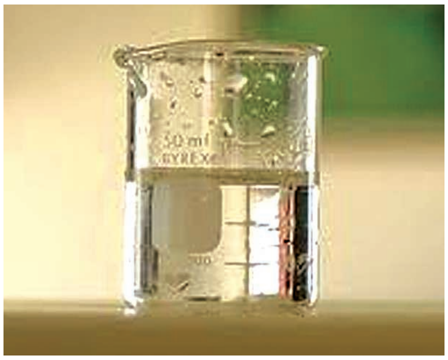


Figure 23. Salt-solution is considered a mixture.

For example, **salt-solution is considered a mixture** because of the following reasons :

(*i*) Salt-solution can be separated into salt and water by the physical process of distillation.

(*ii*) Salt-solution shows the properties of both its constituents, salt as well as water.

(*iii*) The composition of salt-solution is variable. Different amounts of salt can be dissolved in the same amount of water to get salt solutions having different compositions. The salt solution does not have a definite formula.

(*iv*) Salt-solution does not have a fixed boiling point.

Suppose we are given two liquids, one a pure compound and the other a solution, and we have to find out which one is compound and which one is solution (or mixture). In order to distinguish between the two, we should evaporate them separately. **The liquid which evaporates completely, leaving no residue, is a pure compound.** On the other hand, **the liquid which leaves behind a residue on evaporation, is a solution or mixture**. For example, pure water can be distinguished from aqueous salt-solution by evaporation. Pure water evaporates completely leaving no residue, but salt-solution leaves behind salt as residue on evaporation (Please do not say that salt-solution can be distinguished from pure water "by tasting it"!).

The Case of Alloys

Alloys are homogeneous mixtures of metals and cannot be separated into their components by physical methods. Even then **an alloy is considered a mixture** because : (*i*) it shows the properties of its constituents, and (*ii*) it has a variable composition. For example, brass is a homogeneous substance composed of copper and zinc, and cannot be separated into its constituents by physical methods. **Brass is considered a mixture** because : (*i*) it shows the properties of its constituents, copper and zinc, and (*ii*) it has a variable composition (The amount of zinc in brass can vary from 20 to 35 per cent). Before we go further and discuss solutions, suspensions and colloids, **please answer the following questions :**

Figure 24. Brass is an alloy of copper and zinc. Brass is considered to be a mixture. This bucket is made of brass.

Very Short Answer Type Questions

1. State whether the following statement is true or false :
   Milk is a pure substance.
2. Name three mixtures found in nature.
3. Which of the following is a mixture ?
   Salt, Air, Water, Alum, Sugar
4. Name one metal and one non-metal which exist as liquids at room temperature.
5. Name a metal which is soft and a non-metal which is hard.
6. Name a non-metal which is a good conductor of electricity.
7. Name a liquid which can be classified as a pure substance and conducts electricity.
8. Name one solid, one liquid and one gaseous non-metal.
9. Name the property :
   (*a*) which allows metals to be hammered into thin sheets.
   (*b*) which enables metals to be drawn into wires.
10. Which type of elements, metals or non-metals, show the property of brittleness ?
11. What is meant by saying that metals are malleable and ductile ?
12. What is meant by saying that non-metals are brittle ?
13. What is meant by saying that metals are sonorous ?
14. What is meant by saying that metals are lustrous ?
15. What is the general name of the materials which contain at least two pure substances and show the properties of their constituents ?

16. ''The properties of the product are different from those of the constituents''. State whether this statement best describes an element, a compound or a mixture.

17. Name one element, one compound and one mixture.

18. What is the major difference between a solution and an ordinary mixture ?

19. What name is given to those elements which are neither good conductors of electricity like copper nor insulators like sulphur ?

20. Fill in the following blanks with suitable words :

(*a*) An element is made up of only one kind of ....

(*b*) Brine is a ....whereas alcohol is a.............. .

(*c*) Brass is an alloy which is considered a ....

(*d*) The three important metalloids are.............., ... and ....

(*e*) The elements which are sonorous are called..................

Short Answer Type Questions

21. Classify the following into elements and compounds :

(*i*) H_2O (*ii*) He (*iii*) Cl_2 (*iv*) CO (*v*) Co

22. Classify the following as elements or compounds :

Iron, Iron sulphide, Sulphur, Chalk, Washing soda, Sodium, Carbon, Urea

23. What elements do the following compounds contain ?

Sugar, Common salt

24. What are pure substances ? Give two examples of pure substances.

25. What are the two types of pure substances ? Give one example of each type.

26. Which of the following are 'pure substances' ?

Ice, Milk, Iron, Hydrochloric acid, Calcium oxide, Mercury, Brick, Wood, Air

27. What is the other name for impure substances ? Give two examples of impure substances.

28. Which of the following substances are elements ?

Water, Salt, Mercury, Iron, Marble, Diamond, Wood, Nitrogen, Air, Graphite, Hydrogen, Oxygen, Sugar, Chlorine

29. State three reasons why you think air is a mixture and water is a compound.

30. Name two solid, two liquid and two gaseous elements at the room temperature.

31. Explain why, hydrogen and oxygen are considered elements whereas water is not considered an element.

32. What are the three groups into which all the elements can be divided ? Name two elements belonging to each group.

33. State two physical properties on the basis of which metals can be distinguished from non-metals.

34. Compare the properties of metals and non-metals with respect to (*i*) malleability (*ii*) ductility, and (*iii*) electrical conductivity.

35. State any two properties for believing that aluminium is a metal.

36. Give reason why :

(*a*) copper metal is used for making electric wires.

(*b*) graphite is used for making electrode in a dry cell.

37. How would you confirm that a colourless liquid given to you is pure water ?

38. Choose the solutions from among the following mixtures :

Soil, Sea-water, Air, Coal, Soda-water

39. Is air a mixture or a compound ? Give three reasons for your answer.

40. Give two reasons for supposing that water is a compound and not a mixture.

41. Define a compound. Give two points of evidence to show that sodium chloride is a compound.

42. Define a mixture. Give two points of evidence to show that sugar solution is a mixture.

43. State two reasons for supposing that brass is a mixture and not a compound.

44. List five characteristics by which compounds can be distinguished from mixtures.

45. Explain why, a solution of salt in water is considered a mixture and not a compound.

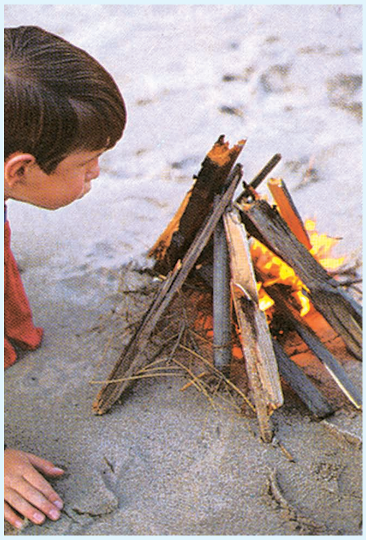
46. State one property in which a solution of sugar in water resembles a mixture of sugar and sand, and one property in which it differs from it.

47. You are given two liquids, one a solution and the other a compound. How will you distinguish the solution from the compound ?

48. Name a non-metal :
(*a*) which is lustrous
(*b*) which is required for combustion
(*c*) whose one of the allotrophic forms is a good conductor of electricity. Name the allotrope.
(*d*) other than carbon which shows allotropy
(*e*) which is known to form the largest number of compounds

49. Name a metal :
(*a*) which can be easily cut with a knife
(*b*) which forms amalgams
(*c*) which has no fixed shape
(*d*) which has a low melting point
(*e*) which is yellow in colour

50. Which of the following are not compounds ?
Chlorine gas, Potassium chloride, Iron powder, Iron sulphide, Aluminium foil, Iodine vapour, Graphite, Carbon monoxide, Sulphur powder, Diamond



Air is needed for the combustion (or burning) of fuels. Which component of air actually supports combustion ?

Long Answer Type Questions

51. (*a*) State the main points of difference between homogeneous and heterogeneous mixtures.
(*b*) Classify the following materials as homogeneous mixtures and heterogeneous mixtures :
Soda-water, Wood, Air, Soil, Vinegar, Alcohol and water mixture, Petrol and water mixture, Chalk and water mixture, Sugar and water mixture, Copper sulphate solution.

52. (*a*) What is meant by (*i*) elements (*ii*) compounds, and (*iii*) mixtures ? Write down the names of two elements, two compounds and two mixtures.
(*b*) Classify the following into elements, compounds and mixtures :
Marble, Air, Gold, Brass, Sand, Diamond, Graphite, Petroleum, Common salt, Sea-water, Chalk

53. (*a*) What are (*i*) metals (*ii*) non-metals, and (*iii*) metalloids ? Give two examples each of metals, non-metals and metalloids.
(*b*) Classify the following into metals, non-metals and metalloids :
Silicon, Mercury, Diamond, Sulphur, Iodine, Germanium, Sodium, Carbon, Magnesium, Copper, Boron, Helium

54 (*a*) What is a mixture ? Give two example of mixtures.
(*b*) What is meant by (*i*) homogeneous mixtures, and (*ii*) heterogeneous mixtures ? Give two examples of homogeneous mixtures and two of heterogenous mixtures.
(*c*) What is the other name of homogenous mixtures ?

55. (*a*) What are the three general classes of matter ? Give one example of each type.
(*b*) Draw a flow-chart for the schematic representation of different types of matter.

Multiple Choice Questions (MCQs)

56. Which of the following is not an element ?
(*a*) graphite (*b*) germanium (*c*) silica (*d*) silicon

57. Which of the following are compounds ?
(*i*) CO (*ii*) No (*iii*) NO (*iv*) Co
(*a*) (*i*) and (*ii*) (*b*) (*ii*) and (*iii*) (*c*) (*i*) and (*iii*) (*d*) (*ii*) and (*iv*)

58. One of the following substances is neither a good conductor of electricity nor an insulator. This substance is :
(*a*) chromium (*b*) germanium (*c*) gallium (*d*) potassium

59. Which of the following is not a mixture ?
(*a*) kerosene (*b*) air (*c*) alcohol (*d*) petrol

60. The element which is not common between the compounds called baking soda and soda ash is
(*a*) sodium (*b*) hydrogen (*c*) oxygen (*d*) carbon

61. "Is malleable and ductile" best describes :
(*a*) a solution (*b*) a metal (*c*) a compound (*d*) a non-metal

62. Which one of the following is not a metalloid ?
(*a*) boron (*b*) silicon (*c*) gallium (*d*) germanium

63. The elements which normally exist in the liquid state are :
(*a*) bromine and iodine (*b*) mercury and chlorine
(*c*) iodine and mercury (*d*) bromine and mercury

64. When a mixture of iron powder and sulphur powder is heated strongly to form iron sulphide, then heat energy is :
(*a*) released (*b*) first absorbed and then released
(*c*) absorbed (*d*) neither absorbed nor released

65. The property/properties which enable copper metal to be used for making electric wires is/are :
(*a*) copper metal is malleable and ductile
(*b*) copper metal is a good conductor of electricity
(*c*) copper metal is ductile and has low electrical resistance
(*d*) copper metal is sonorous and an excellent conductor of electricity

66. On the basis of composition of matter, milk is considered to be :
(*a*) a pure substance (*b*) an impure substance (*c*) an element (*d*) a compound

67. Which of the following statements are true for pure substances ?
(*i*) pure substances contain only one kind of particles
(*ii*) pure substances may be compounds or mixtures
(*iii*) pure substances have the same composition throughout
(*iv*) pure substances can be exemplified by all elements other than nickel
(*a*) (*i*) and (*ii*) (*b*) (*i*) and (*iii*) (*c*) (*iii*) and (*iv*) (*d*) (*ii*) and (*iii*)

68. Which of the following are homogeneous in nature ?
(*i*) ice (*ii*) wood (*iii*) soil (*iv*) air
(*a*) (*i*) and (*iii*) (*b*) (*ii*) and (*iv*) (*c*) (*i*) and (*iv*) (*d*) (*iii*) and (*iv*)

69. Two chemical substances X and Y combine together to form a product P which contains both X and Y

$$X + Y \rightarrow P$$

X and Y cannot be broken down into simpler substances by simple chemical reactions. Which of the following statements concerning X, Y and P are correct ?
(*i*) P is a compound (*ii*) X and Y are compounds
(*iii*) X and Y are elements (*iv*) P has a fixed composition
(*a*) (*i*), (*ii*) and (*iii*) (*b*) (*i*), (*ii*) and (*iv*)
(*c*) (*ii*), (*iii*) and (*iv*) (*d*) (*i*), (*iii*) and (*iv*)

70. Which of the following does not have a fixed melting point/boiling point ?
(*a*) gold (*b*) ethanol (*c*) air (*d*) oxygen

Questions Based on High Order Thinking Skills (HOTS)

71. In the following set of substances, one item does not belong to the set. Select this item and explain why it does not belong to the set :
Hydrogen, Oxygen, Steam, Chlorine

72. Iron powder and sulphur powder were mixed together and divided into two parts A and B. When part A was heated strongly over a burner, then a substance C was formed. The part B was, however, not heated at all. When dilute hydrochloric acid was added to substance C, then gas D was evolved and when dilute hydrochloric acid was added to part B then gas E was evolved.

(*a*) What type of substance is B ?

(*b*) What type of substance is C ?

(*c*) Name the gas (*i*) D, and (*ii*) E ?

(*d*) State one characteristic property of gas D.

(*e*) Write one test to identify gas E.

73. There are three substances X, Y and Z. The substance X does not have a fixed melting point or boiling point and it still shows the individual properties of its constituents. The substance Y is a pure substance which occurs in nature as such. The substance Y has a fixed melting point and boiling point but it cannot be broken down into simpler substances by any chemical means. The substance Z is also a pure substance whose properties are entirely different from those of its constituents. The substance Z can, however, be divided by electrolysis into two substances which belong to the same class of substances as Y.

(*a*) What type of substance could X be ? Name one substance like X.

(*b*) What type of substance could Y be ? Name one substance like Y.

(*c*) What type of substance could Z be ? Name one substance like Z.

(*d*) Which process involves absorption or release of an appreciable amount of energy : formation of substance X or formation of substance Z ?

(*e*) Name the three groups into which all the substances like Y are divided on the basis of their properties.

74. There is a large group of materials P which can be divided into three groups Q, R and S on the basis of their properties. The substances belonging to group Q can be solids, liquids or gases. The solids belonging to group Q are usually electrical insulators. Most of the substances of group R are solids which are good conductors of electricity. The substances belonging to group S are neither insulators like Q nor good conductors like R. The properties of S are intermediate between those of Q and R.

(*a*) What could the group of materials P be ?

(*b*) Name the substances Q. Give two examples of such substances.

(*c*) Name the substances R. Write two examples of such substances.

(*d*) Name the substances S. Give two examples of such substances.

(*e*) Out of Q, R and S, which substances are malleable and ductile ?

75. A, B and C are all liquids. Liquid A has a comparatively low boiling point. On heating, liquid A vaporises completely without leaving behind any residue. Liquid A is being used increasingly as a fuel in motor vehicles either alone or by mixing with petrol. Liquid B has a very high boiling point. It also vaporises completely on heating, without leaving any residue. Liquid B is a conductor of electricity and used in making thermometers. Liquid C has a moderate boiling point. On heating, liquid C vaporises leaving behind a white solid D which is used in cooking vegetables. The condensation of vapours from C give a liquid E which turns anhydrous $CuSO_4$ to blue.

(*a*) Which liquid could be an element ? Name this element.

(*b*) Which liquid could be a mixture ? Name this mixture.

(*c*) Which liquid could be a compound ? Name this compound.

(*d*) What could the solid D be ?

(*e*) What do you think is liquid E ?

ANSWERS

1. False **3.** Air **7.** Mercury **15.** Mixtures **16.** A compound **19.** Metalloids **20.** (*a*) atoms (*b*) mixture ; compound (*c*) mixture (*d*) boron ; silicon ; germanium (*e*) metals **21.** Elements : He, Cl_2 and Co; Compounds : H_2O and CO **23.** (*i*) Sugar is $C_{12}H_{22}O_{11}$. It contains C, H and O elements (*ii*) Common salt is sodium chloride, NaCl. It contains Na and Cl elements **48.** (*a*) Iodine (*b*) Oxygen (*c*) Carbon ; Graphite (*d*) Sulphur (*e*) Carbon **49.** (*a*) Sodium (*b*) Mercury (*c*) Mercury (because it is a liquid) (*d*) Sodium (*e*) Gold **54.** (*c*) Solutions **56.** (*c*) **57.** (*c*) **58.** (*b*) **59.** (*c*) **60.**(*b*) **61.** (*b*) **62.** (*c*) **63.** (*d*) **64.** (*b*) **65.** (*c*) **66.** (*b*) **67.** (*b*) **68.** (*c*) **69.** (*d*) **70.** (*c*) **71.** Steam does not belong to the set. This is because all others are elements whereas steam is a compound **72.** (*a*) Mixture (Fe + S) (*b*) Compound (Iron sulphide, FeS) (*c*) (*i*) Hydrogen sulphide, H_2S (*ii*) Hydrogen, H_2 (*d*) Smell of rotten eggs (*e*) Burns with a 'pop' sound **73.** (*a*) Mixture ; Salt solution (*b*) Element ; Sulphur (*c*) Compound ; Water (*d*) Formation of Z (which is a compound) (*e*) Metals, Non-metals and Metalloids **74.** (*a*) Elements (*b*) Non-metals ; Carbon and Sulphur (*c*) Metals ; Copper and Aluminium (*d*) Metalloids ; Boron and Silicon (*e*) Susbtances R (metals) **75.** (*a*) B ; Mercury (*b*) C ; Salt solution (*c*) A ; Alcohol (*d*) Sodium chloride (Common salt) (*e*) Water.

SOLUTIONS, SUSPENSIONS AND COLLOIDS

Before we discuss the solutions, suspensions and colloids in detail, we should know the meaning of two terms : solute and solvent. **The 'substance which is dissolved' in a liquid to make a solution is called 'solute',** and **the 'liquid' in which solute is dissolved is known as 'solvent'.** For example, salt solution is made by dissolving salt in water, so in salt solution, 'salt' is the 'solute' and 'water' is the 'solvent'. Similarly, the substances like sugar, ammonium chloride, copper sulphate and urea, etc. , which are dissolved in water to make solutions are called 'solutes', whereas water is the 'solvent'. *Usually, the substance present in lesser amount in a solution is considered the solute, and the substance present in greater amount in a solution is considered the solvent.* Please note that **the solute particles are also called 'dispersed particles' and solvents are also known as 'dispersion medium'.** Solutions, suspensions and colloids differ in the size of solute particles (or dispersed particles), the size of particles being minimum in solutions and maximum in suspensions.

(*a*) Salt is a solute.

(*b*) Copper sulphate is also a solute.

(*c*) Water is the most common solvent. It is an aqueous solvent.

(*d*) Acetone is an organic liquid. It is a non-aqueous solvent.

Figure 25. Some solutes and solvents.

Though most of the common solutes are solids but even the liquids and gases can also be solutes. Water is the most common solvent. So, most of the solutions are those in which water is the solvent. Water is an aqueous solvent. The organic liquids like alcohol, acetone, carbon tetrachloride, carbon disulphide and benzene are called non-aqueous solvents. **The solutions made by dissolving various solutes in water are called aqueous solutions.** On the other hand, **the solutions made by dissolving solutes in organic liquids are called non-aqueous solutions.** We will now discuss the solutions, suspensions and colloids in detail, one by one. Let us start with the solutions.

SOLUTIONS

A solution is a homogeneous mixture of two (or more substances). A homogeneous mixture means that the mixture is just the same throughout. **Some common examples of solutions are : Salt solution, Sugar solution, Vinegar, Metal alloys (such as Brass) and Air**. Salt solution is a homogeneous mixture of two substances, salt and water, whereas sugar solution is a homogeneous mixture of two substances, sugar and water. Salt solution and sugar solution are also known as true solutions because in these solutions, the particles of salt and sugar are mixed so well with water that we cannot distinguish one from the other. The true solutions are also known as molecular solutions because the size of dissolved particles in such solutions is the same as that of a molecule. In this chapter, when we talk of a solution, it will mean a true solution or a molecular solution. Some more examples of the solutions are : Sea-water, Copper sulphate solution, Alcohol and water mixture, Petrol and oil mixture, Soda water, Soft drinks (like Coca Cola and Pepsi, etc.), and Lemonade (which is a sweetened drink made from lemon juice or lemon flavouring).

Figure 26. Soft drinks like Coca-cola and Pepsi, etc. are solutions.

The substances like salt, sugar, etc., which dissolve in water completely are said to be 'soluble' in water. **Only soluble substances form true solutions**. Copper sulphate is soluble in water. So, copper sulphate dissolves in water to form copper sulphate solution. Copper sulphate solution is a true solution which is blue in colour.

Figure 27. Copper sulphate dissolves in water to form copper sulphate solution.

To Study the Properties of a Solution

If we shake some sugar with water in a beaker, the sugar seems to disappear in water and we get a transparent sugar solution. The dissolved sugar particles cannot be seen even with a microscope, and the sugar does not settle down even on keeping the solution for quite some time. If we filter the sugar solution, the whole solution passes through the filter paper and no residue is left behind. The sweet taste of the sugar solution, however, shows that sugar is present in it. From these observations we conclude that sugar solution is a homogeneous mixture having the same composition throughout. Sugar solution is a true solution. In a true solution, the particles of the solute break up to such an extent that they disappear into the spaces between the solvent molecules. So, in a sugar solution, the sugar particles break up to such an extent that they disappear into the spaces between the water molecules. **A sugar solution does not scatter a beam of light passing through it and render its path visible** (because the sugar particles present in it are so small that they cannot reflect light rays falling on them). We will now state some of the properties of a true solution.

Properties of a Solution

The important characteristic properties of a solution (or true solution) are as follows :

1. A solution is a homogeneous mixture.
2. The size of solute particles in a solution is extremely small. It is less than 1 nm in diameter (1 nanometre $= 10^{-9}$ metre).
3. The particles of a solution cannot be seen even with a microscope.
4. The particles of a solution pass through the filter paper. So, a solution cannot be separated by filtration.
5. The solutions are very stable. The particles of solute present in a solution do not separate out on keeping.
6. A true solution does not scatter light (This is because its particles are very, very small).

Types of Solutions

We usually think that solutions are formed when solid substances are dissolved in liquids. Though most of the common solutions are made by dissolving solids in liquids, but this is not always so. In fact, solutions can be made by dissolving : solids in solids; solids in liquids ; liquids in liquids ; gases in liquids ; and gases in gases. Please remember that as long as the mixture is homogeneous, the term 'solution' applies to it. The various types of solutions are :

1. Solution of Solid in a Solid. Metal alloys are the solutions of solids in solids. For example, brass is a solution of zinc in copper. Brass is prepared by mixing molten zinc with molten copper and cooling their mixture.

2. **Solution of Solid in a Liquid.** This is the most common type of solutions. Sugar solution and salt solution are the solutions of solids in liquids. A solution of iodine in alcohol called 'tincture of iodine' is also a 'solid in a liquid' type of solution. This is because it contains a solid (iodine) dissolved in a liquid (alcohol).

(*a*) Iodine tincture (or tincture of iodine) is a solid in a liquid type of solution

(*b*) Vinegar is a liquid in a liquid type of solution

(*c*) Carbonated drinks are a gas in a liquid type of solution

Figure 28. Solutions are of different types.

3. **Solution of Liquid in a Liquid.** Vinegar is a solution of acetic acid (ethanoic acid) in water. It is a liquid in liquid type of solution.
4. **Solution of Gas in a Liquid.** Soda-water is a solution of carbon dioxide gas in water. It is a gas in a liquid type of solution.
5. **Solution of Gas in a Gas.** Air is a solution of gases like oxygen, argon, carbon dioxide and water vapour, etc., in nitrogen gas. Nitrogen is the solvent in air and all other gases are solutes.

SUSPENSIONS

We have just studied that the substances which are soluble in water (or any other liquid) form solutions. But **those substances which are insoluble in water form suspensions.**

A suspension is a heterogeneous mixture in which the small particles of a solid are spread throughout a liquid without dissolving in it. Some common examples of suspensions are : **Chalk-water mixture, Muddy water, Milk of Magnesia, Sand particles suspended in water, and Flour in water.** Chalk-water mixture is a suspension of fine chalk particles in water; muddy water is a suspension of soil particles in water; and milk of Magnesia is a suspension of magnesium hydroxide in water. Please note that solid particles and water remain separate in a suspension. The particles do not dissolve in water. We will now study the properties of a suspension.

Figure 29. Milk of Magnesia is a suspension of magnesium hydroxide in water.

To Study the Properties of a Suspension

If we shake some chalk powder with water in a beaker, a milky suspension is formed. We can see the fine particles of chalk suspended throughout the water without dissolving in it. If this suspension of chalk and water is kept undisturbed for some time, the chalk particles settle down at the bottom of the beaker. This means that chalk and water suspension is unstable. If we filter the suspension of chalk and water, the chalk particles are left behind as a residue on the filter paper and clear water is obtained as a filtrate. This means that chalk and water suspension can be separated into chalk and water by filtration. And **if a beam**

Figure 30. Chalk powder does not dissolve in water. Chalk forms a suspension which settles to the bottom after some time.

of light is passed through a chalk and water suspension, it scatters the beam of light and renders its path visible inside it. From this discussion, we get the following properties of a suspension.

Properties of a Suspension

The important characteristic properties of a suspension are given below :

1. A suspension is a heterogeneous mixture.
2. The size of solute particles in a suspension is quite large. It is larger than 100 nm in diameter.
3. The particles of a suspension can be seen easily.
4. The particles of a suspension do not pass through a filter paper. So, a suspension can be separated by filtration.
5. The suspensions are unstable. The particles of a suspension settle down after some time.
6. A suspension scatters a beam of light passing through it (because its particles are quite large).

COLLOIDS

A colloid is a kind of solution in which the size of solute particles is intermediate between those in true solutions and those in suspensions. The size of solute particles in a colloid is bigger than that of a true solution but smaller than those of a suspension. Though colloids appear to be homogeneous to us but actually they are found to be heterogeneous when observed through a high power microscope. So, a colloid is not a true solution. **Some of the examples of colloids (or colloidal solutions) are : Soap solution, Starch solution, Milk, Ink, Blood, Jelly and Solutions of synthetic detergents.** Colloids are also known as colloidal solutions.

Figure 31. Soap solution is a colloid (or colloidal solution).

To Study the Properties of a Colloid

If we shake some soap powder with water in a beaker, we get a colloidal soap solution which is not perfectly transparent, it is somewhat translucent. The soap particles cannot be seen by us. If the soap solution is kept for some time, the soap particles do not settle down (showing that it is quite stable). If we filter the soap solution, the whole solution passes through the filter paper and no residue is left behind (showing that it cannot be separated by filtration). All these observations indicate that soap and water mixture is a true solution. The scattering of light by a soap solution and the examination of soap solution under a high power microscope, however, show that soap solution is not a true solution. This point will become more clear from the following discussion.

In a true solution (like sugar solution), the solute particles are so small that they cannot scatter (or reflect) light rays falling on them. For example, if a beam of light (from a torch) is put on a true solution (say, sugar solution) kept in a beaker in a dark room, the path of light beam is invisible inside the solution when seen from the side (see Figure 32). The beam of light can become visible only when the solute particles are big enough to reflect light falling on them. Since the particles of a true solution do not scatter light, we conclude that they must be very, very small.

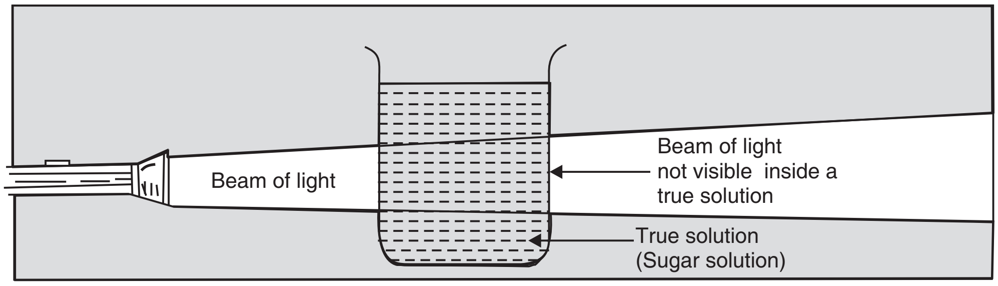


Figure 32. The particles in a true solution do not scatter light. Due to this we cannot see the path of beam of light inside the true solution (in the beaker).

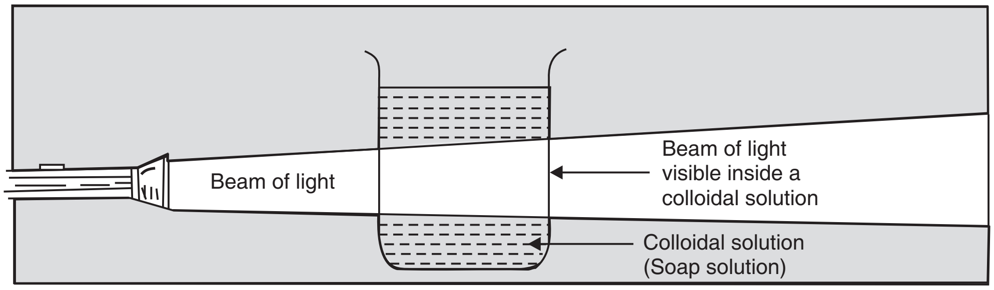


Figure 33. The particles in a colloidal solution (or colloid) scatter light. Due to this we can see the path of beam of light inside the colloidal solution (or colloid) (in the beaker).

In a colloidal solution (or colloid), the particles are big enough to scatter light. This can be shown as follows. If a beam of light is put on a colloidal solution (say, soap solution), kept in a beaker in a dark room, the path of light beam is illuminated and becomes visible when seen from the side (see Figure 33). The path of light beam becomes visible because the colloidal particles are big enough to scatter light falling on them in all the directions. This scattered light enters our eyes and we are able to see the path of light beam.

The scattering of light by colloidal particles is known as Tyndall effect. The scattering of light by colloidal solutions tells us that the colloidal particles are much bigger than the particles of a true solution and hence colloidal solutions are not true solutions. So, **a true solution can be distinguished from a colloidal solution by the fact that a true solution does not scatter a beam of light passing through it but a colloidal solution scatters a beam of light passing through it and renders its path visible.** In other words, a true solution does not show Tyndall effect but a colloidal solution shows Tyndall effect.

The particles of some of the colloidal solutions can be seen through a high power microscope. For example, if a drop of milk is examined under microscope, we can see the small particles of fat floating in the liquid. This observation shows that **colloids are heterogeneous in nature, though they appear to be homogeneous.** Let us write down the properties of colloidal solutions now.

Properties of Colloids

The important characteristic properties of colloids (or colloidal solutions) are as follows :

1. A colloid (or colloidal solution) appears to be homogeneous but actually it is heterogeneous.
2. The size of particles in a colloid (or colloidal solution) is bigger than those in a true solution but smaller than those in a suspension. It is between 1 nm and 100 nm in diameter.
3. The particles of most of the colloids (or colloidal solutions) cannot be seen even with a microscope.
4. The particles of a colloid (or colloidal solution) can pass through a filter paper. So, a colloid cannot be separated by filtration.

5. The colloids (or colloidal solutions) are quite stable. The particles of a colloid do not separate out on keeping.
6. A colloid (or colloidal solution) scatters a beam of light passing through it (because its particles are fairly large).

Though colloids cannot be separated by the process of filtration, but a special technique known as centrifugation can be used to separate the colloidal particles from a colloidal solution.

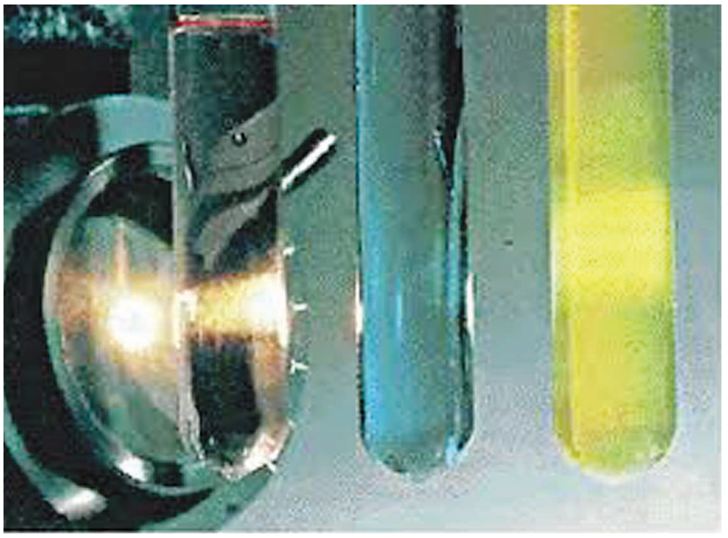


Figure 34. This picture shows that suspensions and colloids exhibit Tyndall effect (scattering of light) but true solutions do not do so. The test-tube on the left side in the above picture contains a suspension which scatters the beam of light passing through it and renders its path visible inside it. The middle test-tube contains a true solution which does not scatter light passing through it. So, we cannot see the beam of light inside the middle test-tube. The test-tube on the right side in the above picture contains a colloid which scatters the light and makes the path of beam of light visible inside it.

To Distinguish a Colloid from a Solution

We can distinguish between colloids (or colloidal solutions) and true solutions by using Tyndall effect as follows :

(*i*) The solution which scatters a beam of light passing through it and renders its path visible, will be a colloid (or colloidal solution).

(*ii*) The solution which does not scatter a beam of light passing through it and does not render its path visible, will be a true solution.

For example, a soap solution scatters a beam of light passing through it and renders its path visible, therefore, soap solution is a colloid (or colloidal solution). On the other hand, a salt solution does not scatter a beam of light passing through it and does not render its path visible, therefore, salt solution is a true solution.

Classification of Colloids

Colloids do not involve only solids and liquids, they may also involve gases. So, colloids are classified according to the physical state of dispersed phase (solute) and the dispersion medium (solvent). Most of the colloids can be classified into the following seven groups :

(*i*) Sol
(*ii*) Solid sol
(*iii*) Aerosol
(*iv*) Emulsion
(*v*) Foam
(*vi*) Solid foam
(*vii*) Gel

All these are the technical names of the groups of colloids. We will now describe all these colloids in brief.

1. Sol. Sol is a colloid in which tiny **solid particles** are dispersed in a **liquid medium**. The examples of sols are : **Ink, Soap solution, Starch solution and most Paints**.

2. Solid sol. Solid sol is a colloid in which **solid particles** are dispersed in a **solid medium**. The example of a solid sol is : **Coloured gemstones** (like Ruby).

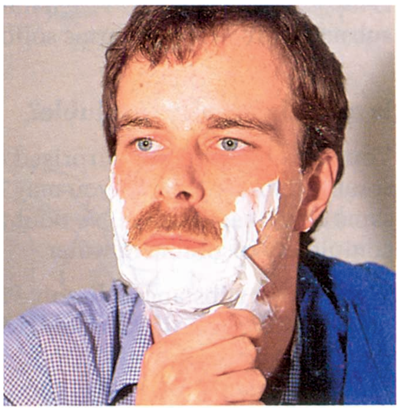
3. Aerosol. An aerosol is a colloid in which a **solid or liquid** is dispersed in a **gas** (including air). The examples of aerosols in which a solid is dispersed in a gas are : **Smoke** (which is soot in air) and **Automobile exhausts**. The examples of aerosols in which a liquid is dispersed in a gas are : **Hairspray, Fog, Mist and Clouds**.

(*a*) Most paints are sols

(*b*) Coloured gemstones (like this ruby) are solid sols

(*c*) Hairspray is an aerosol

(*d*) Milk is an emulsion



(*e*) Shaving cream is a foam

(*f*) Sponge is a solid foam

(*g*) Hair gel is a gel

Figure 35. Sol, solid sol, aerosol, emulsion, foam, solid foam and gel are colloids.

4. Emulsion. An emulsion is a colloid in which minute droplets of one **liquid** are dispersed in another **liquid** which is not miscible with it. Examples of emulsions are : **Milk, Butter and Face cream**.

5. Foam. The foam is a colloid in which a **gas** is dispersed in a **liquid** medium. The examples of foam are : **Fire-extinguisher foam ; Soap bubbles, Shaving cream and Beer foam**.

6. Solid foam. The solid foam is a colloid in which a **gas** is dispersed in a **solid medium**. The examples of solid foam are : **Insulating foam, Foam rubber, Sponge and Bread**.

7. Gel. The gel is a semi-solid colloid in which there is a **continuous network of solid particles dispersed in a liquid**. The examples of gel are : **Jellies, Gelatine and Hair gel**.

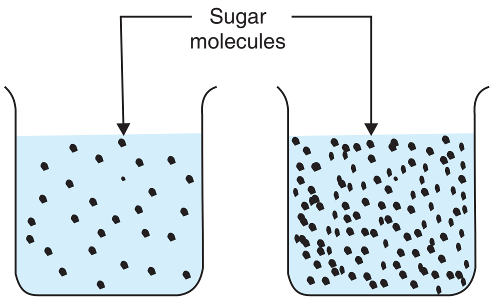
We will now give the classification of colloids in a tabular form for your ready reference.

The Classification of Colloids

Technical name of colloid	*Dispersed phase*	*Dispersion medium*	*Examples*
1. Sol	Solid	Liquid	Ink, Soap solution, Starch solution, Most paints
2. Solid sol	Solid	Solid	Coloured gemstones (like Ruby)
3. Aerosol	(*i*) Solid	Gas	Smoke, Automobile exhausts
	(*ii*) Liquid	Gas	Hairspray, Fog, Mist, Clouds
4. Emulsion	Liquid	Liquid	Milk, Butter, Face cream
5. Foam	Gas	Liquid	Fire-extinguisher foam, Soap bubbles, Shaving cream, Beer foam
6. Solid foam	Gas	Solid	Insulating foam, Foam rubber, Sponge, Bread
7. Gel	Solid	Liquid	Jellies, Gelatine, Hair gel
	Continuous network of solid in liquid		

CONCENTRATION OF A SOLUTION

A solution may have a small amount of solute dissolved in it while another solution may have a large amount of solute dissolved in it. The solution having small amount of solute is said to have low concentration.



(*a*) A dilute solution of sugar. It is said to have low concentration

(*b*) A concentrated solution of sugar. It is said to have high concentration

Figure 36. Sugar solutions at two different concentrations.

Figure 37. The flask given on the left side in this picture contains a dilute solution of potassium permanganate (having low concentration) whereas the flask shown on the right hand side in this picture contains a concentrated solution of potassium permanganate having high concentration.

It is known as a dilute solution. The solution having a large amount of solute is said to be of high concentration. It is known as a concentrated solution (see Figure 36). We can now define the concentration of a solution as follows : **The concentration of a solution is the amount of solute present in a given quantity of the solution.** The concentration of a solution can be expressed in a number of different ways. The most common way of expressing the concentration of a solution is the 'percentage method'. The percentage method of expressing the concentration of a solution refers to the 'percentage of solute' present in the solution. The percentage of solute can be 'by mass' or 'by volume'. This point will become more clear from the following discussion.

If the solution is of a '*solid solute*' dissolved in a liquid, then we consider the '*mass percentage of solute*' in calculating the concentration of solution. So, in the case of a solid solute dissolved in a liquid solvent : **The concentration of a solution is defined as the mass of solute in grams present in 100 grams of the solution.** For example, a 10 per cent solution of common salt means that 10 grams of common salt are present in 100 grams of the solution. Please note that the 100 grams of solution also include 10 grams of the common salt. This means that the 100 grams of common salt solution contain 100 – 10 = 90 grams of water in it. Thus, we can prepare a 10 per cent solution of common salt by dissolving 10 grams of common salt in 90 grams of water (so that the total mass of the solution becomes 10 + 90 = 100 grams). Please note that the concentration of a solution refers to the mass of solute in 100 grams of the *solution* and not in 100 grams of the *solvent*. We can calculate the concentration of a solution in terms of mass percentage of solute by using the following formula :

$$\text{Concentration of solution} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100$$

The mass of solution is equal to the mass of solute plus the mass of solvent. That is :

$$\text{Mass of solution} = \text{Mass of solute} + \text{Mass of solvent}$$

So, we can obtain the mass of solution by adding the mass of solute and the mass of solvent.

In the above given example :

Mass of solute (salt) = 10 g

And, Mass of solvent (water) = 90 g

So, Mass of solution = Mass of solute + Mass of solvent

= 10 + 90

= 100 g

Now, putting these values of 'mass of solute' and 'mass of solution' in the above formula, we get :

$$\text{Concentration of solution} = \frac{10}{100} \times 100$$

$$= 10 \text{ per cent (by mass)}$$

Thus, the concentration of this salt solution is 10 per cent (or 10%) by mass. Please note that if the concentration is in terms of mass, then the words 'by mass' are usually not written with it. For example, in the above case we just say that it is a '10 per cent solution of common salt'. Since common salt is a solid, so it is understood that the percentage is by mass. This is because we do not consider the volume of solids in making solutions. We will now solve some problems based on the calculation of concentration of solutions.

Sample Problem 1. A solution contains 30 g of sugar dissolved in 370 g of water. Calculate the concentration of this solution.

Solution. This solution contains a solid solute (sugar) dissolved in a liquid solvent (water), so we have to calculate the concentration of this solution in terms of the mass percentage of solute (sugar). We know that :

$$\text{Concentration of solution} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100$$

Here, Mass of solute (sugar) = 30 g

And, Mass of solvent (water) = 370 g

So, Mass of solution = Mass of solute + Mass of solvent

$$= 30 + 370$$

$$= 400 \text{ g}$$

Now, putting the values of 'mass of solute' and 'mass of solution' in the above formula, we get :

$$\text{Concentration of solution} = \frac{30}{400} \times 100$$

$$= \frac{30}{4}$$

$$= 7.5 \text{ per cent (or 7.5\%)}$$

Thus, the concentration of this sugar solution is 7.5 per cent (or that it is a 7.5% sugar solution).

Sample Problem 2. If 110 g of copper sulphate is present in 550 g of solution, calculate the concentration of solution.

Solution. Here, Mass of solute (copper sulphate) = 110 g

And, Mass of solution = 550 g

Now, we know that :

$$\text{Concentration of solution} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100$$

$$= \frac{110}{550} \times 100$$

$$= \frac{100}{5}$$

$$= 20 \text{ per cent (or 20\%)}$$

Thus, the concentration of this copper sulphate solution is 20 per cent (or it is a 20% copper sulphate solution).

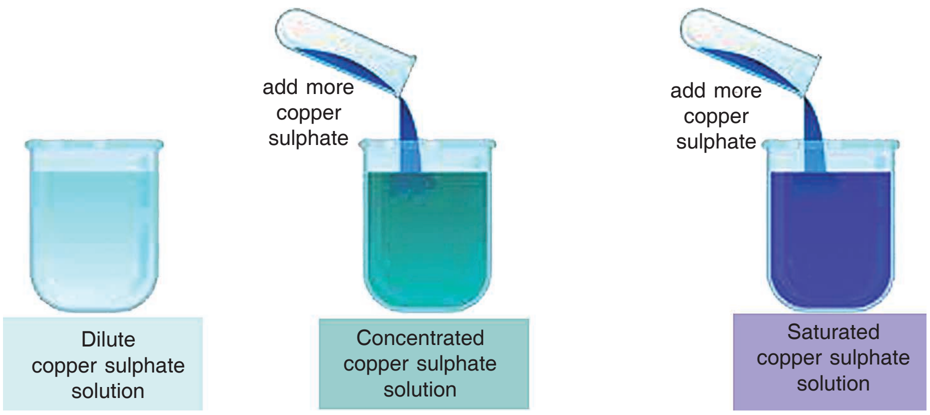


Figure 38. As more and more of copper sulphate (solute) is added, the concentration of its solution goes on increasing. Due to this, the blue colour of copper sulphate solution gets deeper and deeper.

The Case of a Liquid Solute Dissolved in a Liquid Solvent

If the solution is of a *'liquid solute'* dissolved in a liquid solvent, then we usually consider the *'volume percentage of solute'* in determining the concentration of solution. So, in the case of a liquid solute dissolved in a liquid solvent : **The concentration of a solution is defined as the volume of solute in millilitres present in 100 millilitres of the solution.** For example, a 20 per cent solution of alcohol means that 20 millilitres of alcohol are present in 100 millilitres of solution. Please note that the 100 millilitres volume of solution also includes 20 millilitres volume of alcohol. This means that the 100 millilitres of alcohol solution contain 100 – 20 = 80 millilitres of water in it. Thus, we can prepare a 20 per cent solution of alcohol by mixing 20 mL of alcohol in 80 mL of water (so that the total volume of the solution becomes 20 + 80 = 100 mL). Please note that in this case the concentration of solution refers to the volume of liquid solute in 100 mL of *solution* and not in 100 mL of *solvent*. In general, we can calculate the concentration of a solution in terms of volume percentage of solute by using the formula :

$$\text{Concentration of solution} = \frac{\text{Volume of solute}}{\text{Volume of solution}} \times 100$$

In the above example :

Volume of solute (alcohol) = 20 mL

And, Volume of solvent (water) = 80 mL

So, Volume of solution = Volume of solute + Volume of solvent

= 20 + 80

= 100 mL

Now, putting these values of 'volume of solute' and 'volume of solution' in the above formula, we get :

$$\text{Concentration of solution} = \frac{20}{100} \times 100$$

= 20 per cent (by volume)

Thus, the concentration of this alcohol solution is 20 per cent or that it is a 20% alcohol solution (by volume). We will now solve some problems based on the calculation of concentration of solutions containing liquid solutes.

Sample Problem 1. A solution contains 50 mL of alcohol mixed with 150 mL of water. Calculate the concentration of this solution.

Solution. This solution contains a liquid solute (alcohol) mixed with a liquid solvent (water), so we have to calculate the concentration of this solution in terms of volume percentage of solute (alcohol). Now, we know that :

$$\text{Concentration of solution} = \frac{\text{Volume of solute}}{\text{Volume of solution}} \times 100$$

Here, Volume of solute (alcohol) = 50 mL

And, Volume of solvent (water) = 150 mL

So, Volume of solution = Volume of solute + Volume of solvent

= 50 + 150

= 200 mL

Now, putting these values of 'volume of solute' and 'volume of solution' in the above formula we get :

$$\text{Concentration of solution} = \frac{50}{200} \times 100$$

$$= \frac{50}{2}$$

= 25 per cent (by volume)

Thus, the concentration of this alcohol solution is 25 per cent or that it is a 25% alcohol solution (by volume).

Sample Problem 2. If 2 mL of acetone is present in 45 mL of its aqueous solution, calculate the concentration of this solution.

Solution. This solution also contains a liquid solute (acetone) mixed with a liquid solvent water (because it is an aqueous solution), so we have to calculate the concentration of this solution in terms of volume percentage of solute (acetone).

Here, Volume of solute (acetone) = 2 mL

And, Volume of solution = 45 mL

Now, we know that :

$$\text{Concentration of solution} = \frac{\text{Volume of solute}}{\text{Volume of solution}} \times 100$$

$$= \frac{2}{45} \times 100$$

$$= \frac{200}{45}$$

$$= 4.4 \text{ per cent} \quad \text{(by volume)}$$

Thus, the concentration of this acetone solution is 4.4 per cent or that it is a 4.4% acetone solution (by volume).

In industry, when the concentration of a solution is expressed as 'per cent by mass' or 'per cent by weight', it is denoted by the symbol w/w (which means 'weight by weight'). Please note that here the terms 'mass' and 'weight' are being used in the same sense. And when the concentration of a solution is expressed as 'per cent by volume', then it is denoted by the symbol v/v (which means 'volume by volume'). We can see the symbols w/w or v/v on the labels of bottles of many liquid medicines. For example, a particular bottle of the digestion mixture 'Milk of Magnesia' has these words written on the label of its bottle "contains approximately 8.0 % w/w of hydrated magnesium oxide". (Please note that 'hydrated magnesium oxide' means 'magnesium hydroxide').

Figure 39. Acetone is an organic liquid which is a very good solvent. Acetone is used as nail polish remover by women.

SATURATED AND UNSATURATED SOLUTIONS

When we dissolve a solute in a solvent, then a solution is formed. We can dissolve different amounts of solute in the same quantity of the solvent. In this way, we can get many solutions having different concentrations of the same solute. A particular solution may contain less amount of the dissolved solute whereas another solution may contain more amount of the solute in it. For example, we can prepare many salt solutions of different concentrations by dissolving different amounts of salt in the same quantity of water. So, depending upon the amount of solute present, the solutions can be classified into two groups : Unsaturated solutions and Saturated solutions. Let us discuss it in detail.

1. A solution in which more quantity of solute can be dissolved without raising its temperature, is called an unsaturated solution. For example, if in an aqueous solution of salt, more of salt can be dissolved without raising its temperature, then this salt solution will be an unsaturated solution. Actually, an unsaturated solution contains lesser amount of solute than the maximum amount of solute which can be dissolved in it at that temperature.

2. A solution in which no more solute can be dissolved at that temperature, is called a saturated

solution. For example, if in an aqueous salt solution, no more salt can be dissolved at that temperature, then that salt solution will be a saturated solution. Thus, a saturated solution contains the maximum amount of solute which can be dissolved in it at that temperature. It is obvious that a saturated solution contains greater amount of solute than an unsaturated solution.

(*i*) A maximum of 32 grams of potassium nitrate can be dissolved in 100 grams of water at a temperature of 20°C. So, a saturated solution of potassium nitrate at 20°C contains 32 grams of potassium nitrate dissolved in 100 grams of water.

Figure 40. Saturated solution of sodium chloride.

Figure 41. Saturated solution of copper sulphate.

(*ii*) A maximum of 36 grams of sodium chloride (common salt) can be dissolved in 100 grams of water at a temperature of 20°C. So, a saturated solution of sodium chloride at 20°C contains 36 grams of sodium chloride dissolved in 100 grams of water.

In order to test whether a given solution is saturated or not, we should add some more solute to this solution and try to dissolve it by stirring (keeping the temperature constant). If more solute does not dissolve in the given solution, then it will be a saturated solution; but if more solute gets dissolved, then it will be an unsaturated solution.

Effect of 'Heating' and 'Cooling' on a Saturated Solution

A solution is "saturated" at a particular temperature only. So, **if a saturated solution at a particular temperature is heated to a higher temperature, then it becomes unsaturated.** This is because the solubility of solute increases on heating and more of solute can be dissolved on raising the temperature of the solution. Please note that the solubility of a solute in a solution, however, cannot be increased indefinitely on raising the temperature of the solution. We will now describe the effect of cooling on a saturated solution. **If a saturated solution available at a particular temperature is cooled to a lower temperature, then some of its dissolved solute will separate out in the form of solid crystals.** This is because the solubility of solute in the solution decreases on cooling. We will now discuss how a saturated solution can be prepared.

To Prepare a Saturated Solution

We will describe the preparation of a saturated solution of a substance, say sodium chloride, at a temperature of 30°C. We take some water in a beaker and heat it slowly with the help of a burner. Now, we start adding sodium chloride salt to the hot water with a spoon and stir it with a glass rod continuously so that sodium chloride goes on dissolving in water. We take the temperature of water up to 30°C and then keeping this temperature constant, go on adding sodium chloride till no more sodium chloride dissolves in it and some sodium chloride is also left undissolved at the bottom of the beaker. The contents of the beaker are now filtered through a filter paper arranged in a funnel. The clear solution obtained in the form of "filtrate" is the saturated solution of sodium chloride at 30°C.

Figure 42. When a saturated solution of sodium chloride at 30°C (shown in the left side beaker in the above picture) is cooled, then some of the dissolved sodium chloride separates out from the solution and settles down as a solid (as shown in the right side beaker in the above picture).

We will now describe what happens when a saturated solution of sodium chloride at 30°C is allowed to cool. If a saturated solution of sodium chloride at 30°C is allowed to cool, then the crystals of solid sodium chloride will reappear in the solution. Actually, on cooling the solution, the solubility of sodium chloride in water decreases due to which some of the dissolved sodium chloride separates out from the solution and forms crystals. We will now discuss the solubility of solutes.

SOLUBILITY

The maximum amount of a solute which can be dissolved in 100 grams of a solvent at a specified temperature is known as the solubility of that solute in that solvent (at that temperature). If the solvent is water, then we can define solubility as follows : *The maximum amount of a solute which can be dissolved in 100 grams of water at a given temperature, is the solubility of that solute in water (at that temperature).* Please note that solubility is always stated as 'mass of solute per 100 gram of water' (or any other solvent). For example :

(*a*) A maximum of 32 grams of potassium nitrate can be dissolved in 100 grams of water at 20°C, therefore, the solubility of potassium nitrate in water is 32 grams at 20°C.

(*b*) A maximum of 36 grams of sodium chloride (common salt) can be dissolved in 100 grams of water at 20°C, therefore, the solubility of sodium chloride (or common salt) in water is 36 grams at 20°C.

From the above discussion it is obvious that the solubility of a substance (or solute) refers to its saturated solution. So, we can write a yet another definition of solubility as follows : *The solubility of a solute in water at a given temperature is the number of grams of that solute which can be dissolved in 100 grams of water to make a saturated solution at that temperature.* The solubility of different substances in water is different. Since the solubility depends on temperature, so **while expressing the solubility of a substance, we have to specify the temperature also.** The solubilities of some of the substances (or solutes) are given below. All these values of solubilities are 'per 100 grams of water'.

Substance (or Solute)	*Solubility in water (at 20°C)*
1. Copper sulphate	21 g
2. Potassium nitrate	32 g
3. Potassium chloride	34 g
4. Sodium chloride	36 g
5. Ammonium chloride	37 g
6. Sugar	204 g

We will now solve one problem based on the calculation of solubility. In order to calculate the solubility of a substance, all that we have to do is to find the mass of substance dissolved in 100 grams of water. That will give us solubility of that substance. Let us solve the problem now.

Sample Problem. 12 grams of potassium sulphate dissolves in 75 grams of water at 60°C. What is its solubility in water at that temperature ?

Solution. Here we have been given that 75 grams of water dissolves 12 grams of potassium suphate. We have to find how much potassium sulphate will dissolve in 100 grams of water. Now,

75 g of water dissolves = 12 g of potassium sulphate

So, 100 g of water will dissolve = $\frac{12}{75} \times 100$ g of potassium sulphate

= 16 g of potassium sulphate

Thus, the solubility of potassium sulphate in water is 16 g at 60°C.

Effect of Temperature and Pressure on Solubility

The effect of temperature and pressure on the solubility of a substance is as follows :

(*i*) The solubility of solids in liquids usually increases on increasing the temperature; and decreases on decreasing the temperature.

(*ii*) The solubility of solids in liquids remains unaffected by the changes in pressure.

(*iii*) The solubility of gases in liquids usually decreases on increasing the temperature; and increases on decreasing the temperature.

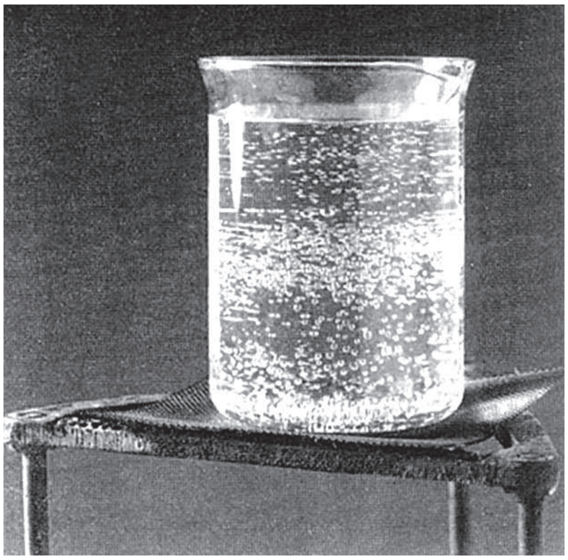


Figure 43. Water always contains some air (which is gas) dissolved in it. When water is heated, the temperature increases and some of the dissolved air comes out forming tiny bubbles. This shows that the solubility of a gas in a liquid decreases on increasing the temperature.

Figure 44. Soda water contains carbon dioxide gas dissolved in water under pressure. When a bottle of soda water is opened, pressure falls and carbon dioxide gas escapes producing a fizz. This shows that the solubility of a gas in a liquid decreases on decreasing the pressure.

(*iv*) The solubility of gases in liquids increases on increasing the pressure; and decreases on decreasing the pressure.

We will describe the effect of temperature on the solubility of a solid substance in water in a little more detail. Look at the solubilities of copper sulphate in water at various temperatures given below :

Temperature	:	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C
Solubility of copper sulphate	:	14 g	17 g	21 g	24 g	29 g	34 g	40 g	47 g

We can see from this data that as the temperature is increased from 0°C to 70°C, the solubility of copper sulphate in water increases from 14 grams to 47 grams. Now, let us see what happens when we cool a saturated solution of copper sulphate from a higher temperature to a lower temperature.

The solubility of copper sulphate at 70°C is 47 grams and the solubility of copper sulphate at 20°C is 21 grams (as shown in the above table). This means that 100 grams of water can dissolve a maximum of 47 grams of copper sulphate at 70°C but only 21 grams at 20°C. So, if we cool a saturated solution of copper sulphate made in 100 grams of water from 70°C to 20°C, then the solubility of copper sulphate will decrease and 47 grams – 21 grams = 26 grams of copper sulphate will separate out from the solution in the form of solid crystals. Let us solve a problem now.

Sample Problem. A student determined the solubility of four substances, potassium nitrate, sodium chloride, potassium chloride and ammonium chloride in water at five different temperatures of 10°C, 20°C, 40°C, 60°C and 80°C, and obtained the following data :

Substance	*Solubility*				
	10°C	20°C	40°C	60°C	80°C
1. Potassium nitrate	21 g	32 g	62 g	106 g	167 g
2. Sodium chloride	36 g	36 g	36 g	37 g	37 g
3. Potassium chloride	35 g	35 g	40 g	46 g	54 g
4. Ammonium chloride	24 g	37 g	41 g	55 g	66 g

(*a*) What mass of potassium nitrate would be needed to make a saturated solution of potassium nitrate in 50 grams of water at 40°C ?.

(*b*) What would be observed if a saturated solution of potassium chloride at 80°C is left to cool to the room temperature ?

(*c*) What is the solubility of each salt at 20°C ? Which salt has the highest solubility at this temperature ?

(*d*) What is the effect of change of temperature on the solubility of a salt as shown by the above data ?

(NCERT Book Question)

Solution (*a*) The solubility of potassium nitrate at 40°C is 62 grams (see the given table). This means that 62 grams of potassium nitrate is needed to make a saturated solution of potassium nitrate in 100 grams of water at 40°C. So, to make a saturated solution in 50 grams of water we will require half of 62 grams of potassium nitrate which is $\frac{62}{2} = 31$ grams of potassium nitrate.

(*b*) When a saturated solution of potassium chloride at 80°C is left to cool, then solid potassium chloride (or crystals of potassium chloride) will gradually separate out from the solution (because the solubility decreases on cooling).

(*c*) The solubility of various salts at 20°C is : Potassium nitrate 32 g ; Sodium chloride 36 g ; Potassium chloride 35 g ; and Ammonium chloride 37 g. Ammonium chloride has the highest solubility (of 37 g) at this temperature of 20°C.

(*d*) The given data shows that the solubility of a salt increases on increasing the temperature.

PHYSICAL AND CHEMICAL CHANGES

There are some changes during which no new substances are formed. On the other hand, there are some other changes during which new substances are formed. So, on the basis of whether new substances are formed or not, we can classify all the changes into two groups : physical changes and chemical changes. We will now discuss physical changes and chemical changes in detail, one by one. Let us start with the physical changes.

Physical Changes

Those changes in which no new substances are formed, are called physical changes. In a physical change, the substances involved do not change their identity. They can be easily returned to their original form by some physical process. This means that physical changes can be easily reversed. The changes in physical state, size and shape of a substance are physical changes. **Some common examples of physical changes are : Melting of ice** (to form water); **Freezing of water** (to form ice); **Boiling of water** (to form steam); **Condensation of steam** (to form water); **Making a solution ; Glowing of an electric bulb; and Breaking of a glass tumbler.** These physical changes are discussed on the next page.

(*i*) When ice is heated, it melts to form water. Though ice and water look different, they are both made of water molecules. Thus, no new chemical substance is formed during the melting of ice. So, **the melting of ice to form water is a physical change.** When water is cooled (as in a refrigerator), then water solidifies to form ice. This is called freezing of water. **The freezing of water to form ice is also a physical change.**

(*ii*) When water is heated, it boils to form steam. Though steam and water look different, they are both made of water molecules. Thus, no new chemical substance is formed during the boiling of water. So, **the boiling of water to form steam is a physical change.** When steam is cooled, it condenses (liquefies) to form water. **The condensation of steam to form water is also a physical change.**


(*a*) Melting of ice to form water


(*b*) Boiling of water to form steam


(*c*) Glowing of the filament of an electric bulb

Figure 45. All these changes are physical changes (which are temporary changes and can be reversed easily).

(*iii*) When an electric bulb is switched on, an electric current passes through its filament. The filament of bulb becomes white hot and glows to give light. When the current is switched off, the filament returns to its normal condition and the bulb stops glowing. No new substance is formed in the bulb during this process. So, **the glowing of an electric bulb is a physical change.**

(*iv*) We take water in a china dish and dissolve some common salt in it. The salt disappears in water and forms a salt solution. So, a change has taken place in making salt solution. Let us now heat this china dish containing salt solution on a burner till all the water evaporates. A white powder is left behind in the china dish. If we taste this white powder, we will find that it is common salt. It is the same common salt which we had dissolved in water earlier. This means that no new chemical substance has been formed by dissolving common salt in water to make salt solution. Thus, **making of a solution is a physical change.**

(*v*) When a glass tumbler breaks, it forms many pieces. Each broken piece of glass tumbler is still glass. So, during the breaking of a glass tumbler, only the size and shape of glass has changed but no new substance has been formed. So, **the breaking of a glass tumbler is a physical change.**

The physical changes are temporary changes which can be reversed easily to form the original substance. For example, the melting of ice to form water is a temporary change. We can reverse this physical change easily by cooling water to form the original substance, ice.

Some more examples of physical changes are : Melting of wax ; Melting of butter in a pan ; Melting of glass ; Dissolving common salt in water ; Making a fruit salad from raw fruits; Mixing of iron filings and sand ; Sublimation of a solid ; Making of soda water by dissolving carbon dioxide in water ; Formation of clouds ; Breaking of a piece of chalk ; Stretching of a rubber band ; Cutting or tearing a piece of paper ; Tearing of cloth ; and Rotation of a fan.

Chemical Changes

Those changes in which new substances are formed, are called chemical changes. In a chemical change, the substances involved change their identity. They get converted into entirely new substances. The new substances usually cannot be returned to their original form. This means that chemical changes are usually irreversible. **Some common examples of chemical changes are : Burning of a magnesium wire ; Burning of paper ; Rusting of iron ; Ripening of fruits, Formation of curd from milk ; and Cooking of food.** Some of these chemical changes are discussed below.

(*i*) When a magnesium wire is heated, it burns in air to form a white powder called 'magnesium oxide'. This magnesium oxide is an entirely new substance. Thus, a new chemical substance is formed during the burning of a magnesium metal wire. So, **the burning of a magnesium wire is a chemical change.**

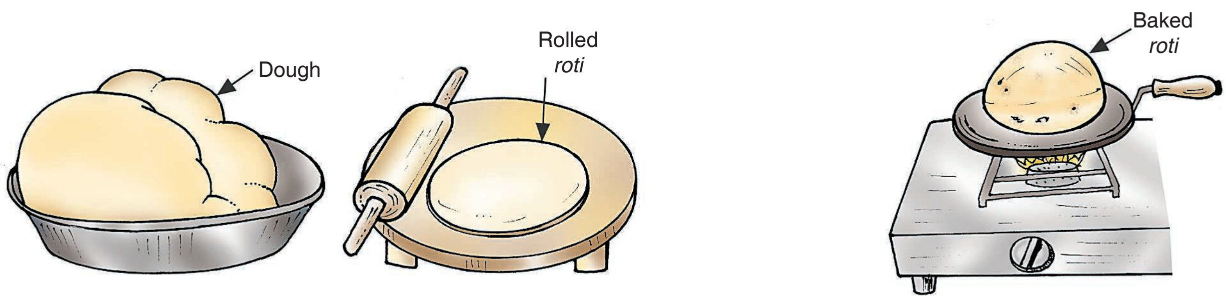
(*a*) Burning of paper (*b*) Rusting of iron (*c*) Ripening of fruits

Figure 46. All these changes are chemical changes (which are permanent changes and cannot be reversed).

(*ii*) If we burn a piece of paper with a lighted match stick then entirely new substances like carbon dioxide, water vapour, smoke and ash are produced. So, **the burning of paper is a chemical change.**

The chemical changes are permanent changes which are usually irreversible. For example, the burning of paper is a permanent change which cannot be reversed. This is because we cannot combine the products of burning of paper to form the original paper once again.

Some more examples of chemical changes are : Burning of candle wax ; Burning of charcoal ; Burning of fuels (like Coal, Wood and LPG) ; Burning of hydrogen in oxygen to form water ; Decomposition of water into hydrogen and oxygen by passing electric current (Electrolysis of water) ; Burning of incense stick (*agarbatti*) ; Formation of iron sulphide from iron and sulphur ; Growth of a plant ; Cutting of trees ; and Digestion of food. During all these changes, new chemical substances are formed. Please note that chemical changes are also known as chemical reactions. The following diagrams show a physical change and a chemical change which take place in the kitchen of our homes everyday :



(*a*) Rolling of *roti* (*b*) Baking of *roti*

Figure 47. The rolling of *roti* out of dough is a physical change but the baking of *roti* on a gas stove is a chemical change.

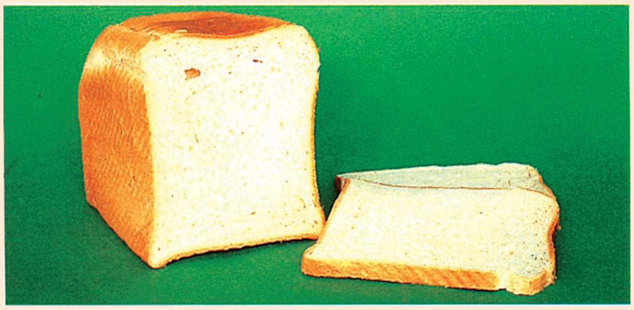
The main differences between physical and chemical changes are given below.

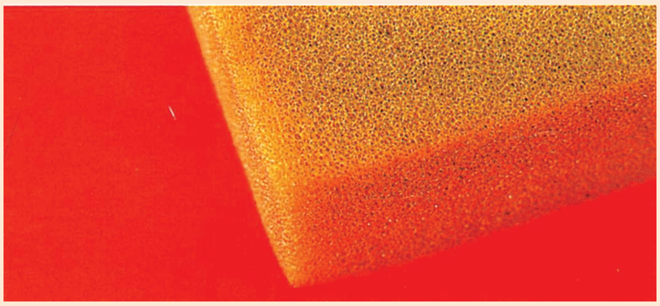
Physical change	*Chemical change*
1. No new substance is formed in a physical change.	1. A new substance is formed in a chemical change.
2. A physical change is a temporary change.	2. A chemical change is a permanent change.
3. A physical change is easily reversible.	3. A chemical change is usually irreversible.
4. Very little heat (or light) energy is usually absorbed or given out in a physical change.	4. A lot of heat (or light) energy is absorbed or given out in a chemical change.
5. The mass of a substance does not alter in a physical change.	5. The mass of a substance does alter in a chemical change.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. Out of a colloid, solution and a suspension :
(*a*) which one has the smallest particles ?
(*b*) which one has the largest particles ?
2. What is the name of the clear liquid formed when a solid dissolves in a liquid ?
3. Which of the two will scatter light : soap solution or sugar solution ? Why ?
4. State whether colloidal solutions are homogeneous or heterogeneous.
5. What is the most common way of expressing the concentration of a solution ?
6. How much water should be added to 15 grams of salt to obtain 15 per cent salt solution ?
7. How much water should be mixed with 12 mL of alcohol so as to obtain 12 % alcohol solution ?
8. A 5 per cent sugar solution means that :
(*a*) 5 g of sugar is dissolved in 95 g of water.
(*b*) 5 g of sugar is dissolved in 100 g of water.
Choose the correct answer.
9. A 15% alcohol solution means :
(*a*) 15 mL alcohol and 85 mL water.
(*b*) 15 mL alcohol and 100 mL water.
Choose the correct answer.
10. Calculate the concentration of a solution which contains 2.5 g of salt dissolved in 50 g of water.
11. What is the concentration of a solution which contains 16 g of urea in 120 g of solution ?
12. A solution contains 5.6 mL of alcohol mixed with 75 mL of water. Calculate the concentration of this solution.
13. If 25 mL of acetone is present in 150 mL of its aqueous solution, calculate the concentration of solution.
14. What happens when the temperature of a saturated sugar solution is increased ?
15. Which of the following contains less solute at a given temperature and pressure ?
Unsaturated solution or Saturated solution.
16. State one instance where water undergoes a physical change and one in which it undergoes a chemical change.
17. State whether the following statements are true or false :
(*a*) Bread is an example of solid foam.
(*b*) Sponge is an example of solid sol.





What type of colloids are bread and sponge ?

18. Choose one term from the following which includes the other three :

aerosol, emulsion, colloid, sol

19. Which of the following is a sol ?

Shaving cream, Milk, Fog, Soap solution, Hairspray

20. Fill in the following blanks :

(*a*) Milk is a .... solution but vinegar is a .... solution.

(*b*) A colloid is a ....mixture and its components can be separated by the technique known as ....

Short Answer Type Questions

21. Define (*a*) solute, and (*b*) solvent

22. What is the difference between solutions and colloids ?

23. What is the difference between colloids and suspensions ?

24. In what respects does a true solution differ from a colloidal solution ?

25. Classify the following into true solutions and colloidal solutions :

Ink, Salt solution, Starch solution, Blood, Sugar solution

26. How will you test whether a given solution is a colloidal solution ?

27. Explain what happens when a beam of light is passed through a colloidal solution.

28. How will you distinguish a colloid from a solution ?

29. How will you differentiate between a suspension and a colloid ?

30. You have been given a suspension and a solution. How could you tell the difference between them by their appearance ?

31. Which of the following will show Tyndall effect ? Why ?

(*a*) Salt solution (*b*) Starch solution

(*c*) Milk (*d*) Copper sulphate solution

32. Name the different types of solutions. Give one example of each.

33. Classify the following into solutions, suspensions and colloids :

Soda-water, Milk, Brine, Blood, Ink, Smoke in air, Chalk water mixture, Milk of Magnesia, Shaving cream, Muddy river water.

34. Define the following :

(*a*) Sol (*b*) Aerosol (*c*) Emulsion (*d*) Foam

Give one example of each.

35. What is meant by the concentration of a solution ?

36. What will happen if a saturated solution is : (*i*) heated, and (*ii*) cooled ?

37. 21.5 g of sodium chloride dissolves in 60 g of water at 25°C. Calculate the solubility of sodium chloride in water at that temperature.

38. 9.72 g of potassium chloride dissolves in 30 g of water at 70°C. Calculate the solubility of potassium chloride at that temperature.

39. Classify the following as physical or chemical changes :

(*i*) Cooking of food (*ii*) Boiling of water

(*iii*) Cutting of trees (*iv*) Dissolving salt in water

(*v*) Digestion of food (*vi*) Melting of ice

40. Which of the following are physical changes and which are chemical changes ?

(*a*) Burning of a magnesium wire

(*b*) Freezing of water

(*c*) Rusting of iron

(*d*) Glowing of an electric bulb

41. Classify the following as physical or chemical changes :

(*i*) Formation of curd from milk (*ii*) Condensation of steam

(*iii*) Growth of a plant (*iv*) Breaking of a glass tumbler

42. Separate the following into physical and chemical changes :

Sublimation of a solid, Decomposition of water into hydrogen and oxygen by passing electric current, Formation of clouds, Making a fruit salad from raw fruits, Dissolving carbon dioxide in water

43. Which of the following are physical changes and which are chemical changes ?

Burning of candle wax, Melting of candle wax, Mixing of iron filings and sand, Burning of wood, Breaking a piece of chalk, Burning a piece of paper, Cutting a piece of paper

44. The 'sea water' can be classified as a homogeneous mixture as well as a heterogeneous mixture ? Comment.

45. Which of the following do not exhibit Tyndall effect ?

Starch solution, Sugar solution, Ink, Salt solution, Copper sulphate solution, Ammonium chloride solution, Fog, Smoke, Car exhausts.

Long Answer Type Questions

46. (*a*) What is a physical change ? Give two examples of physical changes.

(*b*) What is a chemical change ? Give two examples of chemical changes.

47. (*a*) Give the main differences between physical changes and chemical changes.

(*b*) Which of the following are chemical changes and which physical ? Give reason.

(*i*) a glass bottle breaking (*ii*) coal burning in air

(*iii*) making a cake (*iv*) wool being knitted into a sweater

48. (*a*) Define solubility of a substance. How does it vary with temperature ?

(*b*) What do you understand by the statement "the solubility of copper sulphate in water at 20°C is 20.7 g" ?

(*c*) What is the effect of temperature on the solubility of solids in liquids ?

49. (*a*) What is meant by a solution ? Give two examples of solutions.

(*b*) What is a suspension ? Give two examples of suspensions.

(*c*) What is a colloid ? Give two examples of colloids (or colloidal solutions).

50. (*a*) Differentiate between a saturated and an unsaturated solution. How will you test whether a given solution is saturated or not ?

(*b*) How would you prepare a saturated solution of sodium chloride in water at 25°C ? What will happen if this solution is cooled to 10°C ?

Multiple Choice Questions (MCQs)

51. One of the following is a solid foam. This one is :

(*a*) butter (*b*) bread (*c*) shaving cream (*d*) ruby

52. Which of the following is not an emulsion ?

(*a*) milk (*b*) butter (*c*) face cream (*d*) shaving cream

53. One of the following does not show Tyndall effect. This one is :

(*a*) soap solution (*b*) ink (*c*) sugar solution (*d*) starch solution

54. Which one of the following is most likely to exhibit Tyndall effect ?

(*a*) sugar and water mixture (*b*) potash alum and water mixture

(*c*) chalk powder and water mixture (*d*) potassium permanganate and water mixture

55. Milk of Magnesia is :

(*a*) a colloid (*b*) a true solution

(*c*) a homogeneous mixture (*d*) a suspension

56. Which of the following represents the solubility of sugar in water at 20°C ?

(*a*) 21 g (*b*) 204 g (*c*) 37 g (*d*) 164 g

57. Which one of the following is not a chemical change ?

(*a*) formation of curd (*b*) ripening of banana

(*c*) sublimation of naphthalene (*d*) corrosion of photo frame

58. One of the following liquids will leave behind a residue on heating. This one is :

(*a*) brine (*b*) bromine (*c*) mercury (*d*) alcohol

59. Which of the following can be called a suspension ?

(*a*) milk (*b*) milk of magnesia (*c*) salt solution (*d*) vinegar

60. One of the following represents the solution of solid in a solid. This one is :
(*a*) boron (*b*) brass (*c*) beryllium (*d*) bread

61. The rusting of an iron object is called :
(*a*) corrosion and it is a physical as well as a chemical change
(*b*) dissolution and it is a physical change
(*c*) corrosion and it is a chemical change
(*d*) dissolution and it is a chemical change

62. A mixture of sulphur and carbon disulphide is :
(*a*) heterogeneous and shows Tyndall effect
(*b*) homogeneous and shows Tyndall effect
(*c*) heterogeneous and does not show Tyndall effect
(*d*) homogeneous and does not show Tyndall effect

63. Tincture of iodine has antiseptic properties. This solution is made by dissolving :
(*a*) iodine in potassium iodide (*b*) iodine in acetone
(*c*) iodine in water (*d*) iodine in alcohol

64. Which of the following are physical changes ?
(*i*) melting of iron metal (*ii*) rusting of iron metal
(*iii*) bending of an iron rod (*iv*) drawing a wire of iron metal
(*a*) (*i*), (*ii*) and (*iii*) (*b*) (*i*), (*ii*) and (*iv*) (*c*) (*i*), (*iii*) and (*iv*) (*d*) (*ii*), (*iii*) and (*iv*)

65. Which of the following are chemical changes ?
(*i*) decaying of wood (*ii*) burning of wood
(*iii*) sawing of wood (*iv*) hammering of nail into wood
(*a*) (*i*) and (*ii*) (*b*) (*ii*) and (*iii*) (*c*) (*iii*) and (*iv*) (*d*) (*i*) and (*iv*)

Questions Based on High Order Thinking Skills (HOTS)

66. Many indigestion mixtures are suspensions. What do the instructions written on the bottle of an indigestion mixture tell us before taking the mixture, and why ?

67. Three mixtures A, B and C are obtained by stirring three different solids in water taken in separate beakers. When mixture A is allowed to stand for some time, then its particles settle at the bottom of the beaker. When a beam of light is passed through mixture A in a dark room, the path of light becomes visible when observed from the side of the beaker. When mixture B is allowed to stand for a considerable time, even then its particles do not settle down. Mixture B, however, scatters the beam of light just like mixture A. The particles of mixture C do not settle down on keeping and it also does not scatter a beam of light passing through it.
(*a*) What are the mixtures like A known as ?
(*b*) What are the mixtures like B known as ?
(*c*) What are the mixtures like C known as ?
(*d*) Name the phenomenon exhibited by A and B which occurs on passing a beam of light through them.
(*e*) Name one mixture each which is like (*i*) A (*ii*) B, and (*iii*) C.

68. When the solid A is added to water, it dissolves with the evolution of a lot of heat and making little explosions to form two products B and C. The properties of products B and C are entirely different from those of solid A as well as water. Moreover, products B and C cannot be reconverted into solid A and water. When another solid D is added to water, it dissolves with the absorption of a little heat to form a product E which cools down. The product E shows the properties of both, solid D as well as water. Moreover, product E can be converted into solid D and water.
(*a*) What type of change occurs when solid A is dissolved in water ? Why ?
(*b*) What type of change occurs when solid D is dissolved in water ? Why ?
(*c*) Name a metal which you think could behave like solid A. Also name the products B and C.
(*d*) Name the solid D if it is the one which is used in making ordinary dry cells.
(*e*) Name the process by which D can be recovered from E.

69. 100 mL of water at room temperature of 25°C is taken in a beaker and a little of solid S is dissolved in it by stirring to obtain a solution X. More and more of solid S is added to the solution with constant stirring, while keeping the temperature of solution constant at 30°C. After some time it is observed that no more solid dissolves in water and at the same time some solid is also left undissolved at the bottom of the beaker. The contents of beaker are filtered through a filter paper to obtain solution Y in the form of a filtrate.

(*a*) What name is given to solutions like X ?

(*b*) What name is given to solutions like Y ?

(*c*) What will you observe if the solution Y at 30°C is cooled down to 10°C by keeping the beaker in crushed ice ? Why ?

(*d*) What term is used to denote the amount of solid dissolved in 100 grams of water in a solution like Y ?

70. The solubility of ammonium chloride in water at various temperatures is given below :

Temperature	:	10°C	20°C	40°C	60°C	80°C
Solubility	:	24 g	37 g	41 g	55 g	66 g

What mass of ammonium chloride would be needed to make a saturated solution of ammonium chloride in fifty grams of water at 40°C ?

ANSWERS

2. Solution **4.** Heterogeneous **6.** 85 g water **7.** 88 mL water **8.** (*a*) **9.** (*a*) **10.** 4.7% **11.** 13.3% **12.** 6.9% **13.** 16.6% **15.** Unsaturated solution **16.** Physical change : Vaporisation (to form water vapour or steam) ; Chemical change : Electrolysis (to form hydrogen and oxygen) **17.** (*a*) True (*b*) False **18.** Colloid **19.** Soap solution **20.** (*a*) colloidal; true (*b*) homogeneous ; centrifugation **37.** 35.8 g **38.** 32.4 g **44.** When sea water is a mixture of dissolved salts and water only, it is homogeneous ; If sea water also contains suspended impurities like decayed plant or animal material, etc., then it will be heterogeneous **48.** (*b*) It means that a maximum of 20.7 grams of copper sulphate can be dissolved in 100 grams of water at a temperature of 20°C **51.** (*b*) **52.** (*d*) **53.** (*c*) **54.** (*c*) **55.** (*d*) **56.** (*b*) **57.** (*c*) **58.** (*a*) **59.** (*b*) **60.** (*b*) **61.** (*c*) **62.** (*d*) **63.** (*d*) **64.** (*c*) **65.** (*a*) **66.** "Shake well before use". This is because the particles of indigestion mixture settle down at the bottom of the bottle **67.** (*a*) Suspensions (*b*) Colloids (*c*) True solutions (*d*) Tyndall effect (*e*) (*i*) Chalk-water mixture (*ii*) Soap solution (*c*) Salt solution **68.** (*a*) Chemical change ; Because the properties of products B and C are entirely different from those of solid A and water (*b*) Physical change ; Because the product E shows the properties of both, solid D and water (*c*) Sodium ; Sodium hydroxide and Hydrogen (*d*) Ammonium chloride (*e*) Evaporation **69.** (*a*) Unsaturated solution (*b*) Saturated solution (*c*) Some of the dissolved solid will separate from the solution and settle down at the bottom of the beaker ; Because the solubility of solid decreases on cooling (*d*) Solubility **70.** 20.5 g

SEPARATION OF MIXTURES

Many of the materials around us are mixtures. These mixtures have two or more than two substances (or constituents) mixed in them. It may not be possible to use a mixture as such in homes and in industries. We may require only one (or two) separate constituents of a mixture for our use. So, we have to separate the various mixtures into their individual constituents to make them useful in our daily life.

The various constituents of a mixture have different physical properties such as density, solubility, size of particles, behaviour towards magnet, volatility, boiling points, etc. This difference in the physical properties of constituents is used to separate them from a mixture. **The method to be used for separating a mixture depends on the nature of its constituents.** Different mixtures are separated by using different physical processes. **The various physical processes which are commonly used to separate the constituents of mixtures are : Sublimation, Magnet, Solvents, Filtration, Centrifugation, Evaporation, Crystallisation, Chromatography, Distillation, Fractional distillation and Separating funnel.** In some cases, more than one of these processes are used for separating a mixture.

In order to learn the separation of mixtures, we will consider the following three cases :

1. **Mixture of two solids**
2. **Mixture of a solid and a liquid**
3. **Mixture of two liquids**

We will now discuss these three cases in detail, one by one.

SEPARATION OF MIXTURE OF TWO SOLIDS

All the mixtures containing two solid substances can be separated by one of the following methods :

(*i*) By using a suitable solvent
(*ii*) By the process of sublimation
(*iii*) By using a magnet

We will now describe all these methods of separating solid-solid mixtures in detail, one by one.

1. Separation by a Suitable Solvent

In some cases, one constituent of a mixture is soluble in a particular liquid solvent whereas the other constituent is insoluble in it. This difference in the solubilities of the constituents of a mixture can be used to separate them. For example, sugar is soluble in water whereas sand is insoluble in it, so **a mixture of sugar and sand can be separated by using water as solvent**. This will become more clear from the following discussion.

(*a*) Water (*b*) Sugar (*c*) Sand

Figure 48. Sugar is soluble in water but sand is insoluble in water.

To Separate a Mixture of Sugar and Sand

Sugar is soluble in water whereas sand is insoluble in water. This difference in the solubilities of sugar and sand in water is used to separate them. This is done as follows. The mixture of sugar and sand is taken in a beaker and water is added to it. The mixture is stirred to dissolve the sugar in water [see Figures 49 (*a*) and (*b*)]. The sand remains undissolved.

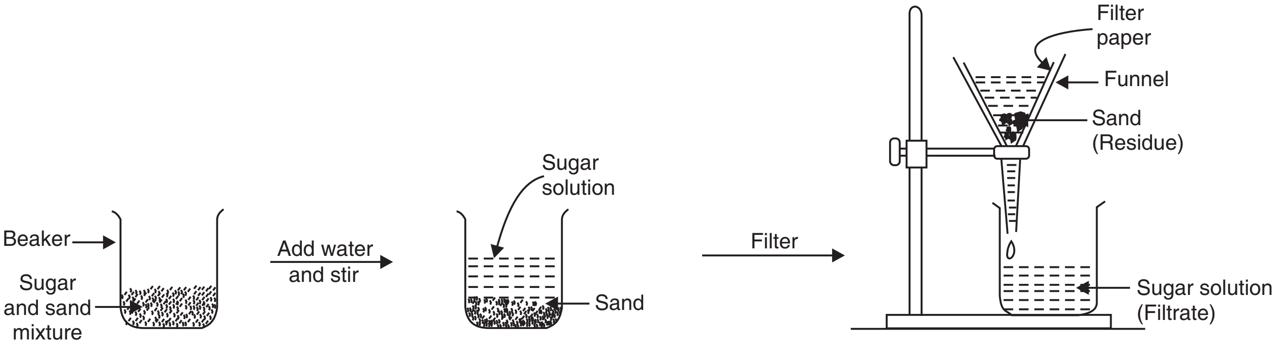


Figure 49. Separation of sugar and sand mixture.

The sugar solution containing sand is filtered by pouring over a filter paper kept in a funnel [see Figure 49 (*c*)]. Sand remains as a residue on the filter paper and sugar solution is obtained as a filtrate in the beaker kept below the funnel. The sugar solution is evaporated carefully to get the crystals of sugar. In this way, a mixture of sugar and sand has been separated by using water as the solvent.

Figure 50. Mixture of common salt and sand.

Common salt is soluble in water whereas sand is insoluble in water. So, **a mixture of common salt (sodium chloride), and sand can also be separated by using water as solvent**. This will be similar to the separation of sugar and sand mixture which has been described above. Please note that copper sulphate, ammonium chloride, potassium nitrate and potash alum are also soluble in water, but carbon and sulphur are insoluble in water. Sugar is soluble in alcohol but salt is insoluble in alcohol, so **a**

mixture of sugar and salt can be separated by using alcohol as solvent. We will now separate a mixture of sulphur and sand.

To Separate a Mixture of Sulphur and Sand

Sulphur is insoluble in water and sand is also insoluble in water, so water cannot be used as a solvent to separate their mixture. Sulphur is, however, soluble in carbon disulphide whereas sand is insoluble in carbon disulphide, therefore, **a mixture of sulphur and sand can be separated by using carbon disulphide as solvent**. This is done as follows.

(*a*) Carbon disulphide (*b*) Sulphur (*c*) Sand

Figure 51. Sulphur is soluble in carbon disulphide but sand is insoluble in it.

The mixture of sulphur and sand is shaken with carbon disulphide. Sulphur dissolves in carbon disulphide whereas sand remains undissolved. The sulphur solution containing sand is filtered when sand is obtained as a residue on the filter paper and sulphur solution is obtained as a filtrate. On evaporating the filtrate, carbon disulphide solvent is eliminated and solid sulphur remains behind.

Salt, sugar and carbon are also insoluble in carbon disulphide. So, they can be separated from sulphur by using carbon disulphide as solvent.

2. Separation by Sublimation

We have already studied the process of sublimation in the previous chapter. We know that **the changing of a solid directly into vapours on heating, and of vapours into solid on cooling is called sublimation**. The solid substance which undergoes sublimation is said to '*sublime*'. **The process of sublimation is used to separate those substances from a mixture which sublime on heating**. The solid substance obtained by cooling the vapours is known as '*sublimate*'. The substances like ammonium chloride, iodine, camphor, naphthalene and anthracene sublime on heating and can be recovered in the form of a sublimate by cooling their vapours. This means that ammonium chloride, iodine, camphor, naphthalene and anthracene change directly from solid to vapours on heating, and from vapours to solid on cooling.

(*a*) Ammonium chloride (*b*) Iodine (*c*) Camphor (*d*) Naphthalene (*e*) Anthracene

Figure 52. Ammonium chloride, iodine, camphor, naphthalene and anthracene undergo sublimation on heating.

Most of the solid substances do not undergo sublimation. For example, substances such as common salt (sodium chloride), sand, iron filings, sulphur and chalk, etc., do not sublime on heating. The process of sublimation is used to separate that component of a solid-solid mixture which sublimes on heating (the other component of the mixture being non-volatile). Thus, **ammonium chloride, iodine, camphor, naphthalene and anthracene can be separated from a mixture by sublimation**. This will become more clear from the following example.

To Separate a Mixture of Common Salt and Ammonium Chloride

Ammonium chloride sublimes on heating whereas common salt does not sublime on heating. So, **we can separate ammonium chloride from a mixture of 'common salt and ammonium chloride' by the process of sublimation.** This is done as follows.

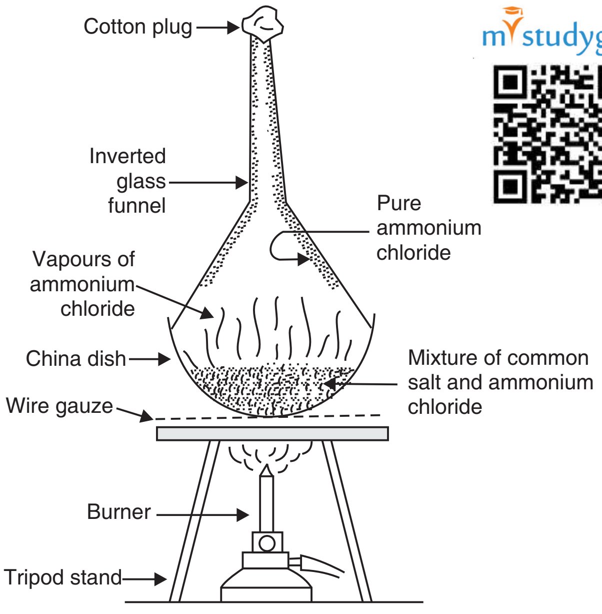


Figure 53. Separation of a mixture by sublimation. Here a mixture of common salt and ammonium chloride is being separated by sublimation.

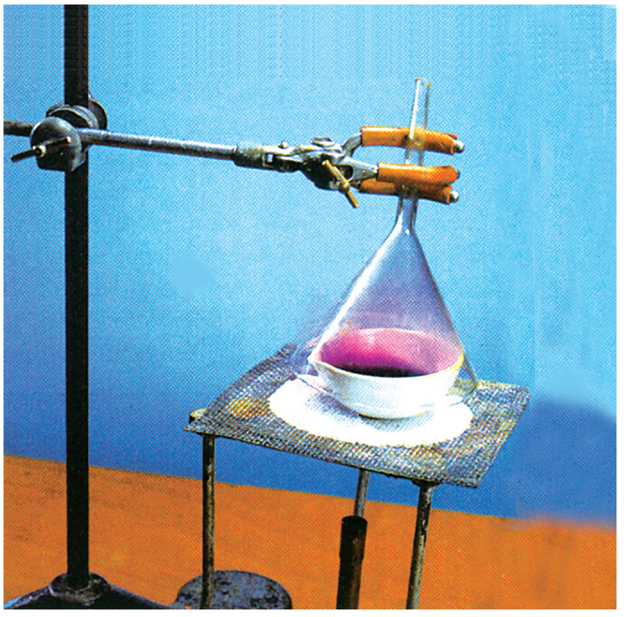


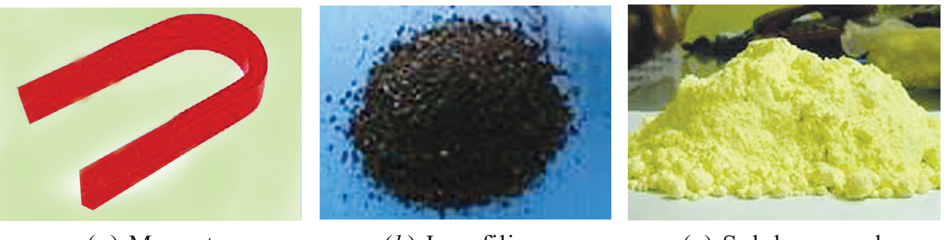
Figure 54. This picture shows the apparatus to separate a mixture of common salt and iodine by the process of sublimation. The iodine sublimes on heating (as indicated by violet vapour in the above picture). Common salt, however, does not sublime on heating.

The mixture of common salt and ammonium chloride is taken in a china dish and placed on a tripod stand (see Figure 53). The china dish is covered with an inverted glass funnel. A loose cotton plug is put in the upper, open end of the funnel to prevent the ammonium chloride vapours from escaping into the atmosphere. The china dish is heated by using a burner. On heating the mixture, ammonium chloride changes into white vapours. These vapours rise up and get converted into solid ammonium chloride on coming in contact with the cold, inner walls of the funnel (see Figure 53). In this way, **pure ammonium chloride collects on the inner sides of the funnel in the form of a sublimate** and can be removed. Common salt does not change into vapours on heating, so it remains behind in the china dish. Thus, the mixture has been separated into its two components : ammonium chloride and common salt. (Please note that the chemical name of common salt is sodium chloride, so we could also write sodium chloride in place of common salt in the above discussion).

Ammonium chloride, iodine, camphor, naphthalene and anthracene can be separated from non-volatile substances like common salt (sodium chloride), sand, iron filings, chalk, etc., by the process of sublimation.

3. Separation by a Magnet

Iron is attracted by a magnet. This property of iron is used to separate it from a mixture. So, **if a mixture contains iron as one of the constituents, it can be separated by using a magnet**. For example, a mixture of iron filings



(*a*) Magnet (*b*) Iron filings (*c*) Sulphur powder

Figure 55. Iron filings are attracted by a magnet but sulphur is not.

and sulphur powder can be separated by using a magnet. This is because iron filings are attracted by a magnet (and stick to it), but sulphur is not attracted by a magnet. This will become more clear from the following discussion.

To Separate a Mixture of Iron Filings and Sulphur Powder

In order to separate iron filings from sulphur powder, a horse-shoe type magnet is moved on the surface of the mixture. The iron filings are attracted by the magnet, they cling to the poles of the magnet and get separated (see Figure 56). This process has to be repeated a number of times to achieve complete separation of iron filings. Sulphur powder is not attracted by a magnet so it remains behind.

A mixture of iron filings and carbon powder can be separated by using a magnet in a similar way. And a mixture of iron filings and sand can also be separated by using a magnet. A carpenter can also separate iron nails from saw-dust by using a magnet. This is because iron nails stick to the magnet but saw-dust does not. In industries, the impurity of iron present in several substances is removed by the use of magnets.

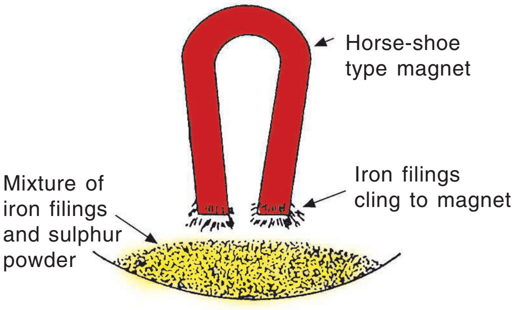


Figure 56. Iron filings being separated from a mixture of 'iron filings and sulphur' by

Separation of Scrap Iron

Waste materials supplied to factories contain a number of scrap metals including iron. So, **in factories, scrap iron is separated from the heap of waste materials by using big electromagnets fitted to a crane.** (A magnet which works with an electric current is called an electromagnet). When a crane fitted with a powerful electromagnet is lowered on to the heap of waste materials, then the scrap iron objects present in the heap cling to the electromagnet (see Figure 57). The crane is then moved up and away to drop these scrap iron objects at a separate place. In this way, scrap iron is separated from the heap of waste materials.

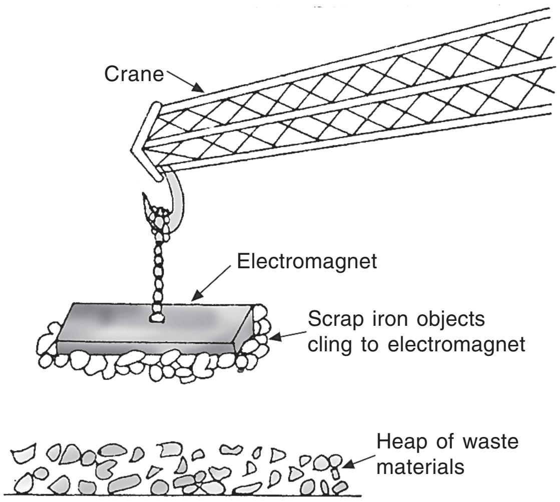


Figure 57. Separation of scrap iron from a heap of waste materials by using an electromagnet.

Figure 58. This photograph shows iron-containing materials being lifted up by an electromagnet attached to a scrapyard crane to be separated from other metal scrap in a factory.

Figure 59. Sometimes tiny iron or steel particles may fall into the eye of a person (like a factory worker). In hospitals, doctors use electromagnets to remove particles of iron or steel from a person's eye.

SEPARATION OF MIXTURE OF A SOLID AND A LIQUID

All the mixtures containing a solid and a liquid are separated by one of the following processes :

(*i*) By filtration **(*iv*) By crystallisation**
(*ii*) By centrifugation **(*v*) By chromatography**
(*iii*) By evaporation **(*vi*) By distillation**

We will now discuss all these methods in detail, one by one. Before we go further and describe the process of filtration for separating mixtures, we should know something about a filter paper and how it is folded for carrying out filtration.

Filter Paper. A filter paper is a round piece of special paper which has millions of tiny pores (or tiny holes) in it. The pores of a filter paper are so small that they cannot be seen with naked eyes. They can be seen only through a microscope. The liquids (like water, salt solution, oil, etc.) can pass through the tiny pores of a filter paper but solid particles (like chalk particles or sand particles) being large, cannot pass through the tiny pores of the filter paper. **The solid which remains behind on the filter paper is called residue. The liquid which passes through the filter paper is called filtrate.** A filter paper is shown in Figure 60(*a*).

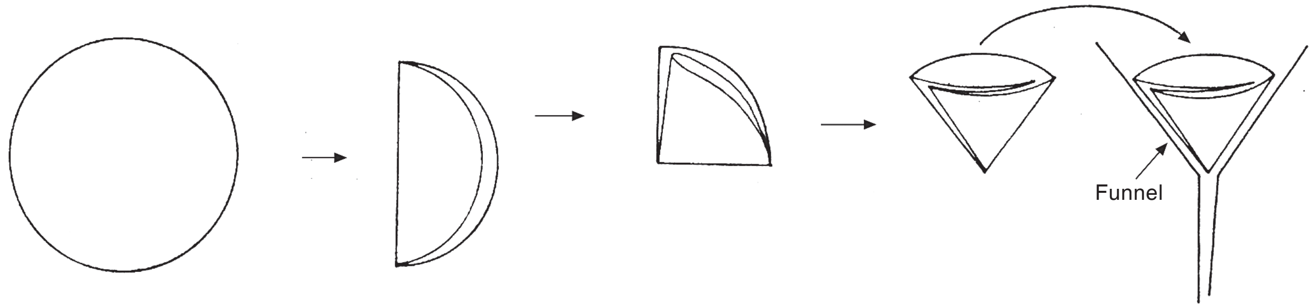


Figure 60. Folding of filter paper to form a cone.

Folding of Filter Paper. Before a filter paper can be used for the process of filtration, it is folded properly to make a hollow cone (which is then kept in the funnel). The filter paper is folded in the following steps :

(*i*) The round piece of filter paper is taken and folded in half [see Figures 60 (*a*) and (*b*)].

(*ii*) The half folded filter paper is folded again [see Figure 60(*c*)].

(*iii*) The twice folded filter paper is opened to form a hollow cone (by keeping three layers of filter paper on one side and one layer on the other side) [see Figure 60(*d*)].

(*iv*) This cone of filter paper is placed inside a funnel [as shown in Figure 60(*e*)]. It is then used for the process of filtration in a science laboratory.

Keeping these points in mind, we will now describe filtration as a method for separating mixtures.

1. Separation by Filtration

The process of removing insoluble solids from a liquid by using a filter paper is known as filtration. **Filtration is used for separating insoluble substances from a liquid.** The mixture of insoluble solid and the liquid is poured into a filter paper cone fixed in a funnel by using a glass rod as a guide (see Figure 61). The liquid passes through the filter paper and collects in the beaker kept below the funnel. The solid particles (being bigger in size) do not pass through the filter paper and remain behind on the filter paper. The solid substance left behind on the filter paper is called *residue*. The clear liquid obtained is called *filtrate*. In this way, a mixture of insoluble solid in a liquid is separated into the 'solid' and 'clear liquid'.

A mixture of chalk and water is separated by filtration. When the mixture of chalk and water is poured on the filter paper fixed in a funnel, then clear water passes through the filter paper and collects as

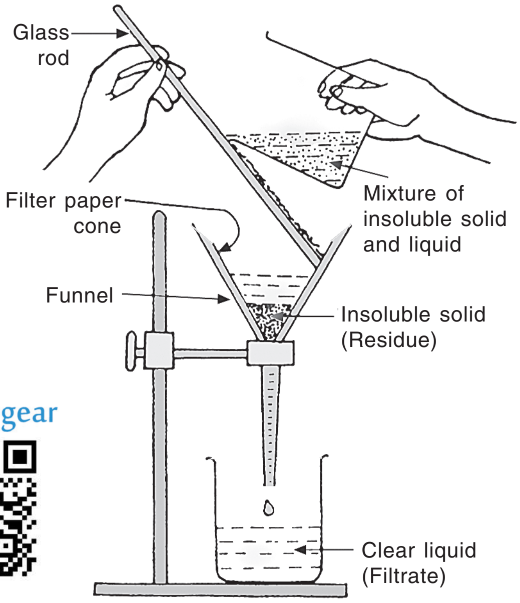


Figure 61. Separation of a mixture by filtration.

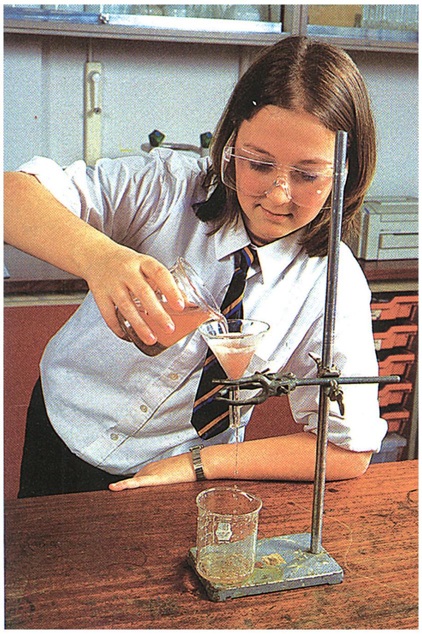


Figure 62. This student is separating a mixture of 'insoluble solid in a liquid' by filtration.

filtrate. The chalk particles remain behind on filter paper as residue. **A mixture of sand and water can also be separated by filtration.** When the mixture of sand and water is poured on a filter paper fixed in a funnel, then clear water passes through filter paper and collects as filtrate. The sand remains behind on the filter paper in the form of a residue.

The 'chalk and water mixture' and 'sand and water mixture'which have been separated by filtration are heterogeneous mixtures of a solid in a liquid. This means that **a heterogeneous mixture of a solid and a liquid can be separated by the process of filtration.** Please note that filtration can separate only insoluble substances (or undissolved substances) present in a liquid. **Filtration cannot remove any solid substances which are dissolved in a liquid.**

In science experiments we use a filter paper as 'filter' for carrying out the process of filtration. But in everyday life, different kinds of 'filters' are used. For example, a wire-mesh, a piece of cotton, a piece of muslin cloth (fine cloth) or even a layer of sand, can be used as 'filters' for various purposes. The size of

Figure 63. The tea strainer has a wire-mesh in it which acts as a filter.

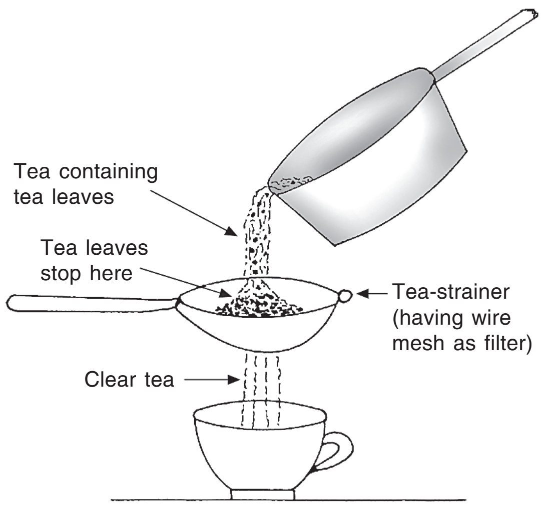


Figure 64. Separation of used tea-leaves from prepared tea by the process of filtration.

holes of the filter to be used depends on the size of the solid particles to be separated from the liquid. When we make tea, we add tea-leaves. Now, to separate used tea-leaves we pour the prepared tea over a tea-strainer (see Figure 64). The tea-strainer has a wire mesh in it which acts as a filter. The liquid tea passes through the small holes of a tea-strainer and collects in the cup below. The tea leaves (being bigger in size) do not pass through the wire mesh of tea-strainer. The tea-leaves remain behind on the tea-strainer. In this way, **the used tea-leaves are separated from prepared tea by the method of filtration.**

In many homes, drinking water is filtered by using special 'water filters' which remove bacteria present in it. In cities, gutter water is filtered through big metallic filters to separate solid materials present in it so as to avoid choking of underground drains (called sewers). The process of filtration plays an important role in the purification of water at water works (which supplies drinking water in a city). This is described below.

Supply of Drinking Water in a City

In cities, drinking water is supplied from water works. In water works, the methods like sedimentation, decantation, loading, filtration and chlorination, etc., are used to remove undesirable materials from water. This is described below.

The source of water supply in a city is either a nearby river or a lake (called reservoir). The river water and lake water usually contain suspended solid substances and some germs. So, before this water can be supplied to homes, it must be purified to remove suspended impurities as well as germs. This is done at a place called water works. The water works of a city is usually situated near the bank of a river or a lake. The purification of river water (or lake water) is done in the following steps :

(*i*) The water from a river (or lake) is pumped by the pumping station into a large reservoir called **sedimentation tank** (see Figure 65). This water is allowed to stand in the sedimentation tank for some time. During this time, many of the insoluble substances present in water settle down at the bottom of the tank.

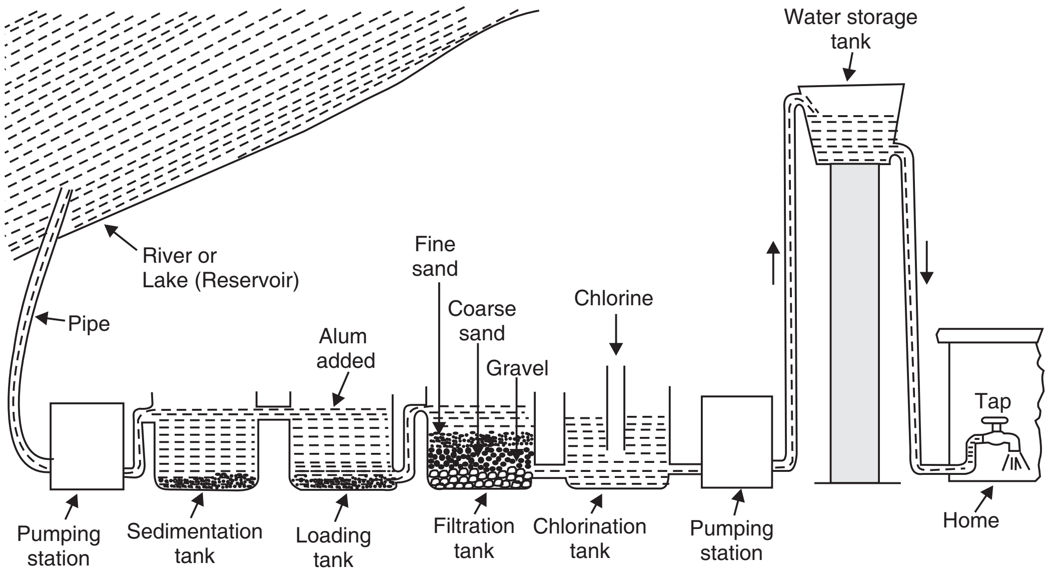


Figure 65. Supply of drinking water in a city.

(*ii*) From the sedimentation tank, water is sent to a '**loading tank**'. In the loading tank, some alum (*phitkari*) is added to water. The heavy particles of dissolved alum deposit on the suspended clay particles in water. In this way, the suspended clay particles in water get 'loaded' with alum particles, become heavy and settle down at the bottom of the tank. Thus, the process of loading (by using alum) removes the suspended clay particles from water.

(*iii*) The water is then passed through a **filtration tank**. The filtration tank has three layers : fine sand layer at the top, coarse sand layer in the middle and gravel (tiny stones) as the bottom layer. The layers of sand and gravel act as filters. When water passes through the layers of sand and gravel, even the small suspended particles and other materials in water get removed.

(*iv*) The clear water is then passed into a **chlorination tank.** A little chlorine gas is added to water in this tank. **Chlorine is added to water to kill the germs present in it.** This is called disinfecting the water (or sterilising the water). The water now becomes fit for drinking (or safe for drinking).

(*v*) The clean and disinfected water is then pumped by a pumping station into **high storage tanks** (see Figure 65). From the high storage tank, water is supplied to homes and factories in the entire city through a network of big and small pipes.

2. Separation by Centrifugation

If we have a mixture of fine suspended particles in a liquid, we can separate it by the process of filtration by using a filter paper. This process is, however, very slow. But we can separate the suspended particles of a substance in a liquid very rapidly by using the method of centrifugation. Centrifugation is done by using a machine called centrifuge. We can now say that : **Centrifugation is a method for separating the suspended particles of a substance from a liquid in which the mixture is rotated (or spun) at a high speed in a centrifuge.**

Figure 66. This is a centrifuge. The lid of this centrifuge has been opened to show the inside details. We can see the four centrifuge tube holders. The motor shaft which rotates the centrifuge tube holders can be seen in the middle.

Figure 67. Blood is a mixture of blood cells in a liquid called plasma. Blood can be separated into blood cells and plasma by centrifugation. The centrifuge tube in the above photograph shows blood cells at the bottom and plasma at the top which have been separated by centrifugation.

In the method of centrifugation, the mixture of fine suspended particles in a liquid is taken in a test-tube (called centrifuge tube). The test-tube is placed in a centrifuge machine and rotated rapidly for some time. As the mixture rotates round rapidly, a force acts on the heavier suspended particles in it and brings them down to the bottom of the test-tube. The clear liquid, being lighter, remains on top (see Figure 69). **We can separate the clay particles suspended in water very rapidly by the method of centrifugation.** The suspension of clay particles in water is taken in a test-tube and rotated very fast in a centrifuge machine. The clay particles settle down at the bottom of the test-tube and clear water remains at the top. They can now be separated by decantation.

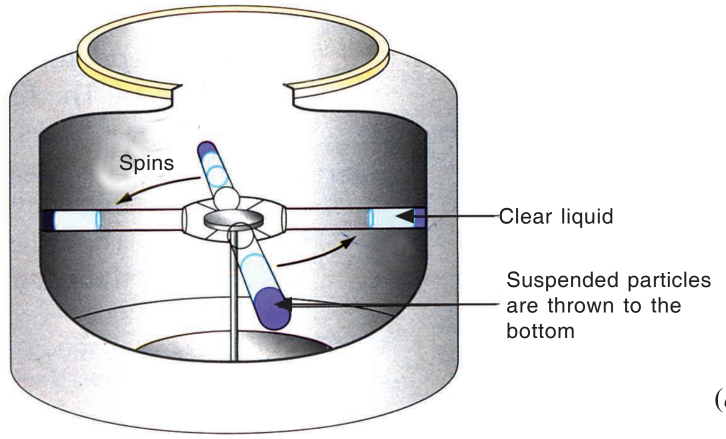
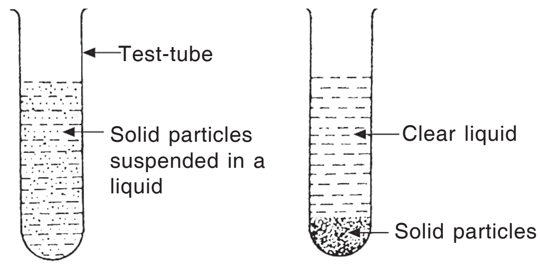


Figure 68. A centrifuge is used to separate suspended solid particles from a liquid, quickly. When the centrifuge is switched on, the test-tubes (containing suspension) held in it swing out and spin (or rotate) at high speed. The centrifugal force acts on suspended particles which forces them to go to the bottom of test-tubes and clear liquid remains on top (This sketch shows four test-tubes spinning at the same time).



(*a*) Before centrifuging (*b*) After centrifuging

Figure 69.

Separation of Cream from Milk

Milk is a suspension of tiny droplets of oil (cream) in a watery liquid. **The process of centrifugation is used in dairies to separate cream from milk.** The milk is put in a closed container in big centrifuge machine. When the centrifuge machine is switched on, the milk is rotated (or spun) at a very high speed in its container. Due to this, the milk separates into 'cream' and 'skimmed milk'. The cream, being lighter, floats over the skimmed milk. It can then be removed. Thus, **cream is separated from milk by centrifugation.** The process of centrifugation is also used in washing machines to squeeze out water from wet clothes and make them dry.

The methods of filtration and centrifugation which we have just discussed can be used to separate an insoluble solid substance from a liquid. They cannot separate a dissolved solid from a liquid. **The separation of a dissolved solid from a liquid can be done by a number of other methods such as evaporation, crystallisation, chromatography and distillation.** We will now discuss all these methods in detail, one by one.

3. Separation by Evaporation

The changing of a liquid into vapours (or gas) is called evaporation. **Evaporation is used to separate a solid substance that has dissolved in water (or any other liquid).** The dissolved substance is left as a solid residue when all the water (or liquid) has evaporated. **The use of process of evaporation for separating a mixture is based on the fact that liquids vaporise easily whereas solids do not vaporise easily.** Though evaporation of a liquid can take place even at room temperature but it is very slow at room temperature. Evaporation can be made quicker by heating the solution.

If we have a mixture of common salt and water, then we cannot separate common salt from water by filtration or centrifugation. This is because common salt is completely dissolved in water and not insoluble in it. We can recover common salt from salt-water mixture (or salt solution) by the process of evaporation.

The common salt dissolved in water can be separated by the process of evaporation. This is done as follows : The solution of common salt and water is taken in a china dish and heated gently by using a burner [see Figure 70(*a*)]. The water present in salt solution will form water vapours and escape into

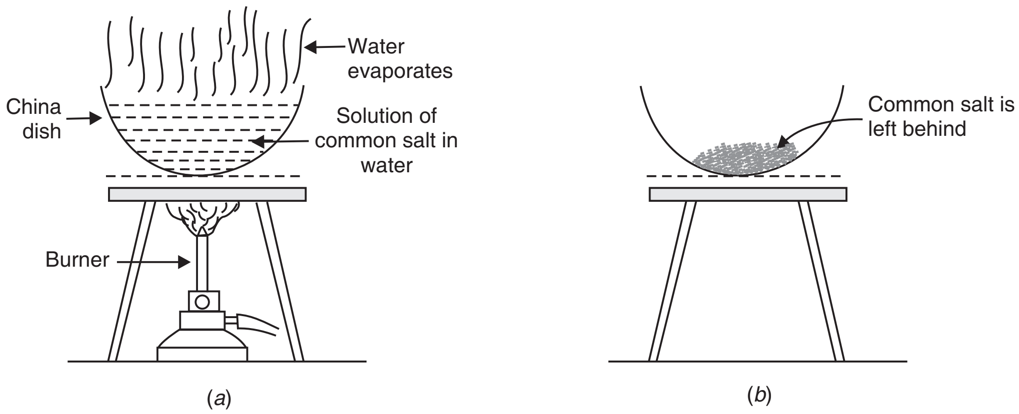


Figure 70. Separation of common salt dissolved in water by evaporation.

atmosphere. When all the water present in the solution of common salt and water gets evaporated, then common salt is left behind in the china dish as a white solid [see Figure 70(*b*)].

The process of evaporation is used on a large scale to obtain common salt from sea-water. Sea-water is trapped in shallow lakes (called lagoons) and allowed to stand there. The heat of sun gradually evaporates water in the shallow lakes and common salt is left behind as a solid.

When a sugar solution is evaporated carefully, then water is eliminated and solid sugar is left behind. We can also separate copper sulphate (blue vitriol) from its solution by the process of evaporation. The substances like potash alum and potassium nitrate, etc., are also separated from their water solutions (called aqueous solutions) by the process of evaporation. It should be noted that during the evaporation of a 'water solution' we get the 'dissolved solid substance' but water cannot be recovered in this method. Water evaporates into the atmosphere. When a solution of sulphur in carbon disulphide is evaporated, then carbon disulphide vaporises and solid sulphur is left behind. It should be clear by now that **evaporation is used for recovering dissolved solid substances from liquid mixtures (or solutions) but the liquid itself cannot be recovered by this method. The liquid vaporises and gets lost to the air.**

Figure 71. This picture shows the experimental set-up for separating salt from water by evaporation. As the water boils away, salt is left behind in the china dish. We can see the salt recovered by evaporation in the china dish in the above photograph.

The blue ink (or black ink) used in fountain pens is a liquid mixture. It is a mixture of a 'dye' in water. This dye is the coloured component of the ink (which gives it a blue or black colour). **We can separate the 'coloured component of ink' (or 'dye' from ink) by the process of evaporation.** Please note that for evaporating ink, we do not heat the china dish containing ink directly over the flame (as we did in the case of salt solution in Figure 70). This is because the 'dye' obtained from ink can get decomposed by the high temperature produced by the direct heating with a burner. We use a 'water bath' for evaporating ink. **A simple water bath can be made by filling a beaker half with water.** We will now describe the experiment to obtain 'dye' from the ink.

Experiment to Obtain Coloured Component (Dye) From Ink

We take a beaker and fill it half with water (This will serve as a water bath). About 5 mL of ink (blue ink or black ink) is put in a china dish. The china dish containing ink is then placed over the mouth of beaker containing water, which is kept on a tripod stand [see Figure 72(*a*)]. We now start heating the beaker with a burner. Soon, the water in beaker starts boiling to form steam. This steam heats the ink in the

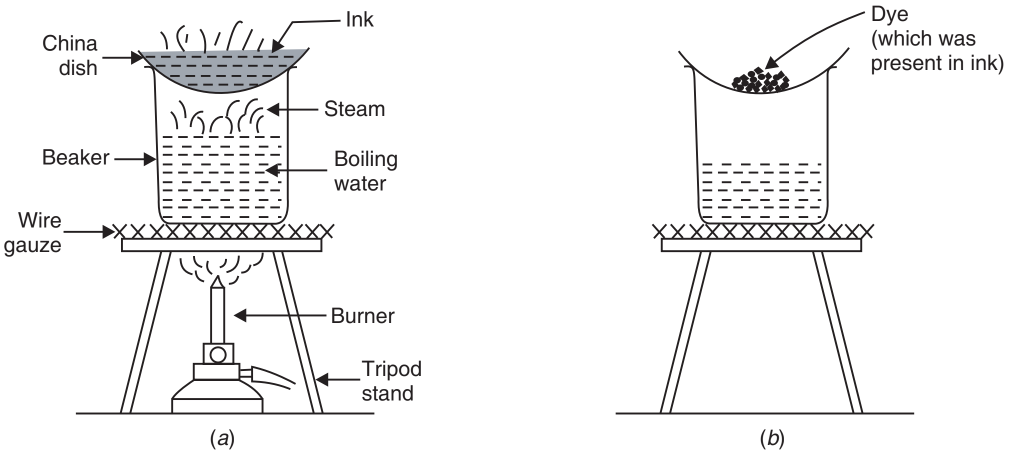


Figure 72. Separation of 'dye' from ink by the process of evaporation.

china dish. Due to this heating, the water present in ink starts evaporating gradually. When all the water has evaporated from ink, we stop heating. We will find that a small amount of a solid coloured material is left in the china dish [see Figure 72 (*b*)]. This coloured material is the dye which was present in the ink. Thus, water has evaporated from the ink and solid dye is left behind. **This experiment shows that ink is not a single substance (or pure substance), it is a mixture.** Ink is a mixture of dye in water.

We have just discussed the separation of a solid from a solution by the process of evaporation. In evaporation, we have to heat the solution to dryness. So, evaporation gives us the solid substance in the form of a powder. Moreover, if any impurities were present in the dissolved solid substance, the same will also be present when it is recovered by evaporation. This, however, is not so in the case of crystallisation.

The process of separation called 'crystallisation' gives us proper crystals (solid particles with flat sides), and impurities also get removed in it. So, in a way, crystallisation is a method of purifying solid substances in which crystals of the pure substance are formed.

The process of crystallisation also begins by evaporating the liquid mixture by heating but it is not continued till dryness. Rather, when the solution becomes sufficiently concentrated (or saturated), heating is stopped and hot concentrated solution is allowed to cool slowly. After some time, the crystals of pure solid substance appear in the solution. Keeping these points in mind, let us study the process of crystallisation in somewhat detail.

4. Purification by Crystallisation

The process of cooling a hot, concentrated solution of a substance to obtain crystals is called crystallisation. The process of crystallisation is used for obtaining a pure solid substance from impure sample. This is done as follows :

1. The impure solid substance is dissolved in the minimum amount of water to form a solution.
2. The solution is filtered to remove insoluble impurities.
3. The clear solution is heated gently on a water bath till a concentrated solution or saturated solution is obtained (This can be tested by dipping a glass rod in hot solution from time to time. When small crystals form on the glass rod, the solution is saturated). Then stop heating.
4. Allow the hot, saturated solution to cool slowly.
5. Crystals of pure solid are formed. Impurities remain dissolved in solution.
6. Separate the crystals of pure solid by filtration and dry.

As an example, we will describe the purification of an impure sample of copper sulphate to obtain pure copper sulphate.

To Obtain Pure Copper Sulphate From an Impure Sample

Impure copper sulphate can be purified by the method of crystallisation to obtain pure copper sulphate. This is done as follows :

1. Take about 10 grams of impure copper sulphate and dissolve it in minimum amount of water in a china dish to make copper sulphate solution.
2. Filter the copper sulphate solution to remove insoluble impurities.

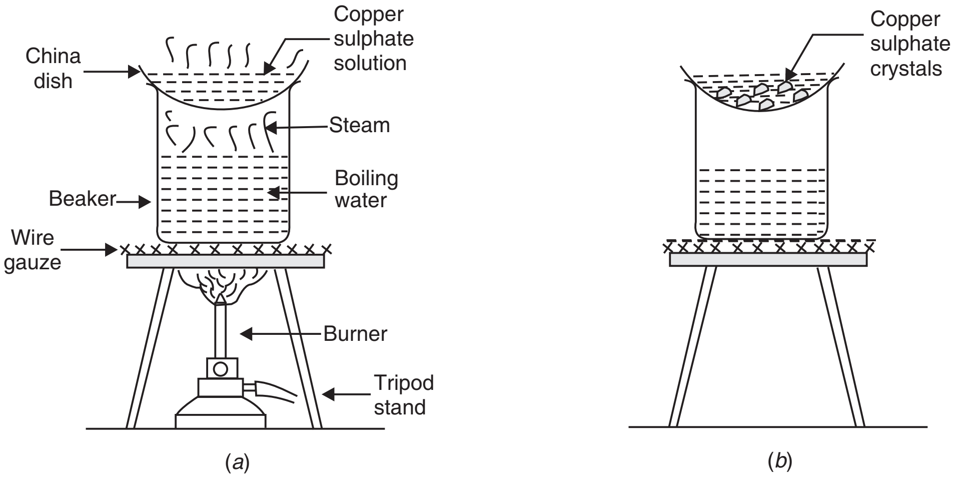


Figure 73. Purification of impure copper sulphate by crystallisation.

3. Heat the copper sulphate solution gently on a water bath [as shown in Figure 73(*a*)] to evaporate water and obtain a saturated solution (This can be tested by dipping a glass rod in hot solution from time to time. When small crystals form on the glass rod, the solution is saturated). Then stop heating.
4. Allow the hot, saturated solution of copper sulphate to cool slowly.
5. Crystals of pure copper sulphate are formed [see Figure 73(*b*)]. Impurities remain behind in the solution.
6. Separate the copper sulphate crystals from solution by filtration and dry.

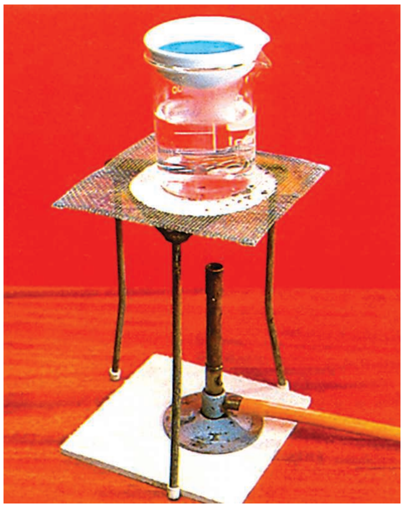


Figure 74. Copper sulphate solution being evaporated over a water bath so as to obtain a saturated solution of copper sulphate.

Figure 75. When the hot, saturated solution of copper sulphate is cooled slowly, crystals of pure copper sulphate are formed. The above picture shows copper sulphate crystals thus obtained.

The process of crystallisation is used to purify a large number of water soluble solids. For example, the common salt obtained from sea-water is an impure substance having many impurities in it. So, **common salt is purified by the process of crystallisation.** An impure sample of alum is also purified by crystallisation.

Crystallisation is a better technique than 'evaporation to dryness' because of the following reasons :

(*i*) Some solids (like sugar) decompose or get charred on heating to dryness during evaporation. There is no such problem in crystallisation.

(*ii*) The soluble impurities do not get removed in the process of evaporation. But such impurities get removed in crystallisation.

5. Separation by Chromatography

Chromatography is a technique of separating two (or more) dissolved solids which are present in a solution in very small quantities. There are many types of chromatography but the simplest form is the **paper chromatography**. So, we will study only paper chromatography in this class. By using paper chromatography, we can separate two (or more) different substances present in the same solution. **This separation is based on the fact that though two (or more) substances are soluble in the same solvent (say, water) but their solubilities may be different**. Some may be more soluble than the others. For example, black ink contains a number of dyes dissolved in water. These dyes have different solubilities in water. This fact is used to separate the dyes present in black ink.

It is most easy to perform chromatography experiments with the mixtures of coloured materials like 'inks' and other 'dyes' because they separate to give coloured components which can be seen easily as coloured spots on the paper. A special type of paper called 'chromatography paper' is used for carrying out separations by chromatography. For ordinary purposes, however, filter paper can also be used for paper chromatography experiments. We will now describe the process of separation of dissolved solids from a solution by paper chromatography by taking the example of black ink. **Black ink is a mixture of several coloured substances (or dyes) which can be separated by paper chromatography.**

To Separate the Dyes Present in Black Ink

The different coloured dyes present in black ink can be separated by performing a paper chromatography experiment as follows :

1. Take a thin and long strip of filter paper. Draw a pencil line on it, about 3 centimetres from one end.

2. Put a small drop of black ink on the filter paper strip at the centre of the pencil line [see Figure 76(*a*)]. Let the ink dry.

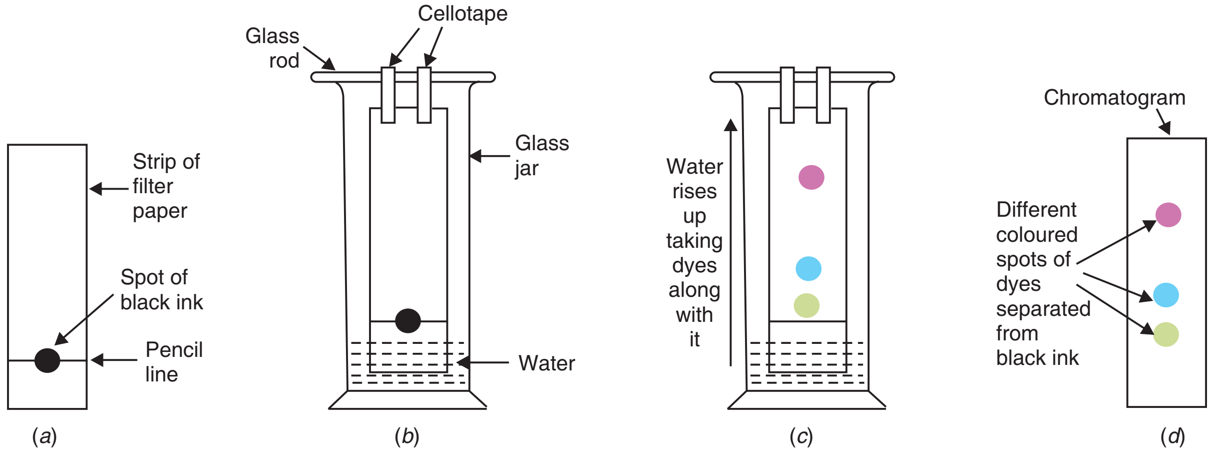


Figure 76. Separation of the 'dyes' in black ink by paper chromatography.

3. When the drop of ink has dried, the filter paper strip is lowered into a tall glass jar containing some water in its lower part (keeping the pencil line at the bottom). The filter paper strip is held vertically by attaching its upper end to a glass rod with cellotape (the glass rod being kept over the mouth of glass jar). Please note that though the lower end of the paper strip should dip in water but the pencil line (having dried ink spot on it) should remain above the water level in the jar [see Figure 76(*b*)].

4. The water gradually rises up the filter paper strip by capillary action. As water moves up the paper strip, it takes along the dyes present in ink. The dye which is more soluble in water dissolves first, rises faster and produces a coloured spot on the paper at a higher position. The less soluble dyes dissolve a little later, rise slower and form coloured spots at lower heights. In this way, all the dyes present in black ink get separated (by forming separate different coloured spots) [see Figure 76(*c*)].

5. When the water reaches near the top end of the filter paper strip, the paper strip is removed from the jar and dried. The paper with its separate coloured spots is called a **chromatogram** [see Figure 76(*d*)].

6. The chromatogram obtained by using black ink in this experiment has three coloured spots on it [see Figure 76(*d*)]. This means that the given sample of black ink has three different dyes mixed in it.

Chromatography is an important tool in chemical analysis. It is used to separate small amounts of dissolved substances. Some of the important **applications (or uses) of chromatography** are given below :

(*i*) Chromatography is used to separate solutions of coloured substances (dyes and pigments).

(*ii*) Chromatography is used in forensic science to detect and identify trace amounts of substances (like poisons) in the contents of bladder or stomach.

(*iii*) Chromatography is used to separate small amounts of products of chemical reactions.

Figure 77. Chromatographic separation of black ink.

6. Separation by Distillation

We can obtain salt from salt-water mixture (or salt solution) by evaporation but water *cannot* be recovered during evaporation, it is lost into the air. **In order to recover both, salt as well as water, from a salt-water mixture (or salt solution), the process of distillation is used.**

Distillation is the process of heating a liquid to form vapour, and then cooling the vapour to get back liquid. Distillation can be represented as :

$$\text{Liquid} \underset{\text{Cooling}}{\overset{\text{Heating}}{\rightleftarrows}} \text{Vapour (or Gas)}$$

The liquid obtained by condensing the vapour is called **'distillate'.** From this discussion we conclude that in order to obtain both, solid as well as liquid from the 'mixture of a solid and a liquid', the process of distillation has to be used. When the homogeneous mixture of solid and a liquid is heated in a closed distillation flask, the liquid, being volatile, forms vapour. The vapours of liquid are passed through a 'condenser' where they get cooled and condense to form pure liquid. This pure liquid is collected in a separate vessel. The solid, being non-volatile, remains behind in the distillation flask.

Before we describe the process of distillation, we should know something about the 'water condenser' which is also known as 'Liebig condenser'. The water condenser is a long glass tube surrounded by a wider glass tube (called water jacket) having an inlet and outlet for water. During distillation, cold water from tap is circulated through the outer tube of condenser. This water takes away heat from the hot vapour passing through the inner tube of condenser and causes its condensation (vapour to liquid change).

We will now describe how a 'salt and water mixture' (or 'salt-solution') can be separated into 'salt' and 'water' by distillation.

To Separate the Salt-Water Mixture (or Salt-Solution)

A mixture of common salt and water can be separated completely by the process of distillation. The apparatus used for distillation is shown in Figure 78.

The salt and water mixture is taken in the distillation flask *A* and heated (see Figure 78.). On heating, water forms vapours (steam) which rise up and come out through the side tube *B* of the distillation flask, and go into water condenser *C*. Cold water from the tap is circulated through the outer tube of condenser

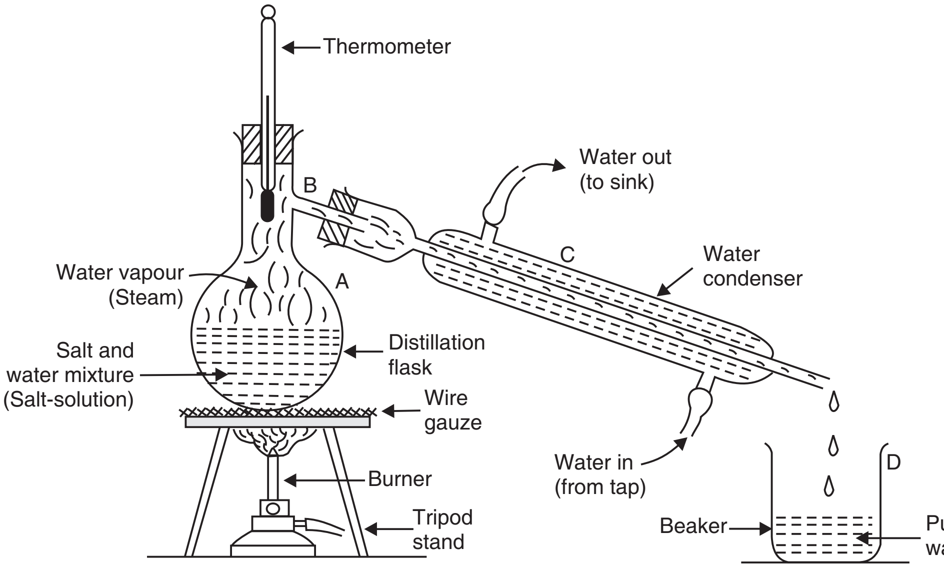


Figure 78. Separation by distillation. Here a mixture of salt and water (or salt-solution) is being separated by distillation.

for cooling the vapours. The hot water vapours get cooled in the condenser to form pure water which trickles down from the condenser and collects in the beaker *D*. This pure water is called **distilled water.** Since the salt is non-volatile (it does not form vapours on heating), so it remains behind in the distillation flask. (Some porcelain pieces are put in the distillation flask in the beginning to have uniform boiling throughout the solution and avoid bumping of the solution due to uneven heating).

Figure 79. A student carrying out the process of distillation in the laboratory to separate salt-water mixture.

Figure 80. Sea water is a mixture of salts and water. In hot and arid countries (having little or no rain), distillation technique is used on a large scale to remove salts from sea water so as to obtain drinking water. This process is carried out in a desalination plant. The above picture shows a desalination plant which produces large quantities of drinking water from sea water in Bahrain.

From the above discussion we conclude that distillation can be used to separate a liquid from dissolved non-volatile solids. Now, ordinary tap water always contains some dissolved salts in it and is never pure. So, **pure water or distilled water is made from tap water by the process of distillation.** There are many coastal areas where drinking water is not available in adequate quantity. **The process of distillation is used to obtain drinking water from sea-water in many countries.**

Distillation can also be used to separate a mixture of two miscible liquids having different boiling points. The liquid having lower boiling point distils over first, and the liquid having higher boiling point distils later. Each liquid, however, contains some amount of the other liquid, so **a complete separation of two miscible liquids cannot be done by simple distillation.** For the complete separation of two (or more) miscible liquids, the process of **fractional distillation** is used.

SEPARATION OF MIXTURE OF TWO (OR MORE) LIQUIDS

All the mixtures containing two (or more) liquids can be separated by one of the following two methods :

(*i*) By the process of fractional distillation.

(*ii*) By using a separating funnel.

Before we discuss the separation of mixtures containing two (or more) liquids, we should know the meaning of 'miscible liquids' and 'immiscible liquids'. This is given below.

Those liquids which mix together in all proportions and form a single layer (when put in a container), are called miscible liquids. *Alcohol* and *water* are miscible liquids because they mix together in all proportions and form a single layer on mixing (The scientific name of common alcohol is ethanol). *Water* and *acetone* are also miscible liquids (The scientific name of acetone is propanone). **A mixture of miscible liquids is separated by the process of fractional distillation.**

Those liquids which do not mix with each other and form separate layers (when put in a container), are called immiscible liquids. *Oil* and *water* are immiscible liquids because they do not mix with each other, and form separate layers on mixing (oil can be mustard oil, groundnut oil, kerosene oil, etc.) Water being heavier forms the lower layer, and oil being lighter forms the upper layer. *Petrol* and *water* are also immiscible liquids. **A mixture of immiscible liquids is separated by using an apparatus called separating funnel.** We will now describe the separation of mixtures containing two (or more) liquids in detail.

1. Separation by Fractional Distillation

Fractional distillation is the process of separating two (or more) miscible liquids by distillation, the distillate being collected in fractions boiling at different temperatures. A mixture of two miscible liquids can be separated by the process of fractional distillation. **The separation of two liquids by fractional distillation depends on the difference in their boiling points.** Fractional distillation is carried out by using a **fractionating column.**

A simple fractionating column is a long vertical glass tube filled with glass beads (see Figure 81). The glass beads provide a large surface area for hot vapours to cool and condense repeatedly. **In most simple terms, a fractionating column can be regarded as an arrangement for providing different temperature zones inside it (during distillation), the highest temperature being at the bottom of the column and the lowest temperature near its top.** The fractionating column is fitted in the neck of the distillation flask containing the mixture of liquids to be separated. We will now take one example to understand how a mixture of miscible liquids is separated by fractional distillation.

To Separate a Mixture of Alcohol and Water

Alcohol (or ethanol), and water are miscible liquids. The boiling point of alcohol is 78°C and the boiling point of water is 100°C. Since the boiling points of alcohol and water are different, therefore, **a mixture of alcohol and water can be separated by fractional distillation.** The apparatus used for fractional distillation of alcohol and water mixture is shown in Figure 81.

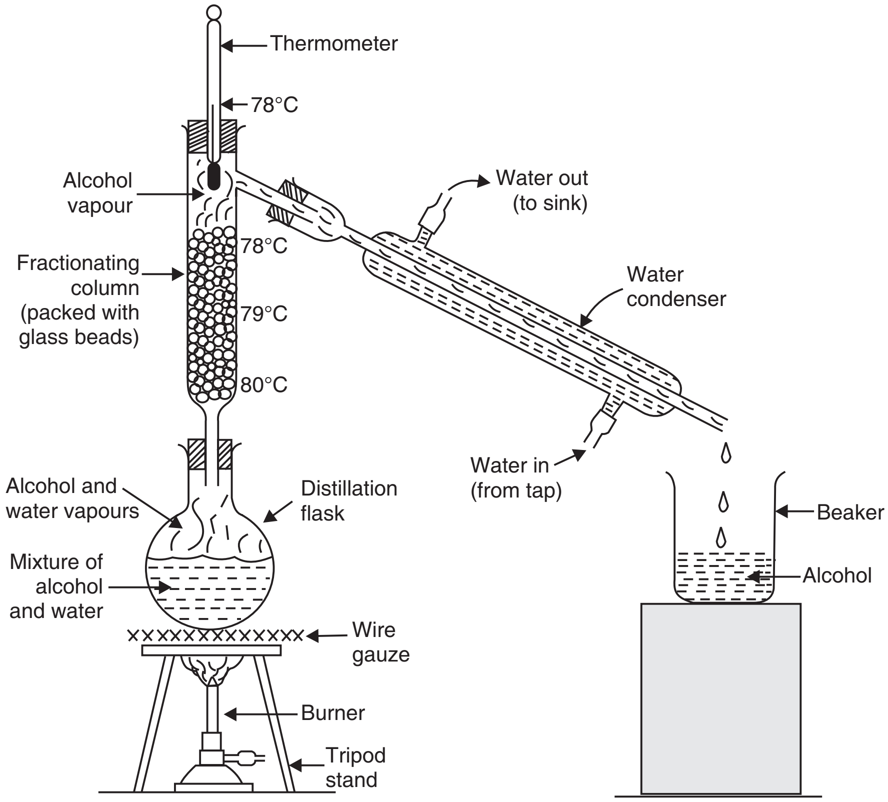


Figure 81. Separation of a mixture of two miscible liquids (here alcohol and water) by fractional distillation.

The mixture of alcohol and water is heated in a distillation flask fitted with a fractionating column (see Figure 81). When the mixture is heated, both alcohol and water form vapours as their boiling points approach. The alcohol vapour and water vapour rise up in the fractionating column. The upper part of the fractionating column is cooler, so as the hot vapours rise up in the column, they get cooled, condense and trickle back into the distillation flask. As the experiment goes on, the fractionating column warms up by the heat released by the condensed vapours. After some time, a temperature gradient is created in the fractionating column, the temperature at the top of the column being much less than at its bottom.

When the temperature at the top of the fractionating column reaches 78°C (which is the boiling point of alcohol), then alcohol vapour passes into the condenser, gets cooled and collects in a beaker kept at the other end of the condenser (see Figure 81). The alcohol-water mixture is kept boiling at such a rate that the thermometer shows the boiling point of alcohol (78°C). In this way, all the alcohol distils over and gets separated. It is collected as the first fraction.

Please note that when thermometer is showing the boiling point of alcohol (78°C), no water distils over. This is due to the fact that the temperature at the top of the fractionating column (78°C) is much less than the boiling point of water, which is 100°C. So, all the water vapour condenses before reaching the

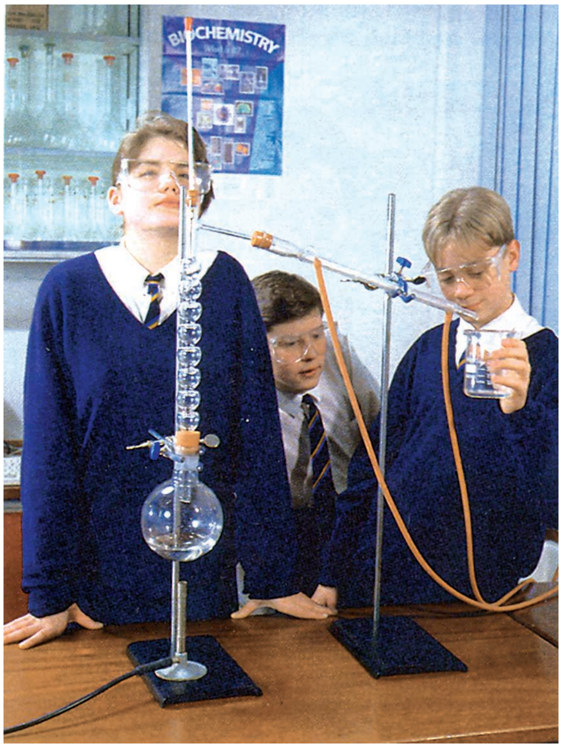


Figure 82. This photograph shows the students carrying out fractional distillation in the laboratory to separate a mixture of alcohol and water.

top of the fractionating column and falls back into the distillation flask.

Having collected the alcohol fraction, the flask is heated more strongly so that the thermometer shows a temperature of 100°C, which is the boiling point of water. When the temperature at the top of the fractionating column becomes 100°C, water vapour passes into the condenser, gets cooled and condenses. This pure water is collected in another beaker as the second fraction. Heating is continued till all the water distils over. In this way, the alcohol-water mixture has been separated into two fractions boiling at 78ºC and 100°C, respectively.

It is clear from the above discussion that by using fractional distillation, a mixture of two (or more) miscible liquids can be separated completely. **Fractional distillation separates the various liquids according to their boiling points : the more volatile liquid (having lower boiling point) distils over first, and the less volatile liquid (having higher boiling point) distils over later.** Acetone and water are miscible liquids. The boiling point of acetone is 56°C and the boiling point of water is 100°C. So, **a mixture of acetone and water can be separated by fractional distillation.** Please note that **a mixture of more than two miscible liquids can also be separated by fractional distillation** (provided they all have different boiling points). For example, a mixture of acetone, alcohol and water can be separated by fractional distillation.

Applications of Fractional Distillation

1. Fractional distillation is used to separate mixtures of miscible liquids (like alcohol-water mixture and acetone-water mixture) in the laboratory.
2. Fractional distillation is used to separate crude oil 'petroleum' into useful fractions such as kerosene, petrol and diesel, etc.
3. Fractional distillation (of liquid air) is used to separate gases of the air.

Separation of the Gases of the Air

Air is a mixture of gases like nitrogen, oxygen, argon, carbon dioxide, helium, neon, krypton, and xenon, etc. The major component of air is nitrogen (78.03%). The second major component of air is oxygen (20.99%), and the third major component of air is argon (0.93%). All the remaining gases of air constitute only 0.05% of air. Nitrogen is used for making fertilisers. Oxygen is used for making steel in factories, and in hospitals (to help patients having breathing difficulties). Argon is filled in electric bulbs. All these gases are obtained from air on a large scale. This is because air is the cheapest source of these gases. **The various gases of air are separated from one another by the fractional distillation of liquid air.** This separation is based on the fact that **the different gases of air have different boiling points** (when in liquid form). The boiling points of the three major gases of air, nitrogen, oxygen and argon, are given below :

Gas	*Boiling point (of liquefied gas)*	
Nitrogen	–196°C	(Lowest boiling point)
Argon	–186°C	
Oxygen	–183°C	(Highest boiling point)

Liquid air is an extremely cold liquid. Liquid air contains all the component gases in the liquid form. When liquid air is warmed gradually during fractional distillation, the various liquefied gases present in it boil off at different temperatures (according to their boiling points) and collected separately at different heights in the fractional distillation column. We will now describe how gaseous air is converted into liquid air, and how the three major components, nitrogen, oxygen and argon, are separated from it.

Air is separated into its component gases in the following steps :

1. The air is first filtered to remove dust, then water vapour and carbon dioxide are removed (If water vapour and carbon dioxide are not removed, they would become solid in the cooling process and block the pipes).

2. Air is compressed to a high pressure and then cooled. This cooled air is then allowed to expand quickly into a chamber through a jet. This expansion cools the air even more.
3. The process of compression, cooling and rapid expansion of air is repeated again and again making the air more and more cool. Ultimately the air gets so cooled that it turns into a liquid. In this way, liquid air is obtained.
4. The liquid air is fed into a tall fractional distillation column from near its bottom and warmed up slowly.
   (*a*) Liquid nitrogen (present in liquid air) has the lowest boiling point of, –196°C. So, on warming, liquid nitrogen boils off first to form nitrogen gas. This nitrogen gas is collected from the top part of the fractional distillation column.
   (*b*) Liquid argon (present in liquid air) has a slightly higher boiling point of, –186°C. So, liquid argon boils off next and collected as argon gas in the middle part of the fractional distillation column.
   (*c*) Liquid oxygen (present in liquid air) has a still higher boiling point of, –183°C. So, liquid oxygen boils off last and collected as oxygen gas from the bottom of the fractional distillation column.

Figure 83. Gases from the air are separated in this Fractional Distillation Plant.

A flow diagram showing the main processes involved in obtaining different gases from air is given below :

mYstudygear

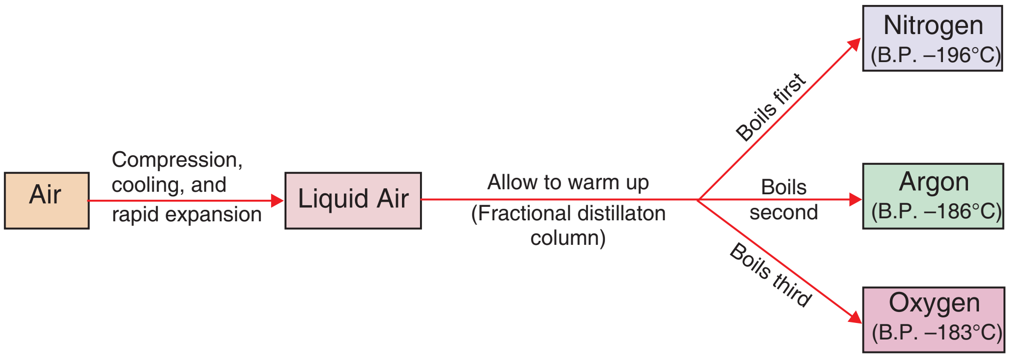


Figure 84. Separation of the major gases of air.

2. Separation by a Separating Funnel

A mixture of two immiscible liquids can be separated by using a separating funnel (shown in Figure 85). A separating funnel is a special type of funnel which has a stop-cock (or tap) in its stem to allow the flow of a liquid from it, or to stop the flow of liquid from it. **The separation of two immiscible liquids by a separating funnel depends on the difference in their densities**. We will now describe how a mixture of two immiscible liquids is separated by using a separating funnel.

The mixture of two immiscible liquids is put in a separating funnel and allowed to stand for some time. The mixture separates into two layers according to the densities of the liquids in it. The heavier liquid or denser liquid (having higher density) forms the lower layer whereas the lighter liquid (having lower density) forms the upper layer (see Figure 85). On opening the stop-cock of separating funnel, the lower layer of heavier liquid comes out first and collected in a beaker. When the lower layer of heavier liquid has completely

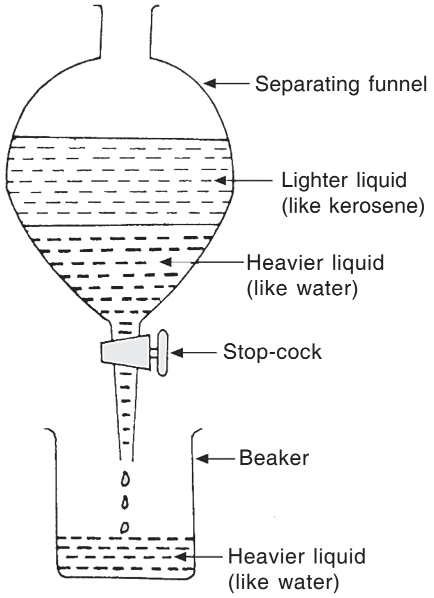


Figure 85. Separation of two immiscible liquids by using a separating funnel.

Figure 86. This photograph shows a student separating a mixture of oil and water by using a separating funnel. The water has been coloured pink so that it shows up more clearly in the photograph.

run off, the stop-cock is closed. The lighter liquid in the upper layer is collected in a separate beaker by opening the stop-cock again.

Water and kerosene oil are two immiscible liquids. So, **a mixture of water and kerosene can be separated by using a separating funnel.** When the mixture of water and kerosene is put in a separating funnel, it forms two layers. Water, being heavier, forms the lower layer in the separating funnel whereas kerosene, being lighter, forms the upper layer (see Figure 85). On opening the stop-cock of separating funnel, the lower layer of water comes out first and collected in a beaker. When the water layer has completely run off, then the stop-cock is closed. The kerosene is left behind in the separating funnel. It can be removed in a separate beaker by opening the stop-cock again.

A mixture of petrol and water can also be separated by using a separating funnel. Petrol and water are immiscible liquids so they form two layers in the separating funnel. Water being heavier, forms the lower layer whereas petrol being lighter, forms the upper layer. On opening the stop-cock of separating funnel, the lower layer of water comes out first and collected in a beaker. When the water layer has completely run off, then the stop-cock is closed. The petrol is left behind in the separating funnel. It can be collected in a separate beaker by opening the stop-cock again.

Please note that groundnut oil (or cooking oil), and mustard oil are also immiscible with water. So, a mixture of groundnut oil (or cooking oil) and water can be separated by using a separating funnel. Similarly, a mixture of mustard oil and water can also be separated by using a separating funnel. It should be noted that both, groundnut oil and mustard oil, are lighter than water and hence form upper layer in the separating funnel. Please note that there are two differences in the properties of oil (like kerosene oil, mustard oil, groundnut oil, etc.) and water which enable their separation by a separating funnel. These are :

(*i*) **oil and water are immiscible liquids,** and
(*ii*) **oil and water have different densities.**

Mercury, carbon disulphide, chloroform, benzene and ether are also immiscible with water. So, a mixture of mercury and water ; carbon disulphide and water ; chloroform and water ; benzene and water, or ether and water, can be separated by using a separating funnel. Please remember that mercury, carbon disulphide and chloroform are heavier than water but benzene and ether are lighter than water.

A mixture of more than two immiscible liquids can also be separated by using a separating funnel. For example, a mixture of mercury, water and benzene can be separated in this way. When a mixture of mercury, water and benzene is put in a separating funnel, it separates into three layers. Mercury, being heaviest liquid, forms the bottom layer, water forms the middle layer, and benzene, being lightest, forms the top layer. On opening the stop-cock, mercury will run out first, followed by water and then benzene. This type of separation (in which the heavier liquid forms lower layer and lighter liquid forms upper layer) is useful in industry. For example, during the extraction of iron in the blast furnace, the heavier molten iron forms the lower layer at the base of blast furnace whereas the lighter slag (molten waste material) forms a separate layer on the top of molten iron. The two layers can be 'tapped' off separately from the blast furnace.

Separation of Mixtures by Using More Than One Method

A mixture which has only two components (or constituents) can be usually separated by a single method. On the other hand, a mixture which has more than two components can be separated into individual components by a combination of methods of separation. These methods are applied turn by turn. The separation of mixtures by using a combination of methods will become clear from the following examples.

Sample Problem 1. How will you separate iron filings, ammonium chloride and sand from their mixture ?

Answer. Whenever we want to separate the components of a mixture, we should first find out some properties which are different for different components. In this question we have three components to be separated. These are : iron filings, ammonium chloride and sand. Now, iron is attracted by a magnet whereas ammonium chloride undergoes sublimation. But sand does not have any of these properties. So, this difference in the properties of iron filings, ammonium chloride and sand will be used to separate them from their mixture.

The mixture containing iron filings, ammonium chloride and sand is separated as follows :

(*i*) Iron filings are attracted by a magnet so they are removed by the method of magnetic separation. When a magnet is moved in this mixture, iron filings cling to the magnet and get separated. We are then left with ammonium chloride and sand.

(*ii*) Ammonium chloride sublimes on heating whereas sand does not sublime. So, ammonium chloride is separated from sand by the process of sublimation. When the mixture containing ammonium chloride and sand is heated, then ammonium chloride forms vapours easily. These vapours on cooling give pure ammonium chloride. Sand is left behind.

From the above discussion we conclude that a mixture of iron filings, ammonium chloride and sand has been separated into its components by a combination of two methods : magnetic separation and sublimation. *Please note that we have given so many details in answering this question just to make you understand clearly. There is no need for the students to write so many details while writing their answers.*

Sample Problem 2. Describe a method of separating common salt from a mixture of common salt and chalk powder.

Answer. This mixture contains two constituents : common salt and chalk powder. Now, common salt is soluble in water whereas chalk powder is insoluble in water. So, this difference in their solubility will be used to separate them. This is done as follows :

(*i*) Some water is added to the mixture of common salt and chalk powder, and stirred. Common salt dissolves in water to form salt solution whereas chalk powder remains undissolved.

(*ii*) On filtering, chalk powder is obtained as a residue on the filter paper and salt solution is obtained as filtrate.

(*iii*) The salt solution (filtrate) is evaporated to dryness when common salt is left behind.

Sample Problem 3. You are given a mixture of sand, water and mustard oil. How will you separate the components of this mixture ?

Answer. This mixture contains three components : sand, water and mustard oil. Now, sand is a solid which is insoluble in water as well as mustard oil. Water and mustard oil are immiscible liquids.

(*i*) The mixture of sand, water and mustard oil is filtered. Sand is left on the filter paper as residue. Water and mustard oil collect as filtrate.

(*ii*) The filtrate containing water and mustard oil is put in a separating funnel. Water forms the lower layer and mustard oil forms the upper layer in separating funnel. The lower layer of water is run out first by opening the stop-cock of the separating funnel. Mustard oil remains behind in the separating funnel and can be removed separately.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. Name the solvent you would use to separate a mixture of sulphur and carbon.
2. Name the process you would use to separate ammonium chloride from a mixture of sodium chloride and ammonium chloride.
3. Which method can be used to separate a mixture of naphthalene and common salt ?
4. Name the process you would use to separate a mixture of anthracene and copper sulphate ?
5. Name the property of any one of the components which can be used for separating the following mixture :
Salt and Camphor
6. What type of magnet is fitted on a crane to separate scrap iron objects from a heap of waste materials in factories ?
7. Name the property of one of the constituents which can be used to separate a mixture of salt and iodine
8. Name the process you would use to separate a mixture of two miscible liquids (like acetone and water).
9. What difference in the property of two miscible liquids enables their separation by fractional distillation ?
10. Name one pair of substances whose mixture can be separated by fractional distillation.
11. Name one pair of liquids which can be separated by using a separating funnel.
12. State whether the following statements are true or false :
(*a*) Alcohol can be separated from a mixture of alcohol and water by a separating funnel.
(*b*) Salt and water can be recovered from an aqueous salt solution by the process of evaporation.
13. Name the source from which nitrogen and oxygen are obtained on a large scale.
14. Name the process by which the various gases of the air are separated.
15. A carpenter wants to separate iron nails from saw-dust. Which method of separation should he choose ?
16. Name any two solid substances whose mixture can be separated by sublimation.
17. Name one pair of substances whose mixture can be separated completely by distillation.
18. How will you separate a mixture of chalk powder and water ?
19. Name the process which can be used to separate a mixture of salt solution and sand.
20. Name the process which can be used to recover salt from an aqueous salt solution.
21. Name the process which is used in milk dairies to separate cream from milk.
22. State one application of centrifugation.
23. What is the general name of the process by which tea-leaves are separated from prepared tea ?
24. Name the process you would use to separate a mixture of water and alcohol.
25. Name the apparatus you would use to separate oil from water.
26. What differences in the properties of oil and water enable their separation by a separating funnel ?
27. (*a*) Name the process by which common salt is obtained from sea-water.
(*b*) Name the process by which common salt is purified.
28. Name the process which can be used to purify an impure sample of copper sulphate.
29. (*a*) Name the process by which all the dye can be recovered from black ink.
(*b*) Name the process by which the various 'dyes' (coloured materials) present in black ink can be separated.

30. Which technique is used in a washing machine to squeeze out water from wet clothes while drying ?

31. Which technique can be used to detect and identify traces of poison present in the stomach wash of a person ?

32. Fill in the following blanks with suitable words :

(*a*) Miscible liquids are separated by ....

(*b*) Immiscible liquids are separated by using a ....

(*c*) A mixture of kerosene and petrol can be separated by ....

(*d*) The separation of liquids by fractional distillation is based on the difference in their ....

(*e*) The gases of air can be separated by fractional distillation of liquid air because they have different.............

(*f*) A heterogeneous mixture of liquid and solid is conveniently separated by..............

(*g*) If a mixture contains iron filings as one of the constituents, it can be separated by using a................ .

Short Answer Type Questions

33. How will you separate a mixture containing sand and sugar ?

34. What difference in the properties of common salt and sand would enable you to separate a mixture of these two substances ?

35. Describe a method to separate a mixture of common salt and sand.

36. How would you separate a mixture of sugar and salt ?

37. How will you separate a mixture of sodium chloride and sand ?

38. Write a method to separate a mixture of sand and potash alum.

39. How would you obtain sodium chloride from a mixture of sodium chloride and sulphur without using water ?

40. How would you separate iodine from a mixture of iodine and common salt ?

41. Describe a method to separate a mixture of camphor and sand.

42. How will you separate a mixture of iron filings and powdered carbon ?

43. How will you separate a mixture of iron filings and sulphur powder without using carbon disulphide ?

44. How is scrap iron separated from a heap of waste materials in factories ?

45. How is the impurity of iron present in several substances removed in industries ?

46. How will you separate iron pins from sand ?

47. How will you separate a mixture of common salt, sulphur powder and sand ?

48. A mixture contains water, kerosene and sand. How will you separate this mixture ?

49. Describe the method of separating a mixture containing common salt, sand and ammonium chloride.

50. How will you separate camphor, common salt and iron nails from their mixture ?

51. You are given a mixture of water, groundnut oil and common salt. How will you separate groundnut oil and common salt from it ?

52. Discuss the method of separating a mixture containing chalk powder, iron filings and naphthalene.

53. Describe the various steps involved in the separation of iodine, iron filings and salt from a mixture.

54. How will you separate a mixture of iron filings, chalk powder and common salt ?

55. How will you separate common salt, sand and iron filings from their mixture ?

56. How will you separate a mixture of kerosene oil and water ? Explain with the help of a labelled diagram.

57. How will you separate water from mustard oil ?

58. How will you separate a mixture of cooking oil (groundnut oil) and water ?

59. How will you separate a mixture of mercury, oil and water ?

60. Describe a method for separating a mixture of iron filings and sulphur powder other than that by using a magnet.

61. How is cream separated from milk ?

62. Explain how, impure copper sulphate can be purified by crystallisation.

63. Which method is better for recovering sugar from sugar solution : evaporation or crystallisation ? Give reason for your answer.

64. What is chromatography ? State its two applications.

65. Which of the following can be separated by using a separating funnel and which cannot be separated by using a separating funnel ?

(*a*) water and kerosene mixture

(*b*) water and acetone mixture

Give reasons for your answer.

Long Answer Type Questions

66. With the help of a labelled diagram, describe the method of separating ammonium chloride from a mixture of ammonium chloride and common salt. Mention the difference in the properties of ammonium chloride and sodium chloride which has made this separation possible.

67. How can you obtain pure water from a salt-water mixture (or salt-solution) ? Draw a neat and labelled diagram of the apparatus you would use to obtain pure water from a salt-water mixture (or salt-solution).

68. How is water purified on a large scale at water works ? Explain with the help of a labelled diagram. Name the substance which is added to kill germs in the drinking water supply ?

69. (*a*) What is fractional distillation ? What is the use of fractionating column in fractional distillation ?
(*b*) Draw a labelled diagram of the fractional distillation apparatus used for separating a mixture of alcohol and water.

70. (*a*) Explain how, nitrogen, oxygen and argon gases are separated from air.
(*b*) Draw a flow diagram of the processes involved in obtaining gases like nitrogen, oxygen and argon from air.

Multiple Choice Questions (MCQs)

71. A mixture of milk and groundnut oil can be separated by :
(*a*) sublimation (*b*) evaporation (*c*) separating funnel (*d*) filtration

72. Which of the following mixture cannot be separated by using water as the solvent ?
(*a*) copper sulphate and sand (*b*) sand and potash alum
(*c*) sand and sulphur (*d*) sugar and sand

73. The chemical which can be used to separate a mixture of carbon powder and sulphur powder successfully is :
(*a*) carbon dioxide (*b*) hydrochloric acid (*c*) hydrogen sulphide (*d*) carbon disulphide

74. The dyes present in fountain pen ink can be separated by the technique of :
(*a*) fractional distillation (*b*) infrared photography (*c*) crystallisation (*d*) chromatography

75. Pure copper sulphate can be obtained from an impure sample by the process of :
(*a*) evaporation (*b*) fractional distillation (*c*) centrifugation (*d*) crystallisation

76. The material which is added to water during purification process at the water works so as to disinfect it is :
(*a*) potassium permanganate (*b*) betadine (*c*) chlorine (*d*) potash alum

77. The technique which is used to separate particles of a solid suspended in a liquid quickly is called :
(*a*) decantation (*b*) centrifugation (*c*) sedimentation (*d*) filtration

78. Naphthalene can be separated from sand :
(*a*) by sublimation (*b*) by distillation
(*c*) by crystallisation (*d*) by using water as solvent

79. Which of the following cannot be separated from air by the process of fractional distillation ?
(*a*) oxygen (*b*) argon (*c*) hydrogen (*d*) nitrogen

80. The correct increasing order of the boiling points of liquid oxygen, liquid argon and liquid nitrogen present in liquid air is :
(*a*) nitrogen, oxygen, argon (*b*) nitrogen, argon, oxygen
(*c*) argon, oxygen, nitrogen (*d*) oxygen, argon, nitrogen

81. The boiling point of liquid argon is :
(*a*) –196°C (*b*) –183°C (*c*) –186°C (*d*) –193°C

82. You are given a mixture of iodine in alcohol called tincture iodine. Which method will you use to recover both, iodine as well as alcohol, from this mixture ?
(*a*) evaporation (*b*) simple distillation (*c*) fractional distillation (*d*) crystallisation

83. The best way to recover sugar from an aqueous sugar solution is :
(*a*) evaporation to dryness (*b*) distillation (*c*) filtration (*d*) crystallisation

84. One of the following does not undergo sublimation. This one is :
(*a*) camphor (*b*) dry ice (*c*) silica (*d*) iodine

85. Which one of the following scrap metal cannot be separated by magnetic separation ?
(*a*) nickel (*b*) cobalt (*c*) chromium (*d*) steel

Questions Based on High Order Thinking Skills (HOTS)

86. The liquid air has three components X, Y and Z whose boiling points are : –186°C, –183°C and –196°C, respectively. When liquid air is fed into a tall fractional distillation column from near its bottom and warmed up slowly :
(*a*) Which component will be collected from near the bottom of the fraction distillation column ? Why ?
(*b*) Which component will be collected from the top part of the fractional distillation column ? Why ?
(*c*) Which component will be collected from the middle part of the fractional distillation column ? Why ?
(*d*) What could the component X, Y and Z be ?

87. There are three liquids A, B and C, all having different densities and different boiling points. Liquids A and C are organic in nature whereas liquid B is considered to be inorganic. When liquids A and B are put together in a container, they form a single layer. On the other hand, when, liquids B and C are mixed, they form two separate layers :
(*a*) Which process will you use to separate a mixture of A and B ?
(*b*) Which method will you use to separate a mixture of B and C ?
(*c*) Name the liquids which would behave like (*i*) A (*ii*) B and (*iii*) C.

88. A solid mixture contains four constituents P, Q, R and S. P consists of tiny grains and it is mixed with cement for plastering the walls. Q is a white solid which is recovered on a large scale from sea water by the process of evaporation. R is in the form of tiny particles of a material whose corrosion is called rusting. And S is a white solid which is used in making ordinary dry cells.
(*a*) What could P, Q, R and S be ?
(*b*) How would you separate a mixture containing P, Q, R and S ?

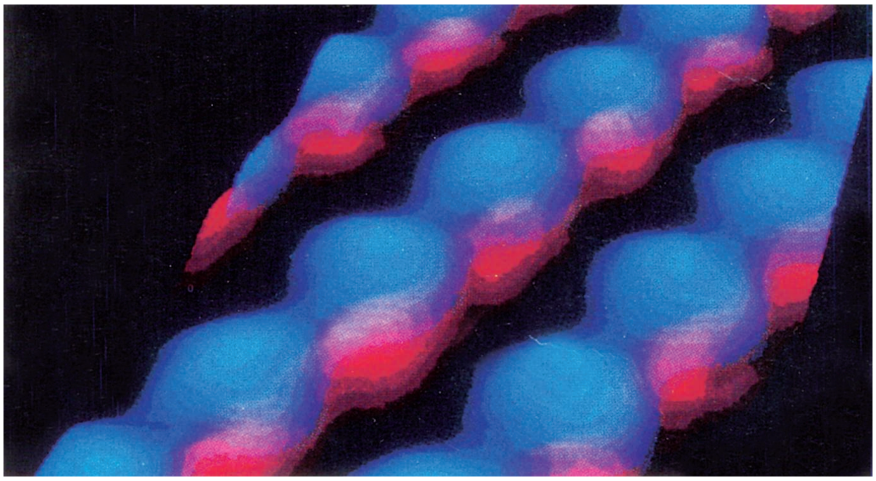
89. Tincture of iodine is a mixture of two materials X and Y. The material Y has a property that its solid form can be converted directly into vapours on heating by a process called Z.
(*a*) What could X be ?
(*b*) What could Y be ?
(*c*) Name the process Z.
(*d*) Which process would you use to recover both the components X and Y from tincture of iodine ?
(*e*) Which process can be used to recover only component Y from tincture of iodine ?

90. The given mixture contains three constituents A, B and C. The constituent A is a yellow coloured, solid element which dissolves in a liquid D. The constituent B is a blue coloured salt which is insoluble in liquid D but dissolves easily in another liquid E. The constitudent C is a liquid which is used in cooking food and forms a solid fat on hydrogenation.
(*a*) What do you think could (*i*) constituent A, and (*ii*) liquid D be ?
(*b*) What could (*i*) constituent B, and (*ii*) liquid E be ?
(*c*) What could liquid C be ?
(*d*) How will you separate the mixture containing A, B and C ?

ANSWERS

5. Camphor undergoes sublimation **9.** Different boiling points **10.** Alcohol and Water **11.** Oil and Water **12.** (*a*) False (*b*) False **13.** Air **16.** Ammonium chloride and Sodium chloride **17.** Salt and Water **23.** Filtration **29.** (*a*) Evaporation (*b*) Chromatography **32.** (*a*) fractional distillation (*b*) separating funnel (*c*) fractional distillation (*d*) boiling points (*e*) boiling points (*f*) centrifugation (*g*) magnet **39.** Use carbon disulphide to dissolve sulphur. Sodium chloride is insoluble in carbon disulphide. On filtering, sodium chloride is obtained as a residue **71.** (*c*) **72.** (*c*) **73.** (*d*) **74.** (*d*) **75.** (*d*) **76.** (*c*) **77.** (*b*) **78.** (*a*) **79.** (*c*) **80.** (*b*) **81.** (*c*) **82.** (*b*) **83.** (*d*) **84.** (*c*) **85.** (*c*) **86.** (*a*) Y ; It has the highest boiling point of, –183°C (*b*) Z ; It has the lowest boiling point of, –196°C (*c*) X ; It has a boiling point of, –186°C, which is lower than that of Y but higher than that of Z (*d*) X is liquid argon ; Y is liquid oxygen ; Z is liquid nitrogen **87.** (*a*) Fractional distillation (*b*) Separating funnel (*c*) (*i*) Alcohol (*ii*) Water (*iii*) Oil **88.** (*a*) P is sand ; Q is common salt ; R is iron filings ; S is ammonium chloride (*b*) First separate R (iron filings) by using a magnet to attract them. Then separate ammonium chloride by sublimation. Shake sand and common salt with water and filter. Sand obtained as residue. Evaporate filtrate to dryness to obtain common salt **89.** (*a*) Alcohol (*b*) Iodine (*c*) Sublimation (*d*) Distillation (*e*) Evaporation **90.** (*a*) (*i*) Sulphur (*ii*) Carbon disulphide (*b*) (*i*) Copper sulphate (*ii*) Water (*c*) Vegetable oil (*d*) Filter the mixture of A, B and C. C (oil) being liquid will be obtained as a filtrate. Residue consists of A (sulphur) and B (copper sulphate). Add water, shake and filter. A (sulphur) is obtained as residue. Evaporate filtrate to obtain B (copper sulphate).

3



ATOMS AND MOLECULES

Sugar, salt, sand, diamond, graphite, copper, silver, gold, iron, aluminium, wood, rocks, minerals, food and fabrics (clothes) are all different kinds of matter. Matter is called *'padarth'* in Hindi. An Indian philosopher, Maharishi Kanad, said that if we go on dividing matter (*padarth*), we will get smaller and smaller particles of matter. Ultimately, we will get the smallest particle of matter, which cannot be divided any further. Based on this philosophy, Kanad was one of the first persons to propose that matter (or *padarth*) is made up of very small particles called *'parmanu'*. John Dalton called these particles by the name of atom. The word 'atom' means 'indivisible'— something which cannot be divided further.

Another Indian philosopher Pakudha Katyayama went a step further and proposed that the particles of matter (atoms or *parmanu*) normally exist in a combined form and various combinations of particles give us various kinds of matter. This combined form of atoms is now called 'molecules'. We now know that **all matter is made up of small particles called atoms and molecules. Different kinds of atoms and molecules have different properties due to which different kinds of matter also show different properties.** Thus, the properties of matter depend on the properties of atoms and molecules from which it is made.

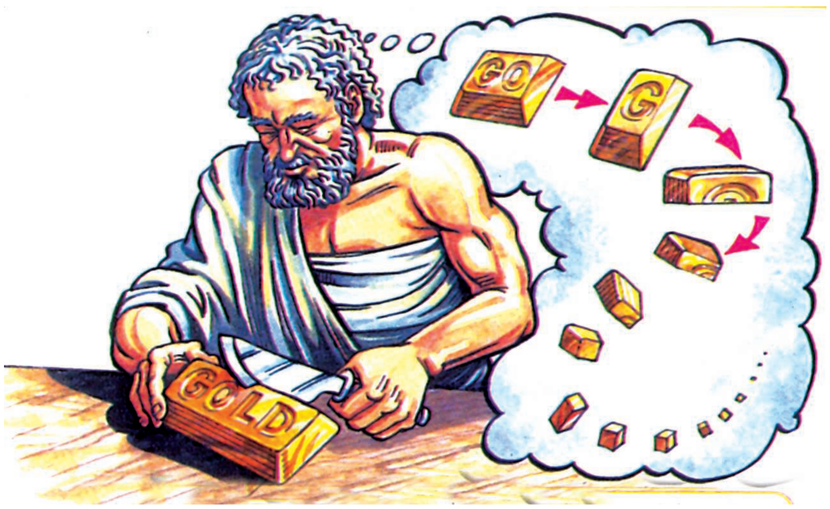


Figure 1. If somehow we could go on dividing matter (say, a gold brick as shown above), we will get smaller and smaller particles. Ultimately we will get the smallest particle of matter which cannot be divided any further. This smallest particle of matter will be atom (or *parmanu*).

We will now describe the laws of chemical combination (established by experiments) which confirmed the idea of atoms being the smallest particles of matter.

LAWS OF CHEMICAL COMBINATION

There are three important laws of chemical combination. These are :

1. Law of conservation of mass (or matter),

2. Law of constant proportions, and

3. Law of multiple proportions.

The laws of chemical combination are the experimental laws which have been formulated by scientists after performing a large number of experiments involving various types of chemical reactions. These experimental laws ultimately led to the idea of 'atoms' being the 'smallest unit' of matter. In fact, the laws of chemical combination played a significant role in the development of Dalton's atomic theory of matter. In this class we will study only two laws of chemical combination : the law of conservation of mass, and the law of constant proportions. The third law of chemical combination, the law of multiple proportions, will be studied in higher classes.

LAW OF CONSERVATION OF MASS

In the 18th century, scientists noticed that if they carried out a chemical reaction in a closed container, then there was no change of mass. This preservation of mass in a chemical reaction led to the formulation of the law of conservation of mass (or law of conservation of matter). Law of conservation of mass was given by Lavoisier in 1774. According to the law of conservation of mass : **Matter is neither created nor destroyed in a chemical reaction.** The substances which combine together (or react) in a chemical reaction are known as 'reactants' whereas the new substances formed (or produced) as a result of chemical reaction are called 'products'. **The law of conservation of mass means that in a chemical reaction, the total mass of products is equal to the total mass of reactants. There is no change in mass during a chemical reaction.** Since there is no gain or loss in mass in a chemical reaction, the mass remains conserved. Please note that the term 'total mass' of reactants and products includes solids, liquids and gases – including air – that are a part of the reaction. The law of conservation of mass will become clear from the following example.

Figure 2. Antoine Lavoisier : The scientist who gave the law of conservation of mass in chemical reactions.

When calcium carbonate is heated, a chemical reaction takes place to form calcium oxide and carbon dioxide. **It has been found by experiments that if 100 grams of calcium carbonate are decomposed completely then 56 grams of calcium oxide and 44 grams of carbon dioxide are formed.** This can be written as :

$$\underset{100\text{ g}}{\text{Calcium carbonate}} \xrightarrow[\text{(Chemical reaction)}]{\text{Heat}} \underbrace{\underset{56\text{ g}}{\text{Calcium oxide}} + \underset{44\text{ g}}{\text{Carbon dioxide}}}_{56\,+\,44\,=\,100\text{ g}}$$

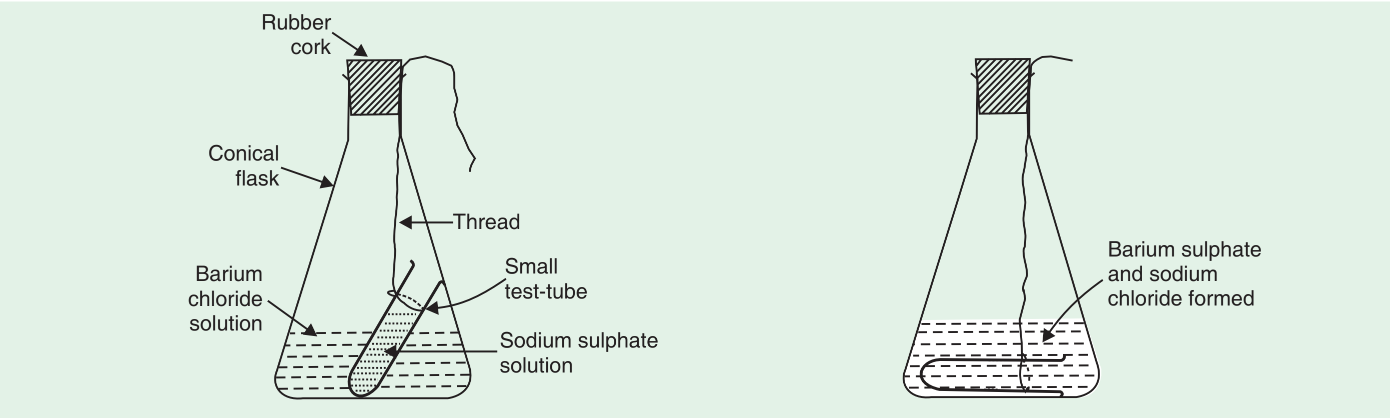
In this example, calcium carbonate is the reactant and it has a mass of 100 g. Calcium oxide and carbon dioxide are the products and they have a total mass of 56 g + 44 g = 100 g. Now, **since the total mass of products (100 g) is equal to the total mass of reactant (100 g), there is no change of mass during this chemical reaction. The mass remains the same or conserved.** So, this example supports the law of conservation of mass.

We can verify the law of conservation of mass in the laboratory by taking known masses of two chemicals (reactants), allowing them to react by mixing them, and then finding the masses of the products formed. There should be no change in the mass. This will become more clear from the following experiment in which we will carry out a chemical reaction between barium chloride and sodium sulphate to form barium sulphate and sodium chloride.

Experiment to Verify Law of Conservation of Mass

Take a clean conical flask fitted with a rubber cork, and a small test-tube having a long thread tied to its neck. All these things are weighed together on a sensitive balance to find the initial mass of this apparatus. Let us perform the experiment now.

(*i*) Take some barium chloride solution in the conical flask. Put some sodium sulphate solution in the small test-tube and lower it carefully in the conical flask by holding from the free end of thread tied to its neck. Fix a rubber cork in the mouth of the flask so that it holds the thread firmly [see Figure 3(*a*)]. The mouth of the small test-tube should remain above the liquid level in the flask so that the reactants do not get mixed at this stage. Find the mass of the apparatus alongwith reactants by weighing on the balance. If we subtract the initial mass of apparatus from this mass, we will get the mass of reactants. Let the mass of reactants be x.



(*a*) Before reaction (*b*) After reaction

Figure 3. Experiment to verify the law of conservation of mass.

(*ii*) Remove the rubber cork from the mouth of conical flask for a moment so that the thread becomes loose. The small test-tube containing sodium sulphate solution now drops in the flask due to which sodium sulphate solution mixes with barium chloride solution [see Figure 3(*b*)]. Now, barium chloride solution reacts with sodium sulphate solution to form a white precipitate of barium sulphate, and sodium chloride solution. We again find the mass of the apparatus alongwith products by weighing on a balance. If we subtract the initial mass of the apparatus from this mass, we will get the mass of products. Suppose the mass of products is y, Now, if the mass of products (y) is equal to the mass of reactants (x), then this experiment verifies the law of conservation of mass.

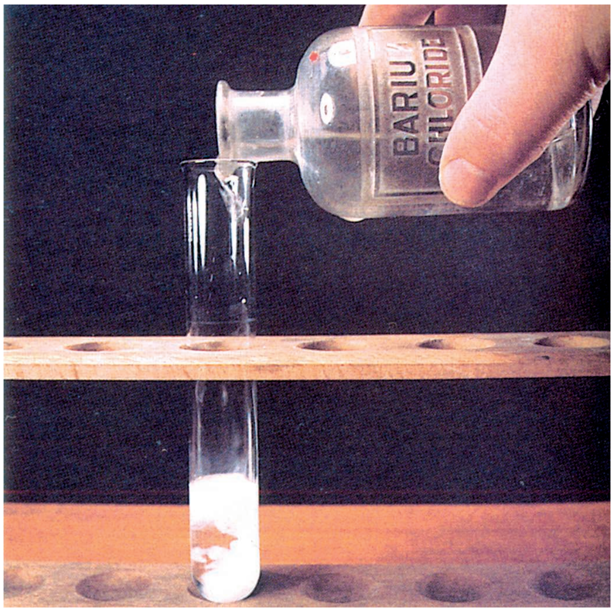


Figure 4. When barium chloride solution is added to sodium sulphate solution, then a chemical reaction takes place in which a white precipitate of barium sulphate and sodium chloride solution are formed.

The chemical reaction taking place in the above experiment can be written as :

$$\underset{\text{(solution)}}{\text{Barium chloride}} + \underset{\text{(solution)}}{\text{Sodium sulphate}} \rightarrow \underset{\text{(white solid)}}{\text{Barium sulphate}} + \underset{\text{(solution)}}{\text{Sodium chloride}}$$

In an experiment to verify the law of conservation of mass, the following data was obtained :

(*i*) Mass of barium chloride taken = 20.8 g
(*ii*) Mass of sodium sulphate taken = 14.2 g
(*iii*) Mass of barium sulphate formed = 23.3 g
(*iv*) Mass of sodium chloride formed = 11.7 g

In this case, barium chloride and sodium sulphate are reactants.

So, Mass of reactants = 20.8 g + 14.2 g
= 35.0 g ... (1)

Here, barium sulphate and sodium chloride are products.

So, Mass of products = 23.3 g + 11.7 g
= 35.0 g ... (2)

Since the total mass of products (35 g) in this chemical reaction is equal to the total mass of reactants (35 g), therefore, the given data verifies the law of conservation of mass. Let us solve some problems now.

Sample Problem 1. Sodium carbonate reacts with ethanoic acid to form sodium ethanoate, carbon dioxide and water. In an experiment, 5.3 g of sodium carbonate reacted with 6 g of ethanoic acid to form 8.2 g of sodium ethanoate, 2.2 g of carbon dioxide and 0.9 g of water. Show that this data verifies the law of conservation of mass. **(NCERT Book Question)**

Solution. All that we have to do in this problem is to calculate the mass of reactants and products separately, and then compare the two. If the two masses are equal, then the law of conservation of mass gets verified. The given reaction can be written as :

$$\underbrace{\text{Sodium carbonate} + \text{Ethanoic acid}}_{\text{Reactants}} \longrightarrow \underbrace{\text{Sodium ethanoate} + \text{Carbon dioxide} + \text{Water}}_{\text{Products}}$$

(*i*) Sodium carbonate and ethanoic acid are reactants.

So, Mass of reactants = Mass of sodium carbonate + Mass of ethanoic acid
= 5.3 + 6
= 11.3 g ... (1)

(*ii*) Sodium ethanoate, carbon dioxide and water are products.

So, Mass of products = Mass of sodium ethanoate + Mass of carbon dioxide + Mass of water
= 8.2 + 2.2 + 0.9
= 11.3 g ... (2)

We find that the mass of reactants is 11.3 g and the mass of products is also 11.3 g. Since the mass of products is equal to the mass of reactants, the given data verifies the law of conservation of mass.

Sample Problem 2. Calcium carbonate decomposes, on heating, to form calcium oxide and carbon dioxide. When 10 g of calcium carbonate is decomposed completely, then 5.6 g of calcium oxide is formed. Calculate the mass of carbon dioxide formed. Which law of chemical combination will you use in solving this problem ?

Solution. This problem is to be solved by using the law of conservation of mass in chemical reactions. In this reaction, calcium carbonate is the reactant whereas calcium oxide and carbon dioxide are products. Now, from the law of conservation of mass we have :

$$\text{Mass of products} = \text{Mass of reactants}$$

or $\quad$ Mass of calcium oxide + Mass of carbon dioxide = Mass of calcium carbonate

So, $\quad$ 5.6 + Mass of carbon dioxide = 10

And, $\quad$ Mass of carbon dioxide = 10 – 5.6

= 4.4 g

Thus, the mass of carbon dioxide formed is 4.4 g.

LAW OF CONSTANT PROPORTIONS

Figure 5. Joseph Proust : The scientist who gave the law of constant proportions in chemical combinations.

The law of constant proportions was given by Proust in 1779. He analysed the chemical composition (type of elements present and percentage of elements present) of a large number of compounds and came to the conclusion that the proportion of each element in a compound is constant (or fixed). Based on these observations, Proust formulated the law of constant proportions. According to the law of constant proportions : **A chemical compound always consists of the same elements combined together in the same proportion by mass.** This law means that whatever be the source from which it is obtained (or the method by which it is prepared), a pure chemical compound is always made up of the same elements in the same mass percentage. For example, water is a compound which always consists of the same two elements, hydrogen and oxygen, combined together in the same constant proportion of 1 : 8 by mass (1 part by mass of hydrogen and 8 parts by mass of oxygen). Let us discuss this in a little more detail.

Figure 6. A student carrying out the electrolysis of water (by passing electric current through it) so as to decompose it into its two constituent elements : hydrogen and oxygen.

We know that water is a compound. If we decompose 100 grams of pure water by passing electricity through it, then 11 grams of hydrogen and 89 grams of oxygen are obtained. Now, if we repeat this experiment by taking pure water from different sources (like river, sea, well, etc.), the same masses of hydrogen and oxygen elements are obtained in every case. This experiment shows that water always consists of the same two elements, hydrogen and oxygen, combined together in the same constant proportion of 11 : 89 or 1 : 8 by mass. And this is the law of constant proportions.

Let us take another example to illustrate the law of constant proportions. Ammonia is a compound. It has been found by analysis that ammonia always consists of the same two elements, nitrogen and hydrogen, combined together in the same ratio of 14 : 3 by mass.

Please note that the law of constant proportions is also known as the law of definite proportions or the law of constant composition. We will now solve some problems based on the law of constant proportions.

Sample Problem 1. In an experiment, 1.288 g of copper oxide was obtained from 1.03 g of copper. In another experiment, 3.672 g of copper oxide gave, on reduction, 2.938 g of copper. Show that these figures verify the law of constant proportions.

Solution. In order to solve this problem we have to calculate the ratio (or proportion) of copper and oxygen in the two samples of copper oxide compound. Now :

(*a*) In the first experiment :

Mass of copper = 1.03 g ... (1)

And, Mass of copper oxide = 1.288 g

So, Mass of oxygen = Mass of copper oxide – Mass of copper

= 1.288 – 1.03

= 0.258 g ... (2)

Now, in the first sample of copper oxide compound :

Mass of copper : Mass of oxygen = 1.03 : 0.258

$= \frac{1.03}{0.258} : 1$

= 3.99 : 1

= 4 : 1 ... (3)

(*b*) In the second experiment :

Mass of copper = 2.938 g ... (4)

And, Mass of copper oxide = 3.672 g

So, Mass of oxygen = Mass of copper oxide – Mass of copper

= 3.672 – 2.938

= 0.734 g ... (5)

Now, in the second sample of copper oxide compound :

Mass of copper : Mass of oxygen = 2.938 : 0.734

$= \frac{2.938}{0.734} : 1$

= 4 : 1 ... (6)

From the above calculations we can see that the ratio (or proportion) of copper and oxygen elements in the two samples of copper oxide compound is the same 4 : 1. So, the given figures verify the law of constant proportions.

Sample Problem 2. Hydrogen and oxygen combine in the ratio of 1 : 8 by mass to form water. What mass of oxygen gas would be required to react completely with 3 g of hydrogen gas ?

(NCERT Book Question)

Solution. Here we have been given that hydrogen and oxygen always combine in the fixed ratio of 1 : 8 by mass. This means that :

1 g of hydrogen gas requires = 8 g of oxygen gas

So, 3 g of hydrogen gas requires = 8 × 3 g of oxygen gas

= 24 g of oxygen gas

Thus, 24 grams of oxygen gas would be required to react completely with 3 grams of hydrogen gas.

Sample Problem 3. When 3 g of carbon is burnt in 8 g of oxygen, 11 g of carbon dioxide is produced. What mass of carbon dioxide will be formed when 3 g of carbon is burnt in 50 g of oxygen ? Which law of chemical combination will govern your answer ? **(NCERT Book Question)**

Solution. Our answer will be governed by the law of constant proportions. Now, since carbon and oxygen combine in the fixed proportion of 3 : 8 by mass to produce 11 g of carbon dioxide, therefore, the same mass of carbon dioxide (11 g) will be obtained even if we burn 3 g of carbon in 50 g of oxygen. The extra oxygen (50 – 8 = 42 g oxygen) will remain unreacted.

Sample Problem 4. A 0.24 g sample of compound of oxygen and boron was found by analysis to contain 0.096 g of boron and 0.144 g of oxygen. Calculate the percentage composition of the compound by mass. **(NCERT Book Question)**

Figure 7. This is boron oxide. It is a compound of boron and oxygen.

Solution. (*i*) Mass of boron in compound = 0.096 g

And, Mass of compound = 0.24 g

So, Percentage of boron (in compound) $= \dfrac{\text{Mass of boron in compound}}{\text{Mass of compound}} \times 100$

$= \dfrac{0.096}{0.24} \times 100$

$= 40$ ... (1)

(*ii*) Mass of oxygen in compound = 0.144 g

And, Mass of compound = 0.24 g

So, Percentage of oxygen (in compound) $= \dfrac{\text{Mass of oxygen in compound}}{\text{Mass of compound}} \times 100$

$= \dfrac{0.144}{0.24} \times 100$

$= 60$ ... (2)

Thus, the percentage composition of the compound is : Boron = 40 %; Oxygen = 60 %.

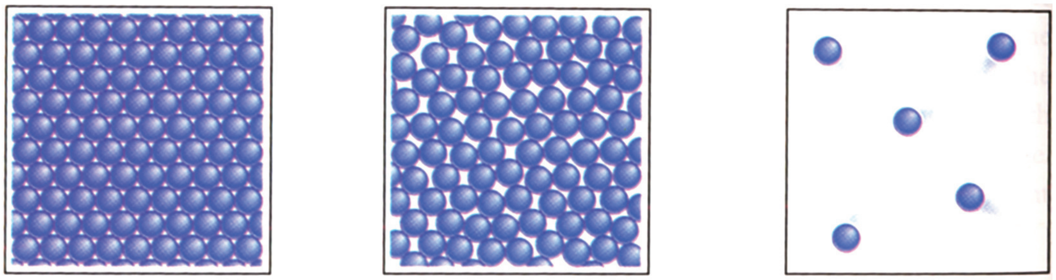
The laws of chemical combination were the experimental laws. **The only logical explanation of the laws of chemical combination is that matter (say, elements) must be made up of minute 'unit particles', which take part in chemical combination in fixed whole numbers. These 'unit particles' of matter were called atoms.** So, in an attempt to explain the laws of chemical combination, Dalton put forward his atomic theory of matter. This is discussed below.

DALTON'S ATOMIC THEORY

The theory that 'all matter is made up of very tiny indivisible particles (atoms)' is called atomic theory of matter. Dalton put forward his atomic theory of matter in 1808. The various postulates (or assumptions) of Dalton's atomic theory of matter are as follows :

1. All the matter is made up of very small particles called 'atoms'.
2. Atoms cannot be divided.
3. Atoms can neither be created nor destroyed.
4. Atoms are of various kinds. There are as many kinds of atoms as are elements.
5. All the atoms of a given element are identical in every respect, having the same mass, size and chemical properties.
6. Atoms of different elements differ in mass, size and chemical properties.
7. Chemical combination between two (or more) elements consists in the joining together of atoms of these elements to form molecules of compounds.

8. The 'number' and 'kind' of atoms in a given compound is fixed.
9. During chemical combination, atoms of different elements combine in small whole numbers to form compounds.
10. Atoms of the same elements can combine in more than one ratio to form more than one compound.



(*a*) Particles in a solid (*b*) Particles in a liquid (*b*) Particles in a gas

Figure 8. According to Dalton's atomic theory, all matter (whether a solid, liquid or a gas) is made of very tiny particles called 'atoms'.

Dalton's atomic theory was based on the laws of chemical combination. For example, the postulate of Dalton's atomic theory that "atoms can neither be created nor destroyed" was the result of law of conservation of mass given by Lavoisier. And the postulates of Dalton's atomic theory that "the elements consist of atoms having fixed mass, and that the number and kind of atoms in a given compound is fixed," came from the law of constant proportions given by Proust.

Dalton's atomic theory was the first modern attempt to describe the behaviour of matter (or properties of matter) in terms of atoms. This theory was also used to explain the laws of chemical combination in terms of atoms. Dalton's atomic theory provides a simple explanation for the laws of chemical combination.

(*a*) The postulates of Dalton's atomic theory that "the elements consist of atoms and that atoms can neither be created nor destroyed" can be used to explain the law of conservation of mass.

(*b*) The postulates of Dalton's atomic theory that "the elements consist of atoms having fixed mass, and that the number and kind of atoms of each element in a given compound is fixed" can be used to explain the law of constant proportions.

Explanation of the Law of Conservation of Mass

According to Dalton's atomic theory, atoms can neither be created nor destroyed. Now, since an atom cannot be created or destroyed, therefore, the number of various types of atoms in the products of a chemical reaction is the same as the number of all those atoms in the reactants. The same number of various atoms in products and reactants will have the same mass. So, the total mass of products is equal to the total mass of reactants. The mass remains the same (or conserved) in a chemical reaction. And this is the law of conservation of mass. This explanation will become more clear from the following example of calcium carbonate.

Figure 9. This is calcium carbonate ($CaCO_3$). On strong heating, calcium carbonate decomposes to form calcium oxide (CaO) and carbon dioxide (CO_2).

Calcium carbonate ($CaCO_3$) is made up of 1 calcium atom, 1 carbon atom and 3 oxygen atoms. The products of its decomposition, calcium oxide (CaO) and carbon dioxide (CO_2), taken together, also contain 1 calcium atom, 1 carbon atom and 3 oxygen atoms. Now, since the number of various types of atoms in the products (CaO and CO_2) and reactant ($CaCO_3$) remains the same, therefore, the mass of products and reactants also remains the same in this reaction. There is no change in mass during the decomposition of calcium carbonate to form calcium oxide and carbon dioxide. The mass remains conserved.

Explanation of the Law of Constant Proportions

According to Dalton's atomic theory, every element consists of small particles called atoms, each having a fixed mass. It also says that atoms of different elements combine to form compounds, and that the ''number'' and ''kind'' of atoms of each element in a compound is fixed. Now, since the ''number of atoms'', the "kind of atoms'', and the ''mass of atoms'' of each element in a given compound is fixed, therefore, a compound will always have the same elements combined together in the same proportion by mass. And this is the law of constant proportions. This explanation will become more clear from the following example of water.

According to Dalton's atomic theory, hydrogen element consists of hydrogen atoms (H), and oxygen element consists of oxygen atoms (O). It also says that two hydrogen atoms always combine with one oxygen atom to form water molecule (H_2O). Since a water molecule always contains the same number of hydrogen and oxygen atoms, each atom having a fixed mass, therefore, the masses of hydrogen and oxygen elements in water will be in constant proportion. And this is the law of constant proportions.

Drawbacks of Dalton's Atomic Theory

It is now known that some of the statements of Dalton's atomic theory of matter are not exactly correct. Some of the drawbacks of the Dalton's atomic theory of matter are given below :

1. One of the major drawbacks of Dalton's atomic theory of matter is that atoms were thought to be indivisible (which cannot be divided). We now know that **under special circumstances, atoms can be further divided into still smaller particles called electrons, protons and neutrons.** So, atoms are themselves made up of three particles : electrons, protons and neutrons.
2. Dalton's atomic theory says that all the atoms of an element have exactly the same mass. It is, however, now known that **atoms of the same element can have slightly different masses.**
3. Dalton's atomic theory said that atoms of different elements have different masses. It is, however, now known that **even atoms of different elements can have the same mass.**

John Dalton

John Dalton was born in 1766 in a poor weaver's family in England. He received his early education from his father and at the village school. Dalton started teaching in the village at the age of 12. In 1793, Dalton left for Manchester to teach physics, chemistry and mathematics in a college. In 1794, he described colour blindness. In 1808, Dalton presented his atomic theory to explain the properties of matter. Dalton's atomic theory of matter became one of the foundations of modern chemistry. Dalton was the first to calculate the masses of the atoms of several elements. He died in 1844.

Figure 10. John Dalton : The scientist who gave atomic theory of matter.

ATOMS

Just as all the houses are made up of bricks, in the same way, all the matter is made up of atoms. Thus, atoms are the building blocks of all the matter around us. In chemistry, atom is defined as follows : **An atom is the smallest particle of an element that can take part in a chemical reaction.** Atoms of most of the elements are very reactive and do not exist in the free state (as single atoms). They exist in combination with the atoms of the same element or another element. There are as many kinds of atoms as are elements.

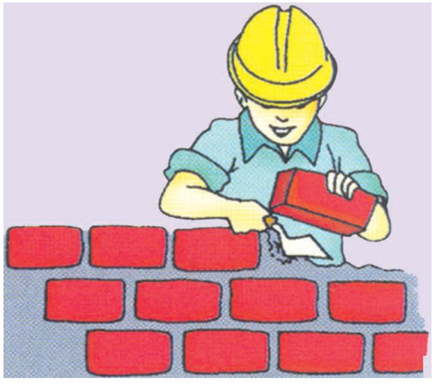


Figure 11. Just as bricks are the building blocks of all the houses, atoms are the building blocks of all matter.

Atoms are very, very small in size. An idea of the extremely small size of atoms can be had from the fact that 35,000,000 copper atoms arranged end to end in a line would cover a distance of about

1 centimetre ! **The size of an atom is indicated by its radius which is called 'atomic radius'** (radius of atom). **Atomic radius is measured in 'nanometres'** (which is a very, very small unit of measuring length). The symbol of a nanometre is **nm.**

$$1 \text{ nanometre} = \frac{1}{10^9} \text{ metre}$$

or $$1 \text{ nm} = \frac{1}{10^9} \text{ m}$$

or $$1 \text{ nm} = 10^{-9} \text{ m}$$

Hydrogen atom is the smallest atom of all. The atomic radius of a hydrogen atom is 0.037 nanometre (or 0.037 nm). If we express the radius of a hydrogen atom in metres, it will be 0.037×10^{-9} metre which means 0.000000000037 metre ! It is really very, very small. The atomic radii of some of the common elements are given below (Please note that 'radii' is the plural of radius).

Atomic Radii of Some Common Elements

Element	*Atomic radius (Radius of atom)*	*Element*	*Atomic radius (Radius of atom)*
1. Hydrogen	0.037 nm	7. Sodium	0.191 nm
2. Carbon	0.077 nm	8. Magnesium	0.160 nm
3. Nitrogen	0.074 nm	9. Calcium	0.197 nm
4. Oxygen	0.073 nm	10. Iron	0.126 nm
5. Chlorine	0.099 nm	11. Copper	0.128 nm
6. Sulphur	0.104 nm	12. Gold	0.144 nm

Atoms are so small that we cannot see them even under the most powerful optical microscope. Electron microscope (which uses electrons for its working) can produce extremely magnified images of tiny objects. The most advanced type of electron microscope is the Scanning Tunnelling Microscope (STM). Scanning tunnelling microscope can produce computer-generated images (pictures) of the surface of elements which show the individual atoms. The atoms show up as blurred spheres (see Figure 12). Thus, **the scanning tunnelling microscope enables us to see atoms, though indirectly.**

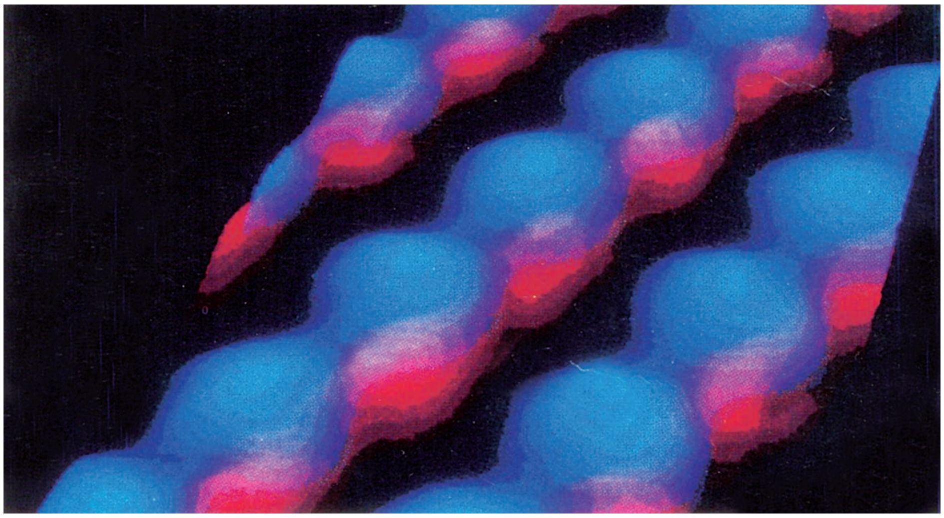


Figure 12. Individual atoms can be seen as bumps on the surface of a solid by using a Scanning Tunnelling Microscope (STM). The picture above is an STM image of the surface of a solid substance called gallium arsenide made up of gallium atoms and arsenic atoms. The blurred spheres in this picture are 'atoms'. The gallium atoms are shown in blue colour and arsenic atoms in red colour (these are not their actual colours).

SYMBOLS OF ELEMENTS

A 'symbol' is a thing (like a 'sketch' or 'letter', etc.) which represents or stands for something else. When we say 'the symbols of elements', it means 'the symbols of the atoms of the elements' (because elements are made up of atoms). We will first discuss the Dalton's symbols of elements and then the modern symbols of elements.

Dalton's Symbols of Elements

Dalton was the first scientist to use the symbols to represent elements in a short way. Dalton's symbol for an element represented the 'element' as well as 'one atom' of that element. Some of the symbols of elements given by Dalton are shown below :

Element	*Dalton's symbol*	*Element*	*Dalton's symbol*
Hydrogen	⊙	Iron	Ⓘ
Carbon	●	Copper	Ⓒ
Oxygen	○	Silver	Ⓢ
Phosphorus		Gold	Ⓖ
Sulphur	⊕	Lead	Ⓛ
Platinum	Ⓟ	Mercury	

Dalton's symbols for elements were difficult to draw and inconvenient to use. So, Dalton's symbols are only of historical importance. They are not used at all. **It was J.J. Berzelius of Sweden who proposed that the first letter (or the first letter and another letter) of the name of an element be used as its symbol.** This idea led to the modern symbols of elements which are described below.

Figure 13. Jons Jakob Berzelius : The scientist who proposed the first letter (or first letter and another letter) of the name of an element as its symbol.

Modern Symbols of Elements

In order to write the chemical reactions conveniently, each element is represented by a separate symbol. **The symbol of an element is the "first letter" or the "first letter and another letter" of the English name or Latin name of the element.** For example,

The symbol of Hydrogen is H (First letter of name)

The symbol of Oxygen is O (First letter of name)

So, in the case of hydrogen and oxygen, the first letters of their English names are taken as their symbols. There are, however, some elements whose names begin with the same letter. For example, the names of elements Carbon, Calcium, Chlorine and Copper, all begin with the same letter C. In such cases, one of the elements is given a "one letter" symbol but all other elements are given "two letter" symbols. The "two letters" are the "first letter" and "another letter" of the English name or Latin name of the element. Please note that this "another letter" may or may not be the "second letter" of the name. Thus,

The symbol of Carbon is C (First letter of name)
The symbol of Calcium is Ca (First and second letter of name)
The symbol of Chlorine is Cl (First and third letter of name)
The symbol of Copper is Cu (First and second letter of its Latin name Cuprum)

It should be noted that in a 'two letter' symbol, the first letter is the 'capital letter' but the second letter is the 'small letter'. The chemical symbols of some of the important elements derived from their English names are given below :

Symbols Derived from English Names of the Elements

English name of the element	*Symbol*	*English name of the element*	*Symbol*
1. Hydrogen	H	14. Sulphur	S
2. Helium	He	15. Chlorine	Cl
3. Lithium	Li	16. Argon	Ar
4. Boron	B	17. Calcium	Ca
5. Carbon	C	18. Manganese	Mn
6. Nitrogen	N	19. Nickel	Ni
7. Oxygen	O	20. Zinc	Zn
8. Fluorine	F	21. Bromine	Br
9. Neon	Ne	22. Krypton	Kr
10. Magnesium	Mg	23. Iodine	I
11. Aluminium	Al	24. Barium	Ba
12. Silicon	Si	25. Cobalt	Co
13. Phosphorus	P	26. Uranium	U

Figure 14. This is calcium element. The symbol of calcium is Ca (which has been derived from its English name 'Calcium').

Figure 15. This is sodium element. The symbol of sodium is Na (which has been derived from its Latin name 'Natrium').

Figure 16. This is potassium element. The symbol of potassium is K (which has been derived from its Latin name 'Kalium').

In our study of chemistry we use the English names of the elements, so we are not familiar with the Latin names of the elements. **Most of the confusion, therefore, arises in the symbols derived from the Latin names of the elements.** Please note the following symbols carefully and try to remember them correctly, they have been derived from the Latin names of the elements.

Symbols Derived from Latin Names of the Elements

English name of the element	*Symbol*	*Latin name of the element*
1. Sodium	Na	Natrium
2. Potassium	K	Kalium
3. Iron	Fe	Ferrum
4. Copper	Cu	Cuprum
5. Silver	Ag	Argentum
6. Gold	Au	Aurum
7. Mercury	Hg	Hydragyrum
8. Lead	Pb	Plumbum
9. Tin	Sn	Stannum

Figure 17. This is lead. It is an element which is classified as a metal. The symbol of lead is Pb which is derived from its Latin name Plumbum. Lead is a metal having very high density (11.35 kg/m^3).

Figure 18. The very high density of lead enables it to stop dangerous radiations from radioactive materials. The staff working in the X-ray departments of hospitals and in laboratories where radioactive materials are handled, wear jackets containing lead to protect them (from the harmful effects of radiations).

These days, the names and symbols of all newly discovered elements are approved by the International Union of Pure and Applied Chemistry (IUPAC).

ATOMIC MASS OF AN ELEMENT

Actual masses of the atoms of the elements are very, very small. For example, one atom of hydrogen (H) has a mass of 1.673×10^{-24} gram or 0.000000000000000000000001673 gram. It is not convenient to use such small and complicated figures in our calculations, therefore, it was necessary to define atomic masses in such a way that we get simple figures for them. In order to understand the present definition of atomic mass, we should first know the meaning of carbon-12 atom (read as carbon twelve atom). **Carbon-12 atom is that atom of carbon which has 6 protons and 6 neutrons in its nucleus so that its mass number is 12.**

Carbon-12 atom has been assigned an atomic mass of exactly 12 atomic mass units (Atomic mass unit was earlier written in short as 'amu' but these days atomic mass unit is denoted by the letter 'u'). This means that a carbon-12 atom has been assigned an atomic mass of exactly 12 u. Now, since a carbon-12 atom has been assigned an atomic mass of 12 atomic mass units, therefore, the atomic mass unit should be equal to $\frac{1}{12}$ (one-twelfth) the mass of a carbon-12 atom. That is :

$$\textbf{Atomic mass unit} = \frac{\mathbf{1}}{\mathbf{12}} \textbf{ the mass of a carbon-12 atom}$$

$$\text{or} \qquad 1\text{ u} = \frac{1}{12} \text{ the mass of a carbon-12 atom}$$

Thus, **one atomic mass unit (1 u) is defined as exactly one-twelfth the mass of an atom of carbon-12.** It is clear from this discussion that for the purpose of determining atomic masses of various elements, the mass of a carbon-12 atom is taken to be the standard (having a value of 12 units on the atomic mass scale). **The atomic masses of all other elements are determined by comparing the mass of their atom with the mass of a carbon-12 atom.** Keeping these points in mind, we can now define the atomic mass of an element as follows.

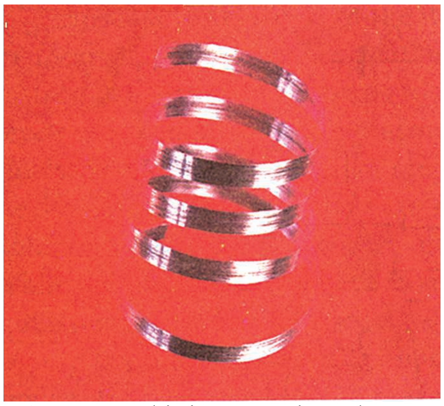


Figure 19. This is magnesium element (or magnesium metal) in the form of a ribbon. One atom of magnesium is 24 times heavier than $\frac{1}{12}$ of a carbon-12 atom, so the atomic mass of magnesium is 24 u.

The atomic mass of an element is the relative mass of its atom as compared with the mass of a carbon-12 atom taken as 12 units. The atomic mass of an element indicates the number of times one atom of the element is heavier than $\frac{1}{12}$ of a carbon-12 atom. For example, the atomic mass of magnesium is 24 u which indicates that one atom of magnesium is 24 times heavier than $\frac{1}{12}$ of a carbon-12 atom. It is clear from the above discussion that **the present standard for the atomic masses is carbon-12 atom which has been assigned an atomic mass of exactly 12 u.** The atomic masses of some of the important elements are given below.

Atomic Masses of Some Common Elements

Element	*Symbol*	*Atomic mass*	*Element*	*Symbol*	*Atomic mass*
1. Hydrogen	H	1 u	8. Phosphorus	P	31 u
2. Carbon	C	12 u	9. Sulphur	S	32 u
3. Nitrogen	N	14 u	10. Chlorine	Cl	35.5 u
4. Oxygen	O	16 u	11. Potassium	K	39 u
5. Sodium	Na	23 u	12. Calcium	Ca	40 u
6. Magnesium	Mg	24 u	13. Iron	Fe	56 u
7. Aluminium	Al	27 u	14. Copper	Cu	63.5 u

It has been found by experiments that the mass of a carbon-12 atom is 1.9926×10^{-23} gram. If we divide this mass by 12, we will get the absolute mass of the atomic mass unit (u). It comes to be 1.6605×10^{-24} gram. This means that the actual mass of the atomic mass unit is 1.6605×10^{-24} gram.

That is, $1 \text{ u} = 1.6605 \times 10^{-24}$ g

By using this value of atomic mass unit, we can find the actual mass (or absolute mass) of the atom of any element. Before we end this discussion, it will be good to note the significance of the chemical symbol of an element which is given below.

Significance of the Symbol of an Element

1. Symbol represents name of the element.
2. Symbol represents one atom of the element.
3. Symbol also represents one mole of atoms of the element. That is, symbol also represents 6.022×10^{23} atoms of the element.
4. Symbol represents a definite mass of the element (equal to atomic mass expressed in grams).

As an example, let us give the significance of symbol C

1. Symbol C represents carbon element.
2. Symbol C represents one atom of carbon element.
3. Symbol C also represents one mole of carbon atoms. That is, symbol C also represents 6.022×10^{23} atoms of carbon.
4. Symbol C represents 12 grams of carbon (which is equal to the atomic mass of carbon expressed in grams).

HOW DO ATOMS EXIST

The atoms of only a few elements called noble gases (such as helium neon, argon and krypton, etc.) are chemically unreactive and exist in the free state (as single atoms). Atoms of most of the elements are chemically very reactive and do not exist in the free state (as single atoms). **Atoms usually exist in two ways :**

1. in the form of molecules, and

2. in the form of ions.

When atoms form molecules or ions, they become stable (because in doing so they acquire the stable electron arrangements of noble gases). The molecules and ions stick together in large numbers to form the various types of matter around us. Though we cannot see the individual molecules or ions with our eyes, we can, however, see the various substances which are a big collection of molecules or ions. For example, we cannot see the individual iodine molecules (I_2) with our eyes because they are very, very small but we can see iodine crystal as a violet coloured solid because it is a collection of millions and millions of iodine molecules held together. Similarly, we cannot see the individual sodium ions (Na^+) and chloride ions (Cl^-) but we can see the sodium chloride compound (common salt) as a white powder because it is formed by the collection of millions and millions of sodium ions and chloride ions. We will now discuss the molecules and ions in detail, one by one.

Figure 20. This is iodine crystal which is made up of iodine molecules. We cannot see the individual iodine molecules because they are very, very small. We can, however, see this iodine crystal because it is a collection of millions and millions of iodine molecules.

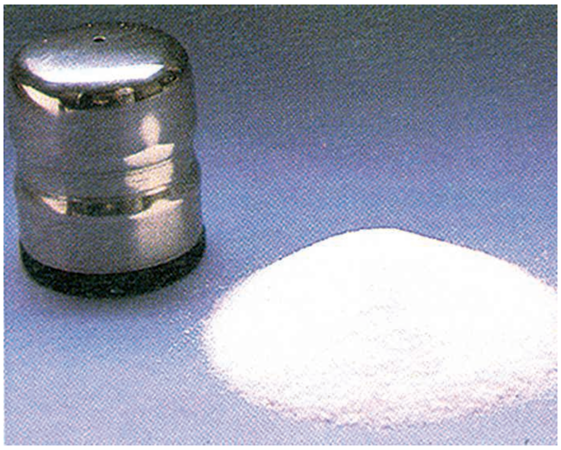


Figure 21. This is sodium chloride compound which is made up of sodium ions and chloride ions. We cannot see the individual sodium ions and chloride ions because they are very, very small. We can, however, see this sodium chloride compound because it is a collection of millions and millions of sodium ions and chloride ions.

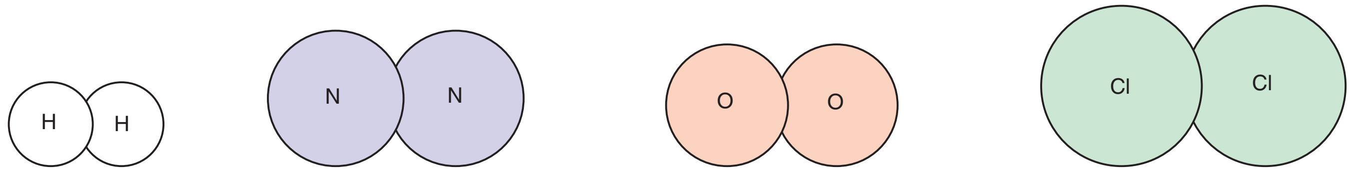
MOLECULES

A molecule is an electrically neutral group of two (or more) atoms chemically bonded together. The forces which hold the atoms together in a molecule are called covalent bonds. Thus, a combination of atoms is called a molecule. We know that atoms of most of the elements are very reactive and cannot exist in the free state (as single atoms). This is not so with molecules. Molecules can exist in free state because they are very stable. This gives us another definition of molecule which can be written as follows : **A molecule is the smallest particle of a substance (element or compound) which has the properties of that substance and can exist in the free state.**

Molecules can be formed either by the combination of atoms of the 'same element' or of 'different elements'. Depending on this, there are two types of molecules : molecules of elements, and molecules of compounds. This is discussed below.

1. Molecules of Elements

The molecule of an element contains two (or more) similar atoms chemically combined together. For example, a molecule of hydrogen element contains 2 hydrogen atoms combined together, and it is written as H_2 [see Figure 22(*a*)]. **Hydrogen gas consists of H_2 molecules and not of single atoms H.** Hydrogen molecule (H_2) is a diatomic molecule because it contains 2 atoms per molecule. Similarly, **nitrogen gas exists as N_2 molecules, oxygen gas as O_2 molecules and chlorine gas as Cl_2 molecules** [see Figures 22(*b*), (*c*) and (*d*)]. Bromine element, which is a liquid, consists of Br_2 molecules and iodine element, which is a solid, consists of I_2 molecules.



(*a*) Hydrogen molecule, H_2 (*b*) Nitrogen molecule, N_2 (*c*) Oxygen molecule, O_2 (*d*) Chlorine molecule, Cl_2

Figure 22. Molecules of elements.

Ozone gas has 3 oxygen atoms combined together, so **ozone exists in the form of O_3 molecules**. Phosphorus element has 4 phosphorus atoms combined together, so **phosphorus exists in the form of P_4 molecules.** Solid sulphur element has 8 sulphur atoms joined together, therefore, **sulphur exists in the form of S_8 molecules.** The noble gases like helium, neon, argon and krypton, etc., exist as single atoms He, Ne, Ar and Kr, respectively. So, their atoms and molecules are just the same. Most of the elements which exist as solids, consist of a large cluster of atoms which can be considered to be 'giant molecules' or 'very big molecules'. For example, all the metals consist of giant molecules and they are represented by their

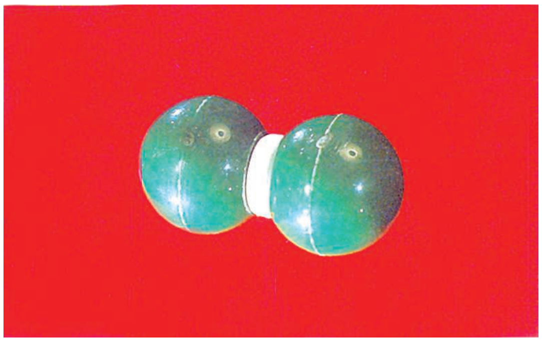


Figure 23. This is the model of a chlorine molecule. The two green balls represent two chlorine atoms. Since a chlorine molecule contains 2 chlorine atoms joined together, it is written as Cl_2.

Figure 24. A molecule of sulphur contains 8 sulphur atoms joined together. So, it is written as S_8.

Figure 25. Graphite is a form of carbon element. Graphite consists of a large cluster of carbon atoms. So, it is considered to be a giant molecule and represented by the symbol C.

symbols. For example, the metal elements like sodium, magnesium, aluminium and iron, etc., are represented by their symbols Na, Mg, Al and Fe, etc., they do not have any separate formulae. Carbon element is a solid non-metal which is also represented by its symbol C. The properties of solid elements are not due to their single atoms but due to big cluster of atoms. We will now discuss atomicity of elements.

The number of atoms present in one molecule of an element is called its atomicity. The atomicity of some of the common elements is discussed below.

(*i*) Noble gases (helium, neon, argon, krypton, etc.) have one atom each in their molecules such as He, Ne, Ar and Kr. So, **the atomicity of noble gases is 1.** Noble gases are said to be *monoatomic* (having 1-atom molecules). **The atomicity of metal elements like sodium (Na), magnesium (Mg), aluminium (Al), copper (Cu) and iron (Fe), etc., is also taken to be 1.** Thus, metals are considered to be *monoatomic*. **The atomicity of carbon element is also 1.** So, carbon is *monoatomic.*

(*ii*) Hydrogen (H_2), nitrogen (N_2), oxygen (O_2), chlorine (Cl_2), bromine (Br_2) and iodine (I_2), all have 2 atoms each in their molecules. So, **the atomicity of hydrogen, nitrogen, oxygen, chlorine, bromine and iodine is 2 each.** In other words, the elements hydrogen, nitrogen, oxygen, chlorine, bromine and iodine are *diatomic* (having 2-atom molecules).

(*iii*) Ozone (O_3) has 3 atoms in its molecule, so **the atomicity of ozone is 3.** Ozone is said to be *triatomic* (having 3-atom molecules).

(*iv*) Phosphorus (P_4) has 4 atoms in its molecule, so **the atomicity of phosphorus is 4.** Phosphorus is said to be *tetra-atomic* (having 4-atom molecules).

Figure 26. Red phosphorus.

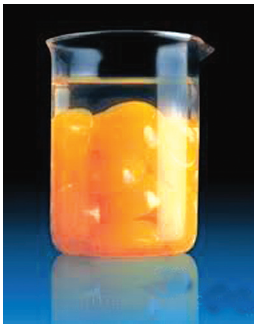


Figure 27. Yellow phosphorus (kept under water).

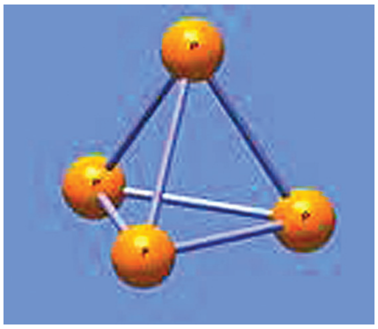
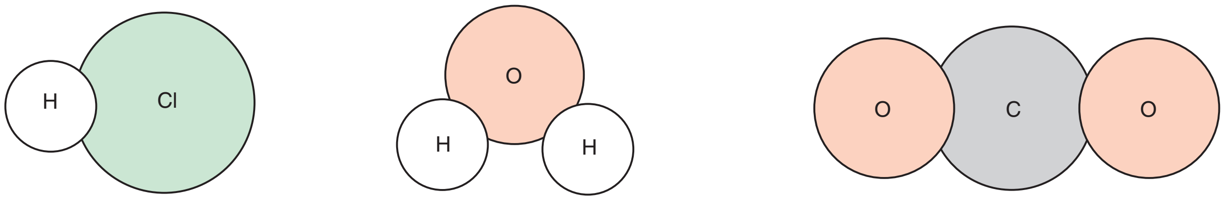


Figure 28. Model of a phosphorus molecule (P_4) showing 4 phosphorus atoms joined together.

(*v*) Solid sulphur (S_8) has 8 atoms in its molecule, so **the atomicity of sulphur is 8.** Sulphur is said to be *octa-atomic* (having 8-atom molecules).

2. Molecules of Compounds

The molecule of a compound contains two (or more) different types of atoms chemically combined together. For example, hydrogen chloride is a compound. The molecule of hydrogen chloride (HCl) contains two different types of atoms : hydrogen atom (H) and chlorine atom (Cl) [see Figure 29(*a*)]. Water is a compound. A molecule of water (H_2O) is made up of two different types of atoms : hydrogen atoms (H) and oxygen atom (O) [see Figure 29(*b*)]. Carbon dioxide (CO_2) is also a compound whose molecule consists of two different types of atoms : carbon atom (C) and oxygen atoms (O) [see Figure 29(*c*)]. Some more examples of the molecules of compounds are : sulphur dioxide (SO_2), methane (CH_4) and ammonia (NH_3). Please note that **a compound which consists of molecules is called a molecular compound.** Hydrogen chloride, water, carbon dioxide, sulphur dioxide, methane and ammonia, are all molecular compounds (which consist of molecules and not ions). We will now discuss chemical formulae.



(*a*) Hydrogen chloride molecule, HCl

(*b*) Water molecule, H_2O

(*c*) Carbon dioxide molecule, CO_2

Figure 29. Molecules of compounds.

Chemical Formulae

A chemical formula represents the composition of a molecule of the substance in terms of the symbols of the elements present in the molecule. A chemical formula is also known as a molecular formula. The formula can be of an element or of a compound. This is explained below.

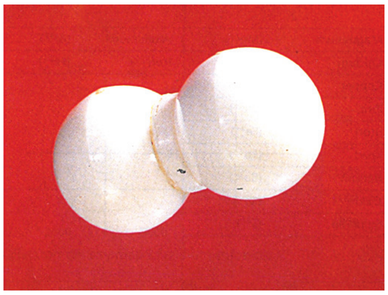


Figure 30. This is the model of a hydrogen molecule (H_2). The two white balls represent two hydrogen atoms.

Formulae of Elements

The chemical formula of an element is a statement of the composition of its molecule in which symbol tells us the element and the subscript (lower figure) tells us how many atoms are present in one molecule. One molecule of hydrogen element contains two atoms of hydrogen, therefore, the formula of hydrogen is H_2. The figure 2 in the formula H_2 indicates that one molecule of hydrogen element contains 2 atoms of hydrogen. Please note that 2H represents 2 separate atoms of hydrogen; H_2 represents 1 molecule of hydrogen, and $2H_2$ represents 2 molecules of hydrogen. Similarly, the molecular formula of oxygen element is O_2, nitrogen is N_2, and chlorine is Cl_2. The inert gases like helium, neon and argon are monoatomic, so their symbols and formulae are just the same. All the metals are represented by their symbols, they do not have any separate formulae. The molecular formulae of some of the common elements are given below :

Molecular Formulae of Some Common Elements

Element	*Formula*	*Element*	*Formula*
Hydrogen	H_2	Bromine	Br_2
Nitrogen	N_2	Iodine	I_2
Oxygen	O_2	Phosphorus	P_4
Chlorine	Cl_2	Sulphur	S_8

Formulae of Compounds

The chemical formula of a compound is a statement of its composition in which the chemical symbols tell us which elements are present and the subscripts (lower figures) tell us how many atoms of each element are present in one molecule of the compound. Water is a compound whose molecule contains 2 atoms of hydrogen and 1 atom of oxygen. So, the formula of water is H_2O. In the formula H_2O, the symbol H_2 indicates 2 atoms of hydrogen (and not a molecule of hydrogen), and O represents 1 atom of oxygen. The figure in front of a formula shows the number of molecules. For example, $2H_2O$ means 2 molecules of water. The figure 2 multiplies the whole formula H_2O and not just the first element. That is, $2H_2O$ contains 4 atoms of hydrogen and two atoms of oxygen. The chemical formulae of some common molecular compounds (which consist of molecules) and the elements present in them are given below.

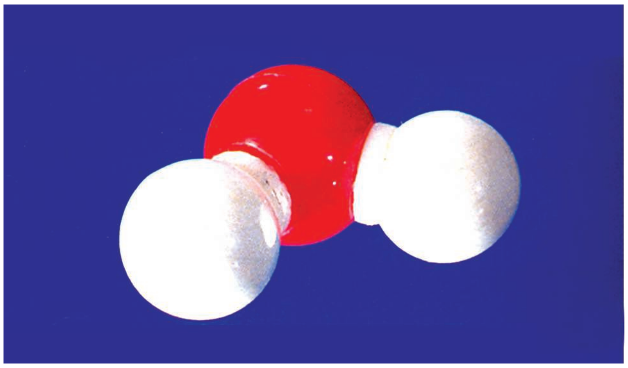


Figure 31. This is a model of water molecule (H_2O). The white balls represent hydrogen atoms whereas the red ball represents oxygen atom.

Formulae of Some Molecular Compounds

Name	*Formula*	*Elements present*
1. Water	H_2O	H and O
2. Carbon dioxide	CO_2	C and O
3. Sulphur dioxide	SO_2	S and O
4. Ammonia	NH_3	N and H
5. Methane	CH_4	C and H
6. Ethanol (Alcohol)	C_2H_5OH	C, H and O
7. Hydrogen chloride	HCl	H and Cl
8. Carbon tetrachloride (Tetrachloromethane)	CCl_4	C and Cl
9. Hydrogen sulphide	H_2S	H and S
10. Carbon disulphide	CS_2	C and S

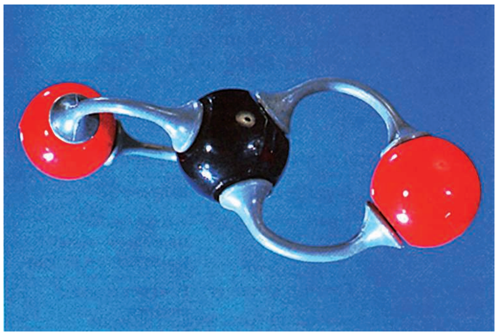


Figure 32. Model of a carbon dioxide molecule (CO_2). The black ball represents carbon atom whereas red balls represent oxygen atoms.

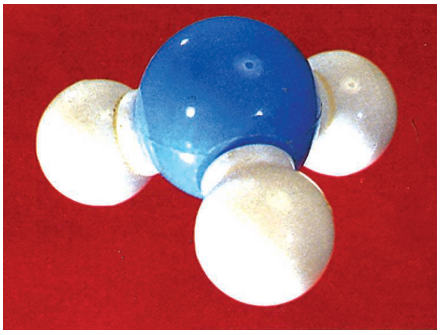


Figure 33. Model of an ammonia molecule (NH_3). The blue ball represents nitrogen atom whereas white balls represent hydrogen atoms.

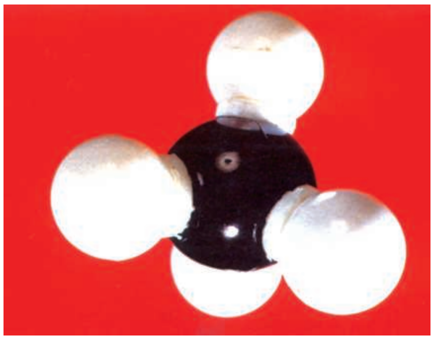


Figure 34. Model of methane molecule (CH_4). The black ball represents carbon atom whereas white balls represent hydrogen atoms.

Molecular Mass

Just as an atom has atomic mass, in the same way, a molecule has a molecular mass. **The molecular mass of a substance is the relative mass of its molecule as compared with the mass of a carbon-12 atom taken as 12 units.** The molecular mass of a substance indicates the number of times one molecule of the substance is heavier than $\frac{1}{12}$ (one-twelfth) of a carbon-12 atom. For example, the molecular mass of hydrogen is 2, which means that a molecule of hydrogen is 2 times heavier than $\frac{1}{12}$ of a carbon-12 atom. The molecular mass is expressed in atomic mass units (u).

Calculation of Molecular Mass

If the molecular formula of a substance is known, its molecular mass can be calculated, because **the molecular mass is equal to sum of the atomic masses of all the atoms present in one molecule of the substance.** For example, one molecule of water (H_2O) contains 2 atoms of hydrogen and 1 atom of oxygen. So, the molecular mass of water will be equal to the sum of the masses of 2 hydrogen atoms and 1 oxygen atom. Knowing that the atomic mass of hydrogen is 1 u and that of oxygen is 16 u, the molecular mass of water can be calculated as follows :

Mass of H atom = 1 u
Mass of 2H atoms = 2 × 1
= 2 u
Mass of O atom = 16 u
Now, Molecular mass of H_2O = Mass of 2H atoms + Mass of O atom
= 2 + 16
= 18 u

Thus, the molecular mass of water (H_2O) is 18 u.

In the case of ionic compounds like sodium chloride which consist of ions (and not molecules) the term formula mass is sometimes used in place of molecular mass. The molecular masses of some common elements, which exist as molecules, are given below :

Molecular Masses of Some Common Elements

Element	*Symbol*	*Atomic mass*	*Molecular formula*	*Molecular mass*
1. Hydrogen	H	1 u	H_2	2 × 1 = 2 u
2. Nitrogen	N	14 u	N_2	2 × 14 = 28 u
3. Oxygen	O	16 u	O_2	2 × 16 = 32 u
4. Chlorine	Cl	35.5 u	Cl_2	2 × 35.5 = 71 u

We will now solve a problem based on the calculation of molecular mass of a compound.

Sample Problem. Calculate the molecular mass of sulphuric acid (H_2SO_4). (Given : Atomic masses : H = 1 u ; S = 32 u ; O = 16 u).

Solution. The molecular formula of sulphuric acid is H_2SO_4. This formula shows that one molecule of sulphuric acid (H_2SO_4) contains 2 atoms of hydrogen, 1 atom of sulphur and 4 atoms of oxygen. So, the molecular mass of H_2SO_4 will be equal to the sum of the masses of 2 hydrogen atoms, 1 sulphur atom and 4 oxygen atoms. Knowing that the atomic mass of hydrogen is 1 u, of sulphur is 32 u and that of oxygen is 16 u, the molecular mass of sulphuric acid can be calculated as follows :

$$\text{Molecular mass of } H_2SO_4 = \underset{\text{atoms}}{\text{Mass of 2H}} + \underset{\text{atom}}{\text{Mass of S}} + \underset{\text{atoms}}{\text{Mass of 4 'O'}}$$

$$= 2 \times 1 + 32 + 4 \times 16$$

$$= 2 + 32 + 64$$

$$= 98 \text{ u}$$

Thus, the molecular mass of sulphuric acid is 98 u.

Figure 35. The molecular formula of sulphuric acid is H_2SO_4.

Before we conclude the discussion on formulae, it will be good to note the significance of the chemical formula of a substance which is given below.

Significance of the Formula of a Substance

1. Formula represents the name of the substance.
2. Formula represents one molecule of the substance.
3. Formula also represents one mole of molecules of the substance. That is, formula also represents 6.022×10^{23} molecules of the substance.
4. Formula gives the names of all the elements present in the molecule.
5. Formula gives the number of atoms of each element present in one molecule.
6. Formula represents a definite mass of the substance (equal to molecular mass expressed in grams).

As an example, let us give the significance of the formula H_2O.

1. H_2O represents water.
2. H_2O represents one molecule of water.
3. H_2O also represents one mole of molecules of water. That is, H_2O also represents 6.022×10^{23} molecules of water.
4. H_2O tells us that water contains two elements, hydrogen and oxygen.
5. H_2O tells us that one molecule of water contains 2 atoms of hydrogen and 1 atom of oxygen.
6. H_2O represents 18 grams of water (which is equal to the molecular mass of water expressed in grams).

Before we go further and discuss ions, **please answer the following questions :**

Very Short Answer Type Questions

1. Write the full form of IUPAC.

2. Name the scientist who gave :

(*a*) law of conservation of mass.

(*b*) law of constant proportions.

3. Name the law of chemical combination :

(*a*) which was given by Lavoisier.

(*b*) which was given by Proust.

4. Name the scientist who gave atomic theory of matter.
5. Which postulate of Dalton's atomic theory is the result of law of conservation of mass given by Lavoisier ?
6. Which part of the Dalton's atomic theory came from the law of constant proportions given by Proust ?
7. Which ancient Indian philosopher suggested that all matter is composed of very small particles ? What name was given by him to these particles ?
8. Name any two laws of chemical combination.
9. 'If 100 grams of pure water taken from different sources is decomposed by passing electricity, 11 grams of hydrogen and 89 grams of oxygen are always obtained'. Which chemical law is illustrated by this statement ?
10. 'If 100 grams of calcium carbonate (whether in the form of marble or chalk) are decomposed completely, then 56 grams of calcium oxide and 44 grams of carbon dioxide are obtained'. Which law of chemical combination is illustrated by this statement ?
11. What are the building blocks of matter ?
12. How is the size of an atom indicated ?
13. Name the unit in which the radius of an atom is usually expressed.
14. Write the relation between nanometre and metre.
15. The radius of an oxygen atom is 0.073 nm. What does the symbol 'nm' represent ?
16. Why is it not possible to see an atom even with the most powerful microscope ?
17. State whether the following statement is true or false :
    The symbol of element cobalt is CO.
18. Define 'molecular mass' of a substance.
19. What is meant by saying that 'the molecular mass of oxygen is 32' ?
20. Fill in the following blanks with suitable words :
    (*a*) In water, the proportion of oxygen and hydrogen is .... by mass.
    (*b*) In a chemical reaction, the sum of the masses of the reactants and the products remains unchanged. This is called............. .

Short Answer Type Questions

21. (*a*) Name the element used as a standard for atomic mass scale.
    (*b*) Which particular atom of the above element is used for this purpose ?
    (*c*) What value has been given to the mass of this reference atom ?
22. Give one major drawback of Dalton's atomic theory of matter.
23. Dalton's atomic theory says that atoms are indivisible. Is this statement still valid ? Give reasons for your answer.
24. Is it possible to see atoms these days ? Explain your answer.
25. What is meant by the symbol of an element ? Explain with examples.
26. (*a*) Give two symbols which have been derived from the ''English names'' of the elements.
    (*b*) Give two symbols which have been derived from the ''Latin names'' of the elements.
27. Give the names and symbols of five familiar substances which you think are elements.
28. State the chemical symbols for the following elements :
    Sodium, Potassium, Iron, Copper, Mercury, Silver.
29. Name the elements represented by the following symbols :
    Hg, Pb, Au, Ag, Sn
30. What is meant by atomicity ? Explain with two examples.
31. What is the atomicity of the following ?
    (*a*) Oxygen (*b*) Ozone (*c*) Neon (*d*) Sulphur (*e*) Phosphorus (*f*) Sodium
32. What is meant by a chemical formula ? Write the formulae of one element and one compound.
33. Write the formulae of the following compounds. Also name the elements present in them.
    (*a*) Water (*b*) Ammonia (*c*) Methane (*d*) Sulphur dioxide (*e*) Ethanol
34. Explain the difference between 2N and N_2.

35. What do the following abbreviations stand for ?
(*i*) O (*ii*) 2O (*iii*) O_2 (*iv*) $3O_2$

36. What do the symbols, H_2, S and O_4 mean in the formula H_2SO_4 ?

37. (*a*) In what form does oxygen gas occur in nature ?
(*b*) In what form do noble gases occur in nature ?

38. What is the difference between 2H and H_2 ?

39. What do the following denote ?
(*i*) N (*ii*) 2N (*iii*) N_2 (*iv*) $2N_2$

40. What is the significance of the formula of a substance ?

41. What is the significance of the formula H_2O ?

42. The molecular formula of glucose is $C_6H_{12}O_6$. Calculate its molecular mass. (Atomic masses : C = 12 u ; H = 1 u ; O = 16 u)

43. Calculate the molecular masses of the following :
(*a*) Hydrogen, H_2 (*b*) Oxygen, O_2 (*c*) Chlorine, Cl_2 (*d*) Ammonia, NH_3 (*e*) Carbon dioxide, CO_2
(Atomic masses : H = 1 u ; O = 16 u ; Cl = 35.5 u ; N = 14 u ; C = 12 u)

44. Calculate the molecular masses of the following compounds :
(*a*) Methane, CH_4 (*b*) Ethane, C_2H_6 (*c*) Ethene, C_2H_4 (*d*) Ethyne, C_2H_2
(Atomic masses : C = 12 u ; H = 1 u)

45. Calculate the molecular masses of the following compounds :
(*a*) Methanol, CH_3OH (*b*) Ethanol, C_2H_5OH

46. Calculate the molecular mass of ethanoic acid, CH_3COOH.
(Atomic masses : C = 12 u ; H = 1 u ; O = 16 u)

47. Calculate the molecular mass of nitric acid, HNO_3. (Atomic masses : H = 1 u ; N = 14 u ; O = 16 u)

48. Calculate the molecular mass of chloroform ($CHCl_3$). (Atomic masses : C = 12 u ; H = 1 u ; Cl = 35.5 u)

49. Calculate the molecular mass of hydrogen bromide (HBr). (Atomic masses : H = 1 u ; Br = 80 u)

50. Calculate the molecular masses of the following compounds :
(*a*) Hydrogen sulphide, H_2S (*b*) Carbon disulphide, CS_2
(Atomic masses : H = 1 u ; S = 32 u ; C = 12 u)

Long Answer Type Questions

51. State the law of conservation of mass. Give one example to illustrate this law.

52. State the law of constant proportions. Give one example to illustrate this law.

53. (*a*) State the various postulates of Dalton's atomic theory of matter.
(*b*) Which postulate of Dalton's atomic theory can explain the law of conservation of mass ?
(*c*) Which postulate of Dalton's atomic theory can explain the law of constant proportions ?

54. (*a*) What is the significance of the symbol of an element ? Explain with the help of an example.
(*b*) Explain the significance of the symbol H.

55 (*a*) What is an atom ? How do atoms usually exist ?
(*b*) What is a molecule ? Explain with an example.
(*c*) What is the difference between the molecule of an element and the molecule of a compound ? Give one example of each.

56. (*a*) Define atomic mass unit. What is its symbol ?
(*b*) Define atomic mass of an element.
(*c*) What is meant by saying that 'the atomic mass of oxygen is 16' ?

Multiple Choice Questions (MCQs)

57. The atomicities of ozone, sulphur, phosphorus and argon are respectively :
(*a*) 8, 3, 4 and 1 (*b*) 1, 3, 4 and 8 (*c*) 4, 1, 8 and 3 (*d*) 3, 8, 4 and 1

58. The symbol of a metal element which is used in making thermometers is :
(*a*) Ag (*b*) Hg (*c*) Mg (*d*) Sg

59. The Latin language name of an element is natrium. The English name of this element is :
(*a*) sodium (*b*) potassium (*c*) magnesium (*d*) sulphur

60. The atomic theory of matter was proposed by :
(*a*) John Kennedy (*b*) Lavoisier (*c*) Proust (*d*) John Dalton

61. One of the following elements has an atomicity of 'one'. This element is :
(*a*) helium (*b*) hydrogen (*c*) sulphur (*d*) ozone

62. The English name of an element is potassium, its Latin name will be :
(*a*) plumbum (*b*) cuprum (*c*) kalium (*d*) natrium

63. The law of conservation of mass was given by :
(*a*) Dalton (*b*) Proust (*c*) Lavoisier (*d*) Berzelius

64. The element having atomicity 'four' is most likely to be :
(*a*) argon (*b*) fluorine (*c*) phosphorus (*d*) francium

65. If 1.4 g of calcium oxide is formed by the complete decomposition of calcium carbonate, then the amount of calcium carbonate taken and the amount of carbon dioxide formed will be respectively :
(*a*) 2.2 g and 1.1 g (*b*) 1.1 g and 2.5 g (*c*) 2.5 g and 1.1 g (*d*) 5.0 g and 1.1 g

66. The law of constant proportions was given by :
(*a*) Proust (*b*) Lavoisier (*c*) Dalton (*d*) Berzelius

67. Out of ozone, phosphorus, sulphur and krypton, the elements having the lowest and highest atomicities are respectively :
(*a*) sulphur and krypton (*b*) krypton and ozone
(*c*) phosphorus and sulphur (*d*) krypton and sulphur

68. One nm is equal to :
(*a*) 10^{-9} mm (*b*) 10^{-7} cm (*c*) 10^{-9} cm (*d*) 10^{-6} m

69. The scientist who proposed the first letter (or first letter and another letter) of the Latin or English name of an element as its symbol, was :
(*a*) Dalton (*b*) Proust (*c*) Lavoisier (*d*) Berzelius

70. The atoms of which of the following pair of elements are most likely to exist in free state ?
(*a*) hydrogen and helium (*b*) argon and carbon (*c*) neon and nitrogen (*d*) helium and neon

71. Which of the following elements has the same molecular mass as its atomic mass ?
(*a*) nitrogen (*b*) neon (*c*) oxygen (*d*) chlorine

72. In water, the proportion of oxygen and hydrogen by mass is :
(*a*) 1 : 4 (*b*) 1 : 8 (*c*) 4 : 1 (*d*) 8 : 1

73. In hydrogen peroxide (H_2O_2), the proportion of hydrogen and oxygen by mass is :
(*a*) 1 : 8 (*b*) 1 : 16 (*c*) 8 : 1 (*d*) 16 : 1

74. The symbols of the elements cobalt, aluminium, helium and sodium respectively written by a student are as follows. Which symbol is the correct one ?
(*a*) CO (*b*) AL (*c*) He (*d*) So

Questions Based on High Order Thinking Skills (HOTS)

75. Copper sulphate reacts with sodium hydroxide to form a blue precipitate of copper hydroxide and sodium sulphate. In an experiment, 15.95 g of copper sulphate reacted with 8.0 g of sodium hydroxide to form 9.75 g of copper hydroxide and 14.2 g of sodium sulphate. Which law of chemical combination is illustrated by this data ? Give reason for your choice.

76. Potassium chlorate decomposes, on heating, to form potassium chloride and oxygen. When 24.5 g of potassium chlorate is decomposed completely, then 14.9 g of potassium chloride is formed. Calculate the mass of oxygen formed. Which law of chemical combination have you used in solving this problem ?

77. In an experiment, 4.90 g of copper oxide was obtained from 3.92 g of copper. In another experiment, 4.55 g of copper oxide gave, on reduction, 3.64 g of copper. Show with the help of calculations that these figures verify the law of constant proportions.

78. Magnesium and oxygen combine in the ratio of 3 : 2 by mass to form magnesium oxide. What mass of oxygen gas would be required to react completely with 24 g of magnesium ?

79. When 5 g of calcium is burnt in 2 g of oxygen, then 7 g of calcium oxide is produced. What mass of calcium oxide will be produced when 5 g of calcium is burnt in 20 g of oxygen ? Which law of chemical combination will govern your answer ?

80. A liquid compound X of molecular mass 18 u can be obtained from a number of natural sources. All the animals and plants need liquid X for their survival. When an electric current is passed through 200 grams of pure liquid X under suitable conditions, then 178 grams of gas Y and 22 grams of gas Z are produced. Gas Y is produced at the positive electrode whereas gas Z is obtained at the negative electrode. Moreover, gas Y supports combustion whereas gas Z burns itself causing explosions.

(*a*) Name (*i*) liquid X (*ii*) gas Y, and (*iii*) gas Z.

(*b*) What is the ratio of the mass of element Z to the mass of element Y in the liquid X ?

(*c*) Which law of chemical combination is illustrated by this example ?

(*d*) Name two sources of liquid X.

(*e*) State an important use of Y in our life.

81. One of the forms of a naturally occurring solid compound P is usually used for making the floors of houses. On adding a few drops of dilute hydrochloric acid to P, brisk effervescence are produced. When 50 g of reactant P was heated strongly, than 22 g of a gas Q and 28 g of a solid R were produced as products. Gas Q is the same which produced brisk effervescence on adding dilute HCl to P. Gas Q is said to cause global warming whereas solid R is used for white-washing.

(*a*) What is (*i*) solid P (*ii*) gas Q, and (*iii*) solid R.

(*b*) What is the total mass of Q and R obtained from 50 g of P ?

(*c*) How does the total mass of Q and R formed compare with the mass of P taken ?

(*d*) What conclusion do you get from the comparison of masses of products and reactant ?

(*e*) Which law of chemical combination is illustrated by the example given in this problem ?

ANSWERS

9. Law of constant proportions **10.** Law of conservation of mass **15.** nanometre (10^{-9} m) **17.** False **20.** (*a*) 8 : 1 (*b*) conservation of mass **21.** (*a*) Carbon (*b*) Carbon-12 atom (*c*) 12 u **31.** (*a*) 2 (*b*) 3 (c) 1 (*d*) 8 (*e*) 4 (*f*) 1 **42.** 180 u **43.** (*a*) 2 u (*b*) 32 u (*c*) 71 u (*d*) 17 u (*e*) 44 u **44.** (*a*) 16 u (*b*) 30 u (*c*) 28 u (*d*) 26 u **45.** (*a*) 32 u (*b*) 46 u **46.** 60 u **47.** 63 u **48.** 119.5 u **49.** 81 u **50.** (*a*) 34 u (*b*) 76 u **57.** (*d*) **58.** (*b*) **59.** (*a*) **60.** (*d*) **61.** (*a*) **62.** (*c*) **63.** (*c*) **64.** (*c*) **65.** (*c*) **66.** (*a*) **67.** (*d*) **68.** (*b*) **69.** (*d*) **70.** (*d*) **71.** (*b*) **72.** (*d*) **73.** (*b*) **74.** (*c*) **75.** Law of conservation of mass ; Because the mass of products (9.75 g + 14.2 g) is equal to the mass of reactants (15.95 g + 8.0 g). There is no change in mass in this reaction **76.** 9.6 g **;** Law of conservation of mass **77.** The ratio (or proportion) of copper and oxygen elements in the two samples of copper oxide compound is the same 4 : 1. So, the given figures verify the law of constant proportions **78.** 16 g **79.** 7g ; Law of constant proportions **80.** (*a*) (*i*) Water (*ii*) Oxygen (*iii*) Hydrogen (*b*) 1 : 8 (*c*) Law of constant proportions (*d*) Rivers and Wells (*e*) Gas Y (oxygen) is necessary for breathing **81.** (*a*) (*i*) Calcium carbonate ($CaCO_3$) in the form of marble (*ii*) Carbon dioxide (CO_2) (*iii*) Calcium oxide (CaO) (*b*) 50 g (*c*) Total mass of Q and R (50 g) is equal to the mass of P taken (50 g) (*d*) The mass of products is equal to the mass of reactant (*e*) Law of conservation of mass

An Important Discussion

Before we can understand the formation of ions, we should know the various particles which are present in an atom (This will be studied in detail in the next chapter). **An atom contains electrons, protons and neutrons.** Each electron has 1 unit negative charge and each proton has 1 unit positive charge. Neutron has no electric charge, it is neutral. **Every atom normally contains an equal number of 'negative electrons' and 'positive protons' which balance the charges in the atom and make an atom electrically neutral.** If, however, one or more electrons are either removed from an atom or added to an atom, then the atom has either less number of electrons than normal or more number of electrons that normal, and it gets an overall electric charge. The atom becomes an ion.

1. **If an atom has less electrons than normal, then it gets positive charge** (because the number of negative electrons becomes less than the number of positive protons).

2. **And if an atom has more electrons than normal, then it gets negative charge** (because then the number of negative electrons becomes more than the number of positive protons).

Please note that **it is only the electrons which can be transferred from one atom to another in the formation of ions**. Protons cannot be transferred from one atom to another because they are present deep inside the atom in its nucleus. Keeping these points in mind, we will now explain the formation of ions.

IONS

An ion is a positively or negatively charged atom (or group of atoms). Examples of the ions are : sodium ion, Na^+, magnesium ion, Mg^{2+}, chloride ion, Cl^-, and oxide ion, O^{2-}. An ion is formed by the loss or gain of electrons by an atom, so it contains an unequal number of electrons and protons. **There are two types of ions : cations and anions.**

1. A Positively Charged Ion is Known as Cation

Sodium ion, Na^+, and magnesium ion, Mg^{2+}, are cations because they are positively charged ions. **A cation is formed by the loss of one or more electrons by an atom.** For example, sodium atom loses 1 electron to form a sodium ion, Na^+, which is a cation :

$$\underset{\text{Sodium atom}}{Na} \xrightarrow{-1\text{ electron}} \underset{\substack{\text{Sodium ion}\\\text{(A cation)}}}{Na^+}$$

Since a cation is formed by the removal of electrons from an atom, therefore, **a cation contains less electrons than a normal atom.** We also know that a normal atom (or a neutral atom) contains an equal number of protons and electrons. Now, since a cation is formed by the loss of one or more electrons by an atom, therefore, *a cation contains less electrons than protons*. **The ions of all the metal elements are cations.** Only the hydrogen ion, H^+, and ammonium ion, NH_4^+, are the cations formed from non-metals. **We will now give the reason for the positive charge on a cation.**

Figure 36. A positively charged sodium ion (or sodium cation), Na^+.

We know that a proton has 1 unit positive charge and an electron has 1 unit negative charge. Now, a normal atom contains an equal number of protons and electrons, so it is electrically neutral. When a normal atom loses electrons to form a cation, then in this cation, the number of electrons becomes less than the number of protons. In other words, we can say that a cation has more protons than electrons. **Due to more protons than electrons, a cation has a positive charge on it.** This will become more clear from the following example.

Let us write down the number of protons and electrons in a sodium atom as well as a sodium ion as shown below :

$$\underset{\text{Sodium atom}}{Na} \xrightarrow{-1\text{ electron}} \underset{\text{Sodium ion}}{Na^+}$$

Sodium atom	Sodium ion
Protons = **11** (+ charge)	Protons = **11** (+ charge)
Electrons = **11** (– charge)	Electrons = **10** (– charge)
Overall charge = 0	Overall charge = 1+

Sodium atom, Na, contains 11 protons and 11 electrons. Since the number of protons and electrons in a sodium atom is equal, it is electrically neutral, having no overall charge. In the sodium ion, Na^+, there are 11 protons but only 10 electrons. This means that there is 1 proton more than electrons. Due to 1 more proton (than electrons), a sodium ion has 1 unit positive charge and it is written as Na^+.

All the metal atoms can lose electrons easily, so all the metal elements form cations (or positive ions). Please note that :

(*i*) **If an atom loses 1 electron, then the cation (positive ion) formed has 1 unit positive charge.** For example, a sodium atom loses 1 electron to form a sodium ion, Na^+, having 1 unit positive charge.

(*ii*) **If an atom loses 2 electrons, then the cation (positive ion) formed has 2 units of positive charge.** For example, a magnesium atom can lose 2 electrons to form a magnesium ion, Mg^{2+}, having 2 units of positive charge.

(*iii*) **And if an atom loses 3 electrons, then the cation (positive ion) formed has 3 units of positive charge.** For example, an aluminium atom can lose 3 electrons to form an aluminium ion, Al^{3+}, having 3 units of positive charge.

Figure 37. Just like sodium, lithium atoms (Li) lose 1 electron each to form lithium ions (Li^+). The picture above shows a rechargeable lithium ion battery.

Figure 38. Lithium ion batteries are used in mobile phones (like the one shown in the above picture).

It is, however, usually not possible to remove more than 3 electrons from an atom due to very high energy required for this purpose. Another point to be noted is that the electrons lost by a metal atom during the formation of a cation (positive ion) are accepted by a non-metal atom (which then turns into an anion or negative ion).

2. A Negatively Charged Ion is Known as Anion

Chloride ion, Cl^-, and oxide ion, O^{2-}, are anions because they are negatively charged ions. **An anion is formed by the gain of one or more electrons by an atom.** For example, a chlorine atom gains (accepts) 1 electron to form a chloride ion, Cl^-, which is an anion :

$$\underset{\text{Chlorine atom}}{Cl} \xrightarrow{+1 \text{ electron}} \underset{\substack{\text{Chloride ion} \\ \text{(An anion)}}}{Cl^-}$$

Since an anion is formed by the addition of electrons to an atom, therefore, **an anion contains more electrons than a normal atom.** We also know that a normal atom (or a neutral atom) contains an equal number of protons and electrons. Now, since an anion is formed by the addition of one or more electrons to an atom, therefore, an anion contains more electrons than protons. **The ions of all the non-metal elements are anions** (except hydrogen ion and ammonium ion). **We will now give the reason for the negative charge on an anion.**

A normal atom contains an equal number of protons and electrons, so it is electrically neutral. When an atom gains electrons to form an anion, then in this anion the number of electrons becomes more than the number of protons. **Due to more electrons, than protons, an anion has a negative charge on it.** This will become more clear from the following example.

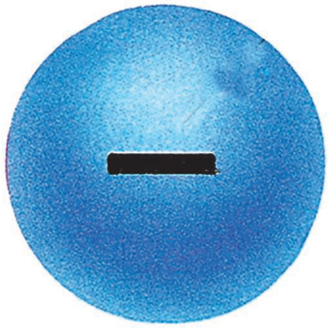


Figure 39. A negatively charged chloride ion (or chloride anion), Cl^-.

Let us write down the number of protons and electrons in a chlorine atom and a chloride ion as shown below :

$$Cl \xrightarrow{+1 \text{ electron}} Cl^-$$

Chlorine atom	Chloride ion
Protons = **17** (+ charge)	Protons = **17** (+ charge)
Electrons = **17** (– charge)	Electrons = **18** (– charge)
Overall charge = 0	Overall charge = 1–

Chlorine atom, Cl, contains an equal number of protons and electrons (17 each), so it is electrically neutral. In the chloride ion, Cl^-, there are 17 protons but 18 electrons. That is, a chloride ion has 1 electron more than protons. Due to 1 more electron than protons, a chloride ion has 1 unit of negative charge and it is written as Cl^-. From this discussion we conclude that an anion contains more electrons than protons.

Most of the non-metal atoms can gain (or accept) electrons easily, so most of the non-metal elements form anions (or negative ions). Please note that :

(*i*) **If an atom gains 1 electron, then the anion (negative ion) formed has 1 unit of negative charge.** For example, a chlorine atom accepts 1 electron to form a chloride ion, Cl^-, having 1 unit negative charge

(*ii*) **If an atom gains 2 electrons, then the anion (negative ion) formed has 2 units of negative charge.** For example, an oxygen atom accepts 2 electrons to form an oxide ion, O^{2-}, having 2 units of negative charge.

(*iii*) **And if an atom gains 3 electrons, then the anion (negative ion) formed will have 3 units of negative charge**. For example, a nitrogen atom can gain 3 electrons to form a nitride ion, N^{3-}, having 3 units of negative charge.

It is, however, usually not possible to add more than 3 electrons to an atom because of the great force of repulsion experienced by the subsequent electrons from the anion (negative ion) already having 3 negative charges. Please note that the electrons which are gained by non-metal atoms are given by the metal atom during chemical reactions.

Simple Ions and Compound Ions (Polyatomic Ions)

(*i*) Those ions which are formed from single atoms are called simple ions. For example, sodium ion, Na^+, is a simple ion because it is formed from a single sodium atom, Na. Similarly, magnesium ion Mg^{2+}, aluminium ion Al^{3+}, oxide ion O^{2-}, chloride ion Cl^-, etc., are all simple ions. **Simple ions are also known as monoatomic ions**.

(*ii*) Those ions which are formed from groups of joined atoms are called compound ions (or polyatomic ions). For example, ammonium ion NH_4^+, is a compound ion which is made up of two types of atoms joined together, nitrogen and hydrogen. Similarly, carbonate ion CO_3^{2-}, sulphate ion SO_4^{2-}, nitrate ion NO_3^- and hydroxide ion OH^-, etc., are all compound ions. **Compound ions are also known as polyatomic ions**.

Some of the common simple ions and compound ions (or polyatomic ions) and their symbols (or formulae) are given below.

Some Common Ions

Name of ion	*Symbol (or Formula)*	*Name of ion*	*Symbol (or Formula)*
1. Sodium ion	Na^+	10. Chloride ion	Cl^-
2. Potassium ion	K^+	11. Bromide ion	Br^-
3. Ammonium ion	NH_4^+	12. Hydroxide ion	OH^-
4. Magnesium ion	Mg^{2+}	13. Nitrate ion	NO_3^-
5. Calcium ion	Ca^{2+}	14. Oxide ion	O^{2-}
6. Copper (II) ion	Cu^{2+}	15. Sulphide ion	S^{2-}
7. Zinc ion	Zn^{2+}	16. Carbonate ion	CO_3^{2-}
8. Iron (II) ion	Fe^{2+}	17. Sulphate ion	SO_4^{2-}
9. Aluminium ion	Al^{3+}	18. Phosphate ion	PO_4^{3-}

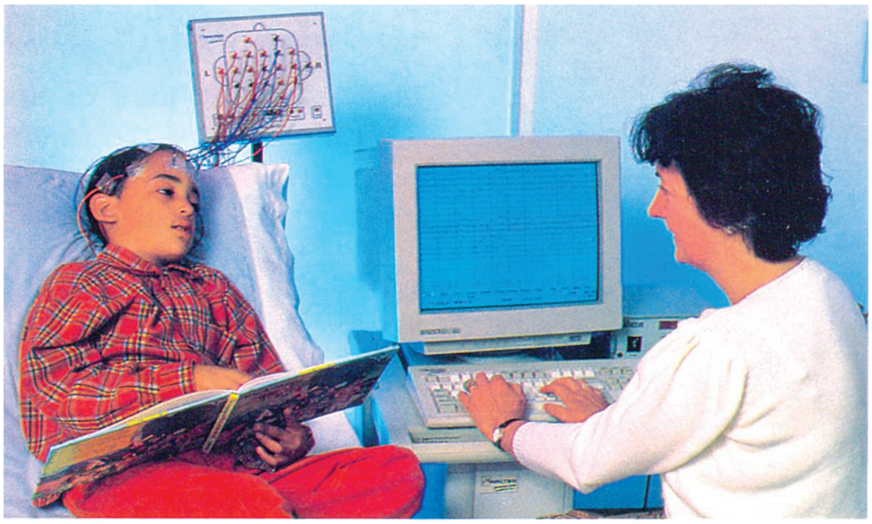


Figure 40. Sodium and potassium are used in the body in sending electrical signals by nerve cells. By measuring brain waves (caused by nerve impulses due to the movement of sodium ions and potassium ions in brain cells), doctors can tell whether there is any ailment (injury, etc.) in the brain of a person. This is done by taking an EEG (Electro-Encephalo-Gram) of the brain which shows a graphic record of the electrical activity in different parts of the brain produced by a device called electroencephalograph (by attaching electrodes to the person's scalp as shown in the above photograph).

IONIC COMPOUNDS

The compounds which are made up of ions are known as ionic compounds. In an ionic compound, the positively charged ions (cations) and negatively charged ions (anions) are held together by the strong electrostatic forces of attraction. The forces which hold the ions together in an ionic compound are known as ionic bonds or electrovalent bonds. Since an ionic compound consists of an equal number of positive ions and negative ions, so the overall charge on an ionic compound is zero. For example, sodium chloride (NaCl) is an ionic compound which is made up of equal number of positively charged sodium ions (Na^+) and negatively charged chloride ions (Cl^-). Some of the common ionic compounds, their formulae and the ions present in them are given below.

Figure 41. Sodium chloride (common salt), sodium nitrate, copper sulphate, magnesium sulphate, iron sulphate and sodium sulphate are all ionic compounds.

Some Ionic Compounds

Name	*Formula*	*Ions present*
1. Sodium chloride	NaCl	Na^+ and Cl^-
2. Potassium chloride	KCl	K^+ and Cl^-
3. Ammonium chloride	NH_4Cl	NH_4^+ and Cl^-
4. Magnesium chloride	$MgCl_2$	Mg^{2+} and Cl^-
5. Calcium chloride	$CaCl_2$	Ca^{2+} and Cl^-
6. Magnesium oxide	MgO	Mg^{2+} and O^{2-}
7. Calcium oxide	CaO	Ca^{2+} and O^{2-}
8. Aluminium oxide	Al_2O_3	Al^{3+} and O^{2-}
9. Sodium hydroxide	NaOH	Na^+ and OH^-
10. Copper sulphate	$CuSO_4$	Cu^{2+} and SO_4^{2-}
11. Calcium nitrate	$Ca(NO_3)_2$	Ca^{2+} and NO_3^-

Please note that all the above ionic compounds are made up of a metal and a non-metal (except ammonium chloride which is an ionic compound made up of only non-metals). So, **whenever we see a compound made up of a metal and a non-metal, we should at once say that it is an ionic compound.** We will now solve one problem based on ionic compunds.

Sample Problem. Write down the names of compounds represented by the following formulae. Also show the ions present in them :

(*i*) $Al_2(SO_4)_3$ (*ii*) $CaCl_2$ (*iii*) K_2SO_4 (*iv*) KNO_3 (*v*) $CaCO_3$ **(NCERT Book Question)**

Solution. (*i*) $Al_2(SO_4)_3$ is aluminium sulphate. Ions present are : Al^{3+} and SO_4^{2-}

(*ii*) $CaCl_2$ is calcium chloride. Ions present are : Ca^{2+} and Cl^-

(*iii*) K_2SO_4 is potassium sulphate. Ions present are : K^+ and SO_4^{2-}

(*iv*) KNO_3 is potassium nitrate. Ions present are : K^+ and NO_3^-

(*v*) $CaCO_3$ is calcium carbonate. Ions present are : Ca^{2+} and CO_3^{2-}

Formula Unit of Ionic Compounds

Before we describe formula mass, we should know the meaning of 'formula unit' of an ionic compound. This is discussed below. An ionic compound is made up of an extremely large number of positively charged ions and negatively charged ions joined together. For example, sodium chloride is an ionic compound which consists of a large (but equal) number of sodium ions, Na^+, and chloride ions, Cl^-, so the actual formula of sodium chloride compound should be $(Na^+)_n\,(Cl^-)_n$ or $(Na^+Cl^-)_n$, where n is a very large number (see Figure 42). **NaCl is the simplest formula of sodium chloride** and not its actual formula.

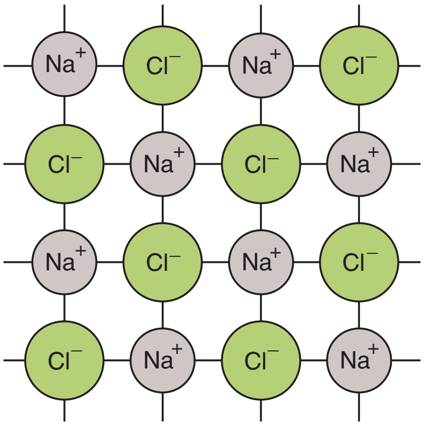


Figure 42. Sodium chloride is an ionic compound which consists of a large (but equal) number of sodium ions (Na^+) and chloride ions (Cl^-).

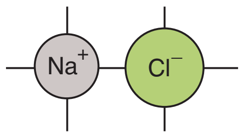


Figure 43. The formula unit of sodium chloride is Na^+Cl^- or NaCl.

Figure 44. This is a highly enlarged image of a crystal of the ionic compound 'sodium chloride' made up of a large number of sodium ions (Na^+) and chloride ions (Cl^-) held together by electrostatic attraction.

The simplest combination of ions that produces an electrically neutral unit, is called a 'formula unit' of the ionic compound. The 'formula unit' of an ionic compound can be thought of as the smallest unit of that compound, it is the equivalent of a 'molecule'of the compound.The formula unit of sodium chloride compound is NaCl (which consists of one Na^+ ion and one Cl^- ion) (see Figure 43). The formula unit of ammonium sulphate is $(NH_4)_2SO_4$. It consists of two NH_4^+ ions and one SO_4^{2-} ion.

Formula Mass

Since the ionic compounds do not consist of molecules, the use of term 'molecular mass' for them is not very correct. So, we use the term 'formula mass' for ionic compounds in which individual molecules do not exist. **The formula mass of an ionic compound is the relative mass of its 'formula unit' as compared with the mass of a carbon-12 atom taken as 12 units.** In other words, formula mass is the sum of the atomic masses of the atoms (or ions) represented by its formula. In order to calculate the formula mass of an ionic compound, we should know the formula of the ionic compound as well as the atomic masses of all the atoms (or ions) present in the formula. The formula mass is then calculated in a way similar to the calculation of molecular mass. Please note that **the atomic mass of an atom and its ion is just the same (because the electrons which convert an atom into an ion have negligible mass).** For example, the formula mass of sodium chloride (NaCl) will be the sum of atomic masses of sodium (Na) and chlorine (Cl). Now, the atomic mass of Na is 23 u and the atomic mass of Cl is 35.5 u, so the formula mass of sodium chloride (NaCl) will be 23 + 35.5 = 58.5 u. We will now solve one problem based on the calculation of formula mass.

Sample Problem. Calculate the formula mass of potassium carbonate (K_2CO_3) (Given : Atomic masses : K = 39 u ; C = 12 u ; O = 16 u) **(NCERT Book Question)**

Solution. We know that :

$$\text{Formula mass of } K_2CO_3 = \text{Mass of 2 K atoms} + \text{Mass of one C atom} + \text{Mass of 3 'O' atoms}$$
$$= 2 \times 39 + 12 + 3 \times 16$$
$$= 78 + 12 + 48$$
$$= 138 \text{ u}$$

Thus, the formula mass of potassium carbonate is 138 u.

CHEMICAL FORMULAE

The chemical formula of a compound represents the composition of a molecule of the compound in terms of the symbols of the elements present in it. In other words, the formula of a compound tells us 'the kind of atoms' as well as 'the number of atoms' of various elements present in one molecule of the compound. In the chemical formula of a compound, the elements present are represented by their symbols and the number of atoms of each element are indicated by writing the digits 2, 3, 4, etc., as subscripts (lower figures) on the right hand side bottom of the symbol. For example, water is a compound made up of 2 atoms of hydrogen element and 1 atom of oxygen element, so the formula of water is written as H_2O. In the formula H_2O, the subscript 2 indicates 2 atoms of hydrogen. In the formula of water, oxygen O is written without a subscript and it indicates 1 atom of oxygen. Please note that 1 atom of oxygen is written just as O and not as O_1. Another point to be noted is that in the case of molecular compounds, the chemical formula represents the composition of molecule which makes up the compound. But in the case of ionic compounds, the chemical formula represents the simplest ratio of ions present in the compound. We will now discuss the naming of simple ionic compounds and simple molecular compounds.

Ionic compounds are formed by the combination between metals and non-metals. While writing the formula of an ionic compound, the metal element is written on the left hand side and the non-metal element is written on the right hand side. In naming the ionic compound, the metal element is named as such but the name of non-metal element is changed to have the ending 'ide' (like oxide, chloride, sulphide, etc.). For example :

(*i*) MgO is named as magnesium oxide (Here oxygen is changed to oxide),
(*ii*) NaCl is named as sodium chloride (Here chlorine is changed to chloride), and
(*iii*) CuS is named as copper sulphide (Here sulphur is changed to sulphide).

Figure 45. Magnesium oxide (MgO).

Figure 46. Sodium chloride (NaCl).

Figure 47. Copper sulphide (CuS).

Please note that in all the above formulae of ionic compounds, the metal elements (Mg, Na, Cu) are written on the left hand side whereas the non-metal elements (O, Cl, S) are written on the right hand side. **A compound made up of only two elements is called a binary compound.** MgO, NaCl and CuS are all binary compounds because they are made up of only two elements each.

Before we discuss the formuale of molecular compounds, we should know something about electronegativity of an element. **The ability of an atom to attract (or pull) the shared electrons of a bond towards it, is known as electronegativity of its element.** The electronegativity of hydrogen (H) is 2.1 ; of carbon (C) is 2.5 ; of nitrogen (N) is 3.0 ; of chlorine (Cl) is 3.0 ; of oxygen (O) is 3.5 ; and of fluorine (F) is 4.0. An element having lower electronegativity is known as less electronegative element whereas an element having higher electronegativity is known as more electronegative element. This information will be helpful in writing the formulae of molecular compounds. We will study electronegativity is detail in higher classes.

Molecular compounds are formed by the combination between two different non-metal elements. While writing the formula of a molecular compound, the less electronegative non-metal element is written on the left hand side whereas the more electronegative non-metal element is written on the right hand side. In naming the molecular compounds, the name of less electronegative non-metal is written as such but the name of more electronegative non-metal is changed to have the ending 'ide'. For example :

(*i*) HCl is named as hydrogen chloride (Here chlorine is changed to chloride), and

(*ii*) H_2S is named as hydrogen sulphide (Here sulphur is changed to sulphide).

Please note that in HCl compound, hydrogen is a less electronegative element, so H is written first on the left hand side in the formula; chlorine is a more electronegative element, so Cl is written on the right hand side in the formula. Similarly, in H_2S compound, H is less electronegative and S is more electronegative due to which H is written first and S is written after that.

When there are more than one atoms of an element in a molecular compound, then 'the number of atoms' is indicated by using appropriate 'prefixes' in the formula (Prefix is a 'word' used before a name). 1 atom is indicated by using the prefix 'mono'; 2 atoms are indicated by using the prefix 'di'; 3 atoms are indicated by using the prefix 'tri'; 4 atoms are indicated by using the prefix 'tetra'; and 5 atoms are indicated by using the prefix 'penta'. Please note that the prefix 'mono' is not written for the first element of the formula even if it has 1 atom. The naming of molecular compounds by using prefixes will become more clear from the following examples :

(*i*) CO is named as carbon monoxide (Here the prefix 'mono' in monoxide means 1 oxygen atom),

(*ii*) CO_2 is named as carbon dioxide (Here the prefix 'di' in dioxide means 2 oxygen atoms),

(*iii*) PCl_3 is named as phosphorus trichloride (Here the prefix 'tri' in trichloride indicates 3 chlorine atoms),

(*iv*) CCl_4 is named as carbon tetrachloride (Here the prefix 'tetra' in tetrachloride shows that there are 4 chlorine atoms), and

(*v*) PCl_5 is named as phosphorus pentachloride (Here the prefix 'penta' shows 5 chlorine atoms).

Figure 48. Phosphorus trichloride, PCl_3.

Figure 49. Carbon tetrachloride, CCl_4.

Figure 50. Phosphorus pentachloride, PCl_5.

The 'prefixes' are needed in naming binary molecular compounds in those cases where the same two non-metal elements form a number of different compounds (having different number of atoms). For example, the same two non-metal elements, nitrogen and oxygen, can combine to form six different compounds such as nitrogen monoxide (NO), nitrogen dioxide (NO_2), dinitrogen monoxide (N_2O), dinitrogen trioxide (N_2O_3), dinitrogen tetroxide (N_2O_4), and dinitrogen pentoxide (N_2O_5). So, it is necessary to use prefixes in such cases. **If, however, two non-metal elements form just one compound, then prefixes are not used in naming such compounds.** For example, the elements hydrogen and chlorine form just one compound HCl. So, HCl is named as hydrogen chloride and not as hydrogen monochloride. Similarly, hydrogen and sulphur form only one compound H_2S, so H_2S is named as hydrogen sulphide and not as hydrogen monosulphide.

Another point to be noted is that **if hydrogen is the first element in a formula, then no prefix (like di, tri, etc.) is put before the name 'hydrogen', even if it has more than one hydrogen atoms.** For example, the compound H_2S is named as hydrogen sulphide and not as dihydrogen sulphide (even though it has 2 hydrogen atoms). **There are, however, some molecular compounds which are known by their common names and not by their scientific names.** For example, though the compound H_2O is actually hydrogen monoxide but it is known by its common name water. Similarly, though the compound NH_3 is actually nitrogen trihydride, but it is known by its common name which is ammonia.

Before we describe the methods of writing the formulae of various compounds, it will be good to remember the valencies of the following common elements. This will help us in writing the correct formulae of the compounds. We can see from the first table given below that some of the metal elements show more than one valency. For example, copper and mercury metals show valencies of 1 and 2 each whereas iron metal shows the valencies of 2 and 3. Let us also write down the valencies of some non-metal elements now as shown in the second table given below.

Valencies of Some Common Metal Elements

Element	*Symbol*	*Valency*
Lithium	Li	1
Sodium	Na	1
Potassium	K	1
Silver	Ag	1
Copper	Cu	1 and 2
Mercury	Hg	1 and 2
Magnesium	Mg	2
Calcium	Ca	2
Zinc	Zn	2
Iron	Fe	2 and 3
Aluminium	Al	3

Valencies of Some Common Non-Metal Elements

Element	*Symbol*	*Valency*
Hydrogen	H	1
Fluorine	F	1
Chlorine	Cl	1
Bromine	Br	1
Iodine	I	1
Oxygen	O	2
Sulphur	S	2
Nitrogen	N	3
Phosphorus	P	3
Carbon	C	4

Figure 51. This is ferrous sulphate ($FeSO_4$). It is also called iron (II) sulphate. The valency of iron in this compound is 2.

Figure 52. This is ferric sulphate [$Fe_2(SO_4)_3$]. It is also called iron (III) sulphate. The valency of iron in this compound is 3.

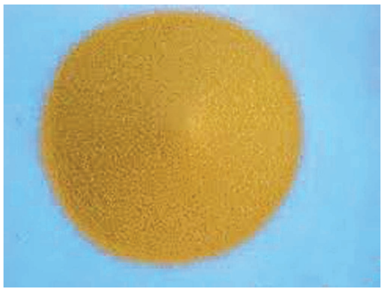


Figure 53. This is titanium nitride (TiN). The valency of nitrogen in this compound is 3.

Though the usual valency of sulphur is 2 as shown in the second table, it also shows valencies of 4 and 6 in some compounds. For example, the valency of S in H_2S is 2, in SO_2 is 4 and in SO_3 is 6. Similarly, though the usual valency of nitrogen and phosphorus is 3, they also show a valency of 5 in some compounds. Please note that an element having a valency of 1 is called monovalent ; valency 2 elements are called divalent ; valency 3 elements are called trivalent ; valency 4 elements are called tetravalent ; valency 5 elements are called pentavalent whereas the valency 6 elements are called hexavalent. Dear student, we have given so many details here so that you are able to write the formulae of various compounds easily and correctly. We will now give the methods of writing the formulae of compounds.

WRITING OF FORMULAE OF MOLECULAR COMPOUNDS

If we know the valencies of elements, then we can work out the formulae of their compounds by balancing the valencies of the different atoms which occur in the compound. For example, if a compound is made up of hydrogen and sulphur elements, then we should adjust the number of hydrogen atoms and sulphur atoms in such a way that the total valencies of hydrogen atoms become equal to the total valencies of sulphur atoms. This will give us the correct formula of the compound. Let us work out the formula of hydrogen sulphide to make this point more clear.

Hydrogen sulphide compound is made up of two elements : hydrogen and sulphur. Now, the valency of hydrogen is 1 and that of sulphur is 2. That is,

Valency of one H atom = 1 ... (1)

And Valency of one S atom = 2 ... (2)

Now, to balance the valency of 2 of a sulphur atom, we will have to take 2 atoms of hydrogen, because :

Valency of two H atoms = 1 × 2

= 2 ... (3)

This means that 2 atoms of H will combine with 1 atom of S to form the compound H_2S. Thus, the formula of hydrogen sulphide is H_2S.

Figure 54. Hydrogen sulphide is a poisonous gas with a smell of rotten eggs. The chemical formula of hydrogen sulphide is H_2S.

We will now describe the 'crossing-over of valencies' method of working out the formulae of molecular compounds. In this method :

1. **We first write the symbols of the elements which form the compound.**
2. **Below the symbol of each element, we write down its valency.**
3. **Finally, we cross-over the valencies of the combining atoms. That is, with first atom we write the valency of second atom (as a subscript); and with the second atom we write the valency of first atom (as subscript). This will give us the required formula.**

This method of writing the formulae will become more clear from the following example. Let us work out the formula of hydrogen sulphide by this method.

1. Hydrogen sulphide compound is made up of hydrogen and sulphur elements. So, first we write down the symbols of hydrogen and sulphur.
2. The valency of hydrogen is 1 and the valency of sulphur is 2. So, below the symbol H we write 1 and below the symbol S we write 2 :

Symbols :	H	S	H	S	H_2S_1 or H_2S	
Valencies :	1	2	1	2		
			Cross-over valencies		Formula	

3. We now cross-over the valencies of H and S atoms. With H atom we write the valency of S (which is 2) as a subscript so that it becomes H_2. With S atom we write the valency of H (which is 1) as a subscript so that it becomes S_1. Now, joining together H_2 and S_1 the formula of hydrogen sulphide becomes H_2S_1 or H_2S (This is because we do not write the subscript 1 with an atom in a formula). Let us solve some problems now.

Sample Problem 1. Work out the formula of carbon dioxide.

Solution. We can work out the formula of carbon dioxide as follows :

1. Carbon dioxide is a compound made up of carbon and oxygen elements. So, first we write down the symbols of carbon (C) and oxygen (O).
2. The valency of carbon is 4 and the valency of oxygen is 2. So, below the symbol C we write 4 and below the symbol O we write 2.

Symbols :	C	O	C	O			
					C_2O_4	or	CO_2
Valencies :	4	2	4	2			
			Cross-over valencies			Formula	

3. We now cross-over the valencies of C and O atoms. The formula becomes C_2O_4. This formula contains 2 carbon atoms and 4 oxygen atoms having a common factor of 2. So, dividing this formula by the common factor of 2, we get the simplest formula CO_2. Thus, the formula of carbon dioxide is CO_2.

Dear student, we have worked out the formula of carbon dioxide by giving so many details just to make you understand the various steps clearly. After a little more practice, these is no need to write so many steps.

Figure 55. Carbon dioxide is a gas having the chemical formula CO_2. Carbon dioxide is used in some fire extinguishers.

Figure 56. Hydrogen chloride is a gas having the chemical formula HCl. When hydrogen chloride gas dissolves in water, it produces hydrochloric acid.

Figure 57. Hydrochloric acid is used in the manufacture of a very versatile plastic called Poly-Vinyl-Chloride (PVC). The pipes shown in this picture are made of PVC.

Sample Problem 2. Work out the formula of hydrogen chloride.

Solution. Hydrogen chloride is made up of hydrogen and chlorine elements. The symbol of hydrogen is H and that of chlorine is Cl. The valency of hydrogen is 1 and the valency of chlorine is also 1. The formula of hydrogen chloride can be worked out as follows :

Symbols :	H	Cl	H	Cl			
					H_1Cl_1	or	HCl
Valencies :	1	1	1	1			
			Cross-over valencies			Formula	

Thus, the formula of hydrogen chloride compound is HCl

Sample Problem 3. The valency of carbon is 4 and that of chlorine is 1. What will be the formula of carbon tetrachloride ?

Solution. We can work out the formula of carbon tetrachloride as follows :

Symbols :	C	Cl	C	Cl	C_1Cl_4 or	CCl_4
Valencies :	4	1	4	1		
			Cross-over valencies			Formula

Thus, the formula of carbon tetrachloride is CCl_4.

Sample Problem 4. The valency of an element X is 1 and that of oxygen is 2. What will be the formula of the compound formed by the combination of element X with oxygen ?

Solution. The formula of compound of element X with oxygen can be found as follows :

Symbols :	X	O	X	O	X_2O_1 or	X_2O
Valencies :	1	2	1	2		
			Cross-over valencies			Formula

Thus, the formula of compound of element X with oxygen is X_2O.

(Please note that the element X of valency 1 is like hydrogen, H. So, the compound X_2O may be like water, H_2O)

Figure 58. Carbon tetrachloride is a liquid molecular compound having the formula, CCl_4. It is a solvent.

Figure 59. Water is a liquid molecular compound having the formula H_2O. It is a solvent.

Figure 60. Carbon disulphide is also a liquid molecular compound. Its formula is CS_2. It is also a solvent.

Sample Problem 5. An element E has a valency of 4.

(*i*) What will be the formula of its chloride ?

(*ii*) What will be the formula of its sulphide ?

Solution. In order to solve this problem, we should know the valencies of chlorine and sulphur elements (because chlorine forms the chloride and sulphur forms the sulphide). Knowing that the valency of chlorine is 1 and that of sulphur is 2, the above problem can be solved as follows :

(*i*) *Formula of chloride of element E*

Symbols :	E	Cl	E	Cl	E_1Cl_4 or	ECl_4
Valencies :	4	1	4	1		
			Cross-over valencies			Formula

Thus, the formula of chloride of element E is ECl_4.

(*ii*) *Formula of sulphide of element E*

Symbols : E S E S

Valencies : 4 2 4 2

Cross-over valencies

E_2S_4 or ES_2

Formula

Thus, the formula of sulphide of element E is ES_2.

(It should be noted that the element E having a valency of 4 is like carbon, C. So, the choride ECl_4 is like carbon tetrachloride, CCl_4, and the sulphide, ES_2, is like carbon disulphide, CS_2).

Sample Problem 6. An element X shows two valencies of 3 and 5. Work out the formulae of two oxides of this element.

Solution. In order to find out the formulae of the oxides of element X, we should know the valency of oxygen element (because an element combines with oxygen element to form the oxide). Knowing that the valency of oxygen is 2, we can write down the formulae of the two oxides of element X as follows :

(*a*) *Formula of oxide of element X when its valency is 3*

Symbols : X O X O

Valencies : 3 2 3 2

Cross-over valencies

X_2O_3

Formula

Thus, the formula of oxide of element X when its valency is 3 is X_2O_3.

(*b*) *Formula of oxide of element X when its valency is 5*

Symbols : X O X O

Valencies : 5 2 5 2

Cross-over valencies

X_2O_5

Formula

Thus, the formula of oxide of element X when its valency is 5 is X_2O_5.

(Please note that the element X of the above problem having valencies of 3 and 5 is like phosphorus, P, so that the oxide X_2O_3 is like phosphorus trioxide, P_2O_3, and the oxide X_2O_5 is like phosphorus pentoxide, P_2O_5).

Figure 61. Phosphorus trioxide (P_2O_3). The valency of phosphorus in this compound is 3.

Figure 62. Phosphorus pentoxide (P_2O_5). The valency of phosphorus in this compound is 5.

Figure 63. Sulphur hexafluoride (SF_6) is a gas. The valency of sulphur in this compound is 6. The cylinders shown above contain sulphur hexafluoride.

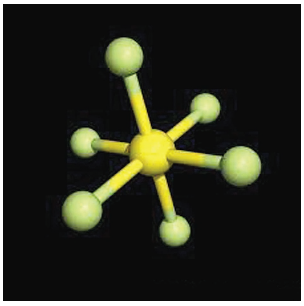


Figure 64. This is a model of sulphur hexafluoride.

Sample Problem 7. An element Z forms an oxide ZO_3.

(*a*) What is the valency of element Z ?

(*b*) What will be the formula of fluoride of Z ?

Solution. (*a*) The compound ZO_3 has three atoms of oxygen. Now :

Valency of one O atom = 2

So, Valency of three O atoms = 2 × 3
= 6

Now, in the compound ZO_3 the valency of Z should be equal to the total valencies of O. Since the total valency of oxygen atoms in this compound is 6, therefore, the valency of element Z should also be 6.

(*b*) Formula of the fluoride of element Z

When element Z combines with fluorine, then its fluoride is formed. Now, valency of element Z is 6 and the valency of element fluorine, F, is 1. So, the formula of fluoride of element Z can be worked out as follows :

Symbols :	Z	F	Z	F	Z_1F_6 or ZF_6	
Valencies :	6	1	6	1		
			Cross-over valencies		Formula	

Thus, the formula of fluoride of element Z is ZF_6.

(Please note that the element Z of this problem is like sulphur element S, so that the oxide ZO_3 is like sulphur trioxide, SO_3, and fluoride ZF_6 is like sulphur hexafluoride, SF_6).

VALENCY OF IONS

In order to write the formulae of ionic compounds, we should know the valencies of positive ions and negative ions which combine to form the ionic compounds. So, we will first discuss the valencies of ions. **The valency of an ion is equal to the charge on the ion.** If an ion has 1 unit charge, its valency is 1 and it is called a monovalent ion. If an ion has 2 units of charge, its valency is 2 and it is called a divalent ion. And if an ion has 3 units of charge, then its valency is 3 and it is called a trivalent ion. Please note that a cation has a positive charge, so it has positive valency ; an anion has negative charge, so it has negative valency. **We should remember the valencies (or charges) of the following cations and anions because then it will become very easy to write the formulae of various ionic compounds.**

Monovalent Cations (Cations Having a Valency of 1+)

Monovalent cations means cations having a valency of 1+. In other words, **monovalent cations means positive ions having a valency of 1+ (one plus).** Some of the important monovalent cations or monovalent positive ions are given below :

1. Hydrogen ion, H^+
2. Lithium ion, Li^+
3. Sodium ion, Na^+
4. Potassium ion, K^+
5. Ammonium ion, NH_4^+
6. Silver ion, Ag^+
7. Copper (I) ion, Cu^+ [Cuprous ion]
8. Mercury (I) ion, Hg^+ [Mercurous ion]

Divalent Cations (Cations Having a Valency of 2+)

Divalent cations means cations having a valency of 2+. In other words, **divalent cations means positive ions having a valency of 2+ (two plus)**. Some of the important divalent cations or divalent positive ions are given below :

1. Magnesium ion, Mg^{2+}
2. Calcium ion, Ca^{2+}
5. Barium ion, Ba^{2+}
6. Copper (II) ion, Cu^{2+}

3. Zinc ion, Zn^{2+}
4. Iron (II) ion, Fe^{2+}
   [Ferrous ion]

[Cupric ion]

7. Mercury (II) ion, Hg^{2+}
   [Mercuric ion]

Figure 65. Silver nitrate compound ($AgNO_3$). It contains a monovalent cation Ag^+ and a monovalent anion NO_3^-

Figure 66. Copper carbonate or copper (II) carbonate ($CuCO_3$). It contains a divalent cation Cu^{2+} and a divalent anion CO_3^{2-}

Figure 67. Ferric chloride or iron (III) chloride ($FeCl_3$). It contains a trivalent cation Fe^{3+} and monovalent anions Cl^-

Trivalent Cations (Cations Having a Valency of 3+)

Trivalent cations means cations having a valency of 3+. In other words, **trivalent cations means positive ions having a valency of 3+ (three plus)**. Some of the important trivalent cations or trivalent positive ions are given below :

1. Aluminium ion, Al^{3+}
2. Iron (III) ion, Fe^{3+}
   [Ferric ion]

Monovalent Anions (Anions Having a Valency of 1–)

Monovalent anions means anions having a valency of 1–. In other words, **monovalent anions means negative ions having a valency of 1– (one minus)**. Some of the important monovalent anions or monovalent negative ions are given below :

1. Hydride ion, H^-
2. Fluoride ion, F^-
3. Chloride ion, Cl^-
4. Bromide ion, Br^-
5. Iodide ion, I^-
6. Nitrite ion, NO_2^-
7. Nitrate ion, NO_3^-
8. Hydroxide ion, OH^-
9. Hydrogencarbonate ion, HCO_3^-
   [Bicarbonate ion]

Figure 68. Potassium iodide compound (KI). It contains a monovalent cation K^+ and a monovalent anion I^-.

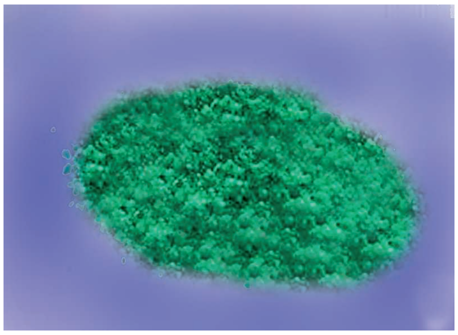


Figure 69. Nickel sulphate compound ($NiSO_4$). It contains a divalent cation Ni^{2+} and a divalent anion SO_4^{2-}.

Figure 70. Calcium phosphate compound [$Ca_3(PO_4)_2$]. It contains a divalent cation Ca^{2+} and trivalent ions $2PO_4^{3-}$.

Divalent Anions (Anions Having a Valency of 2–)

Divalent anions means anions having a valency of 2–. In other words, **divalent anions means negative ions having a valency of 2– (two minus)**. Some of the important divalent anions or divalent negative ions are given below :

1. Oxide ion, O^{2-}
2. Sulphide ion, S^{2-}
3. Sulphite ion, SO_3^{2-}
4. Sulphate ion, SO_4^{2-}
5. Carbonate ion, CO_3^{2-}

Trivalent Anions (Anions Having a Valency of 3–)

Trivalent anions means anions having a valency of 3–. In other words, **trivalent anions means negative ions having a valency of 3– (three minus)**. Some of the important trivalent anions or trivalent negative ions are given below :

1. Nitride ion, N^{3-}
2. Phosphide ion, P^{3-}
3. Phosphate ion, PO_4^{3-}

Please note that **some of the metals like copper, mercury and iron form two types of ions having different charges or different valencies.** For example :

(*a*) Copper metal (Cu) forms two types of ions, Cu^+ and Cu^{2+}. The Cu^+ ion having 1 unit positive charge is known as copper (I) ion where (I) shows that the ion has a valency of 1+. The copper (I) ion Cu^+ is also known as cuprous ion. The second copper ion Cu^{2+} having two units of positive charge is known as copper (II) ion where (II) means that the ion has a valency of 2+. The copper (II) ion Cu^{2+} is also known as cupric ion.

(*a*) This is cuprous oxide or copper (I) oxide, Cu_2O. It contains monovalent copper ions, Cu^+

(*b*) This is cupric oxide or copper (II) oxide, CuO. It contains divalent copper ions, Cu^{2+}

Figure 71. Copper metal (Cu) forms two types of ions, monovalent ions Cu^+ and divalent ions Cu^{2+}.

(*b*) Mercury metal (Hg) also forms two types of ions, Hg^+ and Hg^{2+}. The Hg^+ ion is known as mercury (I) ion or mercurous ion and has a valency of 1+. On the other hand, Hg^{2+} ion is known as mercury (II) ion or mercuric ion and it has a valency of 2+.

(*c*) Iron metal (Fe) forms two types of ions, Fe^{2+} and Fe^{3+}. The Fe^{2+} ion is known as iron (II) ion or ferrous ion and it has a valency of 2+. The Fe^{3+} ion is known as iron (III) ion or ferric ion and it has a valency of 3+.

WRITING OF FORMULAE OF IONIC COMPOUNDS

We will now describe the method of writing the chemical formulae of ionic compounds. First of all we write down the name of compound whose formula is required. Then we write down the symbols of its ions. As a convention, the cation (positive ion) is written on the left hand side and the anion (negative ion) is written on the right hand side. **The number of cations and anions is adjusted in such a way that the total number of positive valencies of cations becomes equal to the total number of negative valencies of anions.** In other words, the number of cations and anions is adjusted in such a way that the total number of positive charges of cations becomes equal to the total number of negative charges of anions (because an ionic compound is electrically neutral, having no over-all charge). The number of cations required (2, 3, 4, etc.) is written on the right side bottom of the symbol of cation but without showing the charge on the cation. For example, if 2 aluminium ions are required to balance the charges in a compound, then $2Al^{3+}$ is written as Al_2 in the formula of the compound. Similarly, the number of anions required (2, 3, 4, etc.) is written on the right side bottom of the symbol of the anion but without showing the charge on the anion. For example, if three sulphate ions are needed to balance the charges in a compound, then $3SO_4^{2-}$ is written as $(SO_4)_3$ in the formula of the compound. Please note that if only 1 cation or anion is required to write the formula of a compound then the digit 1 is not written with the symbol of the ion. For example, if 1 sodium ion Na^+ is needed to write the formula of a compound, then we write just Na for it (and not Na_1). Similarly, if one chloride ion Cl^- is required, then we write just Cl for it (and not Cl_1). Another point to be noted is that **the final formula of an ionic compound is written without showing the charges on the ions involved in it**. Let us take an example to learn the writing of formulae of ionic compounds.

Suppose we have to write the formula of sodium carbonate. Now, sodium carbonate is made up of two types of ions : sodium ion, Na^+, and carbonate ion, CO_3^{2-}.We find that the sodium ion, Na^+, has 1 unit of positive charge whereas carbonate ion, CO_3^{2-}, has 2 units of negative charge. This means that two Na^+ ions are needed to balance the two negative charges (or valencies) of a carbonate ion CO_3^{2-}. So, the sodium carbonate compound is made up of $2Na^+$ ions and one CO_3^{2-} ion, that is, $2Na^+ \, CO_3^{2-}$. Now, when we write the formula of sodium carbonate then $2Na^+$ is written as Na_2 and CO_3^{2-} is written as CO_3 (because charges are not shown in the formula), so that the formula of sodium carbonate becomes Na_2CO_3.

We will now describe the second method of working out the formula of sodium carbonate by the crossing-over of valencies (or charges) of the sodium ion and carbonate ion. First we write down the symbols of sodium ion and carbonate ion (without showing the charges on them). Below the symbol of sodium ion we write the valency (or charge) of sodium ion which is 1+. And below the carbonate ion we write the valency (or charge) of carbonate ion which is 2–. This is shown below :

Symbols :	Na	CO_3	Na	CO_3		
					Na_2CO_3	
Valencies :	1+	2–	1+	2–		
(or Charges)			Cross-over valencies		Formula	

We now cross-over the valencies (or charges) of the sodium ion and carbonate ion. The crossed-over valencies are written as subscripts with the ions (but without their charges). In this way we get Na_2 and CO_3 which on joining give Na_2CO_3. This is the formula of sodium carbonate.

A very important point to note here is that in the 'crossing-over of valencies' method of writing the formulae of ionic compounds, we usually do not write the charges (plus or minus) on the symbols of the ions. This is done just for the sake of convenience and to avoid confusion. The plus and minus charges on the valencies are, however, shown. We will now solve some problems based on the writing of formulae of ionic compounds.

Sample Problem 1. Work out the formula for magnesium chloride.

Solution. Magnesium chloride is an ionic compound made up of magnesium ions (Mg^{2+}) and chloride ions (Cl^-). Magnesium ion has a valency (or charge) of 2+ whereas chloride ion has a valency (or charge) of 1–. The formula for magnesium chloride can be worked out as follows :

Symbols :	Mg	Cl	Mg	Cl	
					Mg_1Cl_2 or $MgCl_2$
Valencies :	2+	1–	2+	1–	
(or Charges)			Cross-over valencies		Formula

Thus, the formula of magnesium chloride is $MgCl_2$.

Figure 72. Sodium carbonate (Na_2CO_3).

Figure 73. Magnesium chloride ($MgCl_2$).

Figure 74. Aluminium sulphate [$Al_2(SO_4)_3$].

Sample Problem 2. Work out the formula for aluminium sulphate.

Solution. Aluminium sulphate is made up of aluminium ions (Al^{3+}) and sulphate ions (SO_4^{2-}). The valency (or charge) of aluminium ion is 3+ whereas the valency or charge of sulphate ion is 2–. The formula for aluminium sulphate can be worked out as follows :

Symbols :	Al	SO_4	Al	SO_4	$Al_2(SO_4)_3$
Valencies :	3+	2–	3+	2–	
(or Charges)			Cross-over valencies		Formula

Thus, the formula of aluminium sulphate is $Al_2(SO_4)_3$.

Sample Problem 3. The symbols of some of the ions are given below :

K^+, Al^{3+}, Br^-, O^{2-}

Using this information, write down the formulae of :

(*i*) Aluminium bromide

(*ii*) Potassium oxide

Solution. (*i*) Formula for aluminium bromide

Symbols :	Al	Br	Al	Br	Al_1Br_3 or $AlBr_3$
Valencies :	3+	1–	3+	1–	
(or Charges)			Cross-over valencies		Formula

Thus, the formula for aluminium bromide is $AlBr_3$.

Please write the formula for potassium oxide yourself. The correct formula will be K_2O.

Sample Problem 4. The valencies of two elements A and B are given below :

Element	*Valency*
A	1+
B	2+

(*i*) What is the formula of sulphate of A ?

(*ii*) What is the formula of nitrate of B ?

Solution. (*i*) *Formula of sulphate of A*

Symbols :	A	SO_4	A	SO_4	A_2SO_4
Valencies :	1+	2–	1+	2–	
(or Charges)			Cross-over valencies		Formula

Thus, the formula of sulphate of element A is A_2SO_4.

(Please note that the element A of valency 1 is like sodium. So, the sulphate A_2SO_4 may be sodium sulphate, Na_2SO_4).

(*ii*) *Formula of nitrate of B*

Symbols :	B	NO_3	B	NO_3		
					$B(NO_3)_2$	
Valencies :	2+	1–	2+	1–		
(or Charges)			Cross-over valencies		Formula	

Thus, the formula of nitrate of element B is $B(NO_3)_2$.

[It should be noted that the element B of valency 2 is like magnesium, so that the nitrate $B(NO_3)_2$ may be magnesium nitrate, $Mg(NO_3)_2$]

Figure 75. Aluminium reacting with bromine to form aluminium bromide, $AlBr_3$.

Figure 76. Sodium sulphate, Na_2SO_4.

Figure 77. Magnesium nitrate, $Mg(NO_3)_2$.

Figure 78. Magnesium sulphate, $MgSO_4$.

Sample Problem 5. The formula of the chloride of a metal is MCl_2. What will be the formula of its sulphate ?

Solution. (*i*) First of all we have to find out the valency of metal M from the formula of its ionic chloride MCl_2. Now, we know that the valency of chlorine (Cl) is 1. Since one atom of M has 2Cl atoms attached to it, so the valency of M is 2 or 2+.

(*ii*) The formula of sulphate of metal M of valency 2 can be found as follows :

Symbols :	M	SO_4	M	SO_4		
					$M_2(SO_4)_2$ or MSO_4	
Valencies :	2+	2–	2+	2–		
(or Charges)			Cross-over valencies		Formula	

Thus, the formula of sulphate of metal M will be MSO_4.

(The metal M of valency 2 is like magnesium, so the chloride MCl_2 is like magnesium chloride, $MgCl_2$, and the sulphate MSO_4 is like magnesium sulphate, $MgSO_4$).

Before we go further and discuss mole concept **please answer the following questions :**

Very Short Answer Type Questions

1. What do we call those particles which have more or less electrons than the normal atoms ?
2. What do we call those particles which have :
   (*a*) more electrons than the normal atoms ?
   (*b*) less electrons than the normal atoms ?
3. Define 'formula mass' of a compound.

4. What do we call those particles which are formed :
(*a*) by the gain of electrons by atoms ?
(*b*) by the loss of electrons by atoms ?

5. State whether the following statements are true or false :
(*a*) A sodium ion has positive charge because it has more protons than a neutral atom
(*b*) A chloride ion has negative charge because it has more electrons than a neutral atom.

6. Write down the formulae for the following compounds :
(*a*) Calcium oxide (*b*) Magnesium hydroxide

7. An element Z has a valency of 3. What is the formula of oxide of Z ?

8. What is the name of a particle which contains 10 electrons, 11 protons and 12 neutrons ?

9. Name the particle which has 18 electrons, 18 neutrons and 17 protons in it.

10. Fill in the following blanks with suitable words :
(*a*) The particle which is formed by the gain of electrons by an atom is called ....
(*b*) The particle which is formed by the loss of electrons by an atom is called.............. .
(*c*) The particle which is formed by the loss or gain of electrons by an atom is called..............
(*d*) A potassium ion has positive charge because it contains less.............. than..................... .
(*e*) A sulphide ion has negative charge because it contains less................ than ....

Short Answer Type Questions

11. Name the elements water is made of. What are the valencies of these elements ? Work out the chemical formula for water.

12. If the valency of hydrogen is 1 and that of nitrogen is 3, work out the formula for ammonia.

13. Work out the formula for sulphur dioxide. (Valencies : S = 4 ; O = 2)

14. If the valency of carbon is 4 and that of sulphur is 2, work out the formula of the compound formed by the combination of carbon with sulphur. What is the name of this compound ?

15. An element X has a valency of 4 whereas another element Y has a valency of 1. What will be the formula of the compound formed between X and Y ?

16. An element B shows valencies of 4 and 6. Write the formulae of its two oxides.

17. An element X of valency 3 combines with another element Y of valency 2. What will be the formula of the compound formed ?

18. Work out the formula for magnesium hydrogencarbonate.

19. An element X has a valency of 2. Write the simplest formula for :
(*a*) bromide of the element
(*b*) oxide of the element

20. Work out the formulae for the following compounds :
(*a*) Sodium oxide (*b*) Calcium carbonate

21. Calculate the formula masses of the following compounds :
(*i*) Sodium oxide, Na_2O
(*ii*) Aluminium oxide, Al_2O_3
(Given : Atomic masses : Na = 23 u ; O = 16 u ; Al = 27 u)

22. Name the following compounds. Also write the symbols/formulae of the ions present in them :
(*a*) $CuSO_4$ (*b*) $(NH_4)_2SO_4$ (*c*) Na_2O (*d*) Na_2CO_3 (*e*) $CaCl_2$

23. Write the cations and anions present, if any, in the following :
(*a*) CH_3COONa (*b*) NaCl (*c*) H_2 (*d*) NH_4NO_3

24. Give the formulae of the compounds formed from the following sets of elements :
(*a*) calcium and fluorine (*b*) hydrogen and sulphur
(*c*) nitrogen and hydrogen (*d*) carbon and chlorine
(*e*) sodium and oxygen (*f*) carbon and oxygen

25. What are (*i*) ionic compounds, and (*ii*) molecular compounds ? Give two examples of each type of compounds.

Long Answer Type Questions

26. (*a*) What is an ion ? How is an ion formed ? Explain with the help of two examples of different ions.

(*b*) The valencies (or charges) of some of the ions are given below :

Ion	*Valency (Charge)*	*Ion*	*Valency (Charge)*
Sodium ion	1+	Bromide ion	1–
Ammonium ion	1+	Hydroxide ion	1–
Calcium ion	2+	Sulphate ion	2–
Lead ion	2+	Phosphate ion	3–

Using this information, write down the formulae of the following compounds :

(*i*) Sodium phosphate (*ii*) Ammonium sulphate

(*iii*) Calcium hydroxide (*iv*) Lead bromide

27. (*a*) What is the difference between a cation and an anion ? Explain with examples.

(*b*) The valencies (or charges) of some of the ions are given below :

Ion	*Valency (Charge)*	*Ion*	*Valency (Charge)*
Sodium ion	1+	Nitrate ion	1–
Copper ion	2+	Sulphide ion	2–

Using this information, write down the formulae of :

(*i*) Sodium sulphide

(*ii*) Copper nitrate

28. Explain the formation of (*i*) sodium ion, and (*ii*) chloride ion, from their respective atoms giving the number of protons and number of electrons in each one of them. What is the reason for positive charge on a sodium ion and a negative charge on a chloride ion ?

29. (*a*) Write the symbols/formulae of two simple ions and two compound ions (or polyatomic ions).

(*b*) An element Y has a valency of 4. Write the formula for its :

(*i*) chloride (*ii*) oxide (*iii*) sulphate (*iv*) carbonate (*v*) nitrate

30. (*a*) Define 'formula unit' of an ionic compound. What is the formula unit of (*i*) sodium chloride, and (*ii*) magnesium chloride ?

(*b*) Calculate the formula masses of the following compounds :

(*i*) Calcium chloride (*ii*) Sodium carbonate

(Given : Atomic masses : Ca = 40 u ; Cl = 35.5 u ; Na = 23 u ; C = 12 u; O = 16 u)

Multiple Choice Questions (MCQs)

31. The atomic number of an element X is 13. What will be the number of electrons in its ion X^{3+} ?

(*a*) 11 (*b*) 15 (*c*) 16 (*d*) 10

32. Which of the following represents a correct chemical formula ?

(*a*) CaCl (*b*) Na_3N (*c*) $NaSO_4$ (*d*) NaS

33. If the number of electrons in an ion Z^{3-} is 10, the atomic number of element Z will be :

(*a*) 7 (*b*) 5 (*c*) 10 (*d*) 8

34. The anion of an element has :

(*a*) more electrons than the normal atom

(*b*) less electrons than the normal atom

(*c*) more protons than the normal atom

(*d*) same number of electrons as normal atom

35. A particle X has 17 protons, 18 neutrons and 18 electrons. This particle is most likely to be :

(*a*) a cation (*b*) an anion (*c*) a molecule (*b*) a compound

36. An element which can exhibit valencies of 2, 4 and 6 can be :

(*a*) copper (*b*) iron (*c*) mercury (*d*) sulphur

37. The atomic number of an element E is 16. The number of electrons in its ion E^{2-} will be :
(*a*) 16 (*b*) 18 (*c*) 15 (*d*) 14

38. The cation of an element has :
(*a*) the same number of electrons as its neutral atom
(*b*) more electrons than a neutral atom
(*c*) less protons than a neutral atom
(*d*) less electrons than a neutral atom

39. Two elements X and Y have valencies of 5 and 3, and 3 and 2, respectively. The elements X and Y are most likely to be respectively :
(*a*) copper and sulphur (*b*) sulphur and iron
(*c*) phosphorus and nitrogen (*d*) nitrogen and iron

40. The number of electrons in an ion Y^{2+} is 10. The atomic number of element Y is most likely to be :
(*a*) 8 (*b*) 12 (*c*) 10 (*d*) 14

41. A particle P has 18 electrons, 20 neutrons and 19 protons. This particle must be :
(*a*) a molecule (*b*) a binary compound (*c*) an anion (*d*) a cation

42. An ionic compound will be formed by the combination of one of the following pairs of elements. This pair of elements is :
(*a*) chlorine and calcium (*b*) calcium and sodium
(*c*) sulphur and carbon (*d*) chlorine and chlorine

43. Molecular compounds are usually formed by the combination between :
(*a*) a metal and a non-metal (*b*) two different non-metals
(*c*) two different metals (*d*) any two gaseous elements

44. The formula of a compound is X_3Y. The valencies of elements X and Y will be respectively :
(*a*) 1 and 3 (*b*) 3 and 1
(*c*) 2 and 3 (*d*) 3 and 2

45. The formula of the sulphate of an element X is $X_2(SO_4)_3$. The formula of nitride of element X will be :
(*a*) X_2N (*b*) XN_2 (*c*) XN (*d*) X_2N_3

Questions Based on High Order Thinking Skills (HOTS)

46. An element A forms an oxide A_2O_5.
(*a*) What is the valency of element A ?
(*b*) What will be the formula of chloride of A ?

47. An element X forms the following compounds with hydrogen, carbon and oxygen :
H_2X, CX_2, XO_2, XO_3
State the three valencies of element X which are illustrated by these compounds.

48. If the aluminium salt of an anion X is Al_2X_3, what is the valency of X ? What will be the formula of the magnesium salt of X ?

49. The formula of carbonate of a metal M is M_2CO_3.
(*a*) What will be the formula of its iodide ?
(*b*) What will be the formula of its nitride ?
(*c*) What will be the formula of its phosphate ?

50. The atom of an element X contains 17 protons, 17 electrons and 18 neutrons whereas the atom of an element Y contains 11 protons, 11 electrons and 12 neutrons.
(*a*) What type of ion will be formed by an atom of element X ? Write the symbol of ion formed.
(*b*) What will be the number of (*i*) protons (*ii*) electrons, and (*iii*) neutrons, in the ion formed from X ?
(*c*) What type of ion will be formed by an atom of element Y ? Write the symbol of ion formed.
(*d*) What will be the number of (*i*) protons (*ii*) electrons, and (iii) neutrons, in the ion formed from Y ?
(*e*) What is the atomic mass of (*i*) X, and (*ii*) Y ?
(*f*) What could the elements X and Y be ?

ANSWERS

1. Ions **2.** (*a*) Anions (*b*) Cations **4.** (*a*) Anions (*b*) Cations **5.** (*a*) False (*b*) True **7.** Z_2O_3 **8.** Sodium ion, Na^+ **9.** Chloride ion, Cl^- **10.** (*a*) anion (*b*) cation (*c*) ion (*d*) electrons ; protons (*e*) protons ; electrons **11.** H_2O **12.** NH_3 **13.** SO_2 **14.** CS_2 ; Carbon disulphide **15.** XY_4 **16.** BO_2 and BO_3 **17.** X_2Y_3 **18.** $Mg(HCO_3)_2$ **19.** (*a*) XBr_2 (*b*) XO **20.** (*a*) Na_2O (*b*) $CaCO_3$ **21.** (*i*) 62 u (*ii*) 102 u **22.** (*a*) Copper sulphate ; Cu^{2+} and SO_4^{2-} (*b*) Ammonium sulphate ; NH_4^+ and SO_4^{2-} (*c*) Sodium oxide ; Na^+ and O^{2-} (*d*) Sodium carbonate ; Na^+ and CO_3^{2-} (*e*) Calcium chloride ; Ca^{2+} and Cl^- **23.** (*a*) Cation : Na^+ ; Anion : CH_3COO^- (*b*) Cation : Na^+ ; Anion Cl^- (*c*) H_2 is a covalent molecule. It has no cation and anion (*d*) Cation : NH_4^+ ; Anion : NO_3^- **24.** (*a*) CaF_2 (*b*) H_2S (*c*) NH_3 (*d*) CCl_4 (*e*) Na_2O (*f*) CO_2 **26.** (*b*) (*i*) Na_3PO_4 (*ii*) $(NH_4)_2SO_4$ (*iii*) $Ca(OH)_2$ (*iv*) $PbBr_2$ **27.** (*b*) (*i*) Na_2S (*ii*) $Cu(NO_3)_2$ **29.** (*b*) (*i*) YCl_4 (*ii*) YO_2 (*iii*) $Y(SO_4)_2$ (*iv*) $Y(CO_3)_2$ (*v*) $Y(NO_3)_4$ **30.** (*a*) (*i*) NaCl (or Na^+Cl^-) (*ii*) $MgCl_2$ (or Mg^{2+} $2Cl^-$) **30.** (*b*) (*i*) 111 u (ii) 106 u **31.** (*d*) **32.** (*b*) **33.** (*a*) **34.** (*a*) **35.** (*b*) **36.** (*d*) **37.** (*b*) **38.** (*d*) **39.** (*d*) **40.** (*b*) **41.** (*d*) **42.** (*a*) **43.** (*b*) **44.** (*a*) **45.** (*c*) **46.** (*a*) 5 (*b*) ACl_5 **47.** 2. 4 and 6 **48.** 2 ; MgX **49.** (*a*) MI (*b*) M_3N (*c*) M_3PO_4 **50.** (*a*) Anion (Negative ion) ; X^- (*b*) (*i*) 17 (*ii*) 18 (*iii*) 18 (*c*) Cation (Positive ion) ; Y^+ (*d*) (*i*) 11 (*ii*) 10 (*iii*) 12 (*e*) (*i*) 35.5 u (*ii*) 23 u (*f*) X : Chlorine (Cl) ; Y : Sodium (Na)

GRAM ATOMIC MASS AND GRAM MOLECULAR MASS

We will now discuss the mole concept. In order to understand the mole concept, we should first know the meaning of the terms ''gram atomic mass'' and ''gram molecular mass''. So, let us discuss these two terms first. Please note that "gram" is the common unit of mass and its symbol is 'g'.

Gram Atomic Mass

The amount of a substance whose mass in grams is numerically equal to its atomic mass, is called gram atomic mass of that substance. In other words, the atomic mass of a substance expressed in grams is called its gram atomic mass. To write the gram atomic mass of a substance, we write its atomic mass and then replace the atomic mass unit 'u' by the word 'gram' or its symbol 'g'. For example :

Atomic mass of oxygen, O = 16 u

So, Gram atomic mass of oxygen, O = 16 grams (or 16 g)

The gram atomic mass of a substance represents the mass of 1 mole of atoms (6.022×10^{23} atoms) of that substance. So, the number of atoms present in 1 gram atomic mass of any substance is 6.022×10^{23} atoms. The atomic mass of hydrogen (H) is 1 u, so the gram atomic mass of hydrogen (H) is 1 gram; the atomic mass of nitrogen (N) is 14 u, so the gram atomic mass of nitrogen (N) is 14 grams ; the atomic mass of oxygen (O) is 16 u, so the gram atomic mass of oxygen (O) is 16 grams; and the atomic mass of sodium (Na) is 23 u, so the gram atomic mass of sodium element is 23 grams.

Before we go further, we will discuss a new term called 'molar mass'. **The molar mass of a substance is the mass of 1 mole of that substance.** The unit of molar mass is **grams per mole** (which is written in short as **g/mol**). The molar mass can be of an element or of a molecular compound. The molar mass of an element is numerically equal to the atomic mass expressed in the units g/mol. And the molar mass of a molecular substance (or compound) is numerically equal to its molecular mass expressed in the units g/mol.

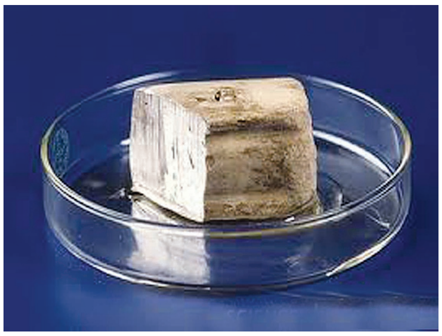


Figure 79. This is sodium element (Na). The atomic mass of sodium is 23 u. So, the gram atomic mass of sodium is 23 grams. We can also say that the molar mass of sodium is 23 gram/mole. 23 grams of sodium element contain 6.022×10^{23} sodium atoms, or 1 mole of sodium atoms.

From the above discussion we conclude that another term which can be used in place of 'gram atomic mass' of an element is the 'molar mass' of element. **The molar mass of an element is the mass of 1 mole of its atoms. The molar mass of an element has 6.022×10^{23} atoms of the element in it.** As we have said above, the molar mass of an element is equal to the atomic mass of the element expressed in the units of g/mol. The atomic mass of hydrogen (H) is 1 u, so the molar mass of hydrogen element (H) is 1 g/mol; the atomic mass of nitrogen (N) is 14 u; so the molar mass of nitrogen element (N) is 14 g/mol ; the atomic mass of oxygen (O) is 16 u, so the molar mass of oxygen element (O) is 16 g/mol; and the atomic mass of sodium (Na) is 23 u, so the molar mass of sodium element (Na) is 23 g/mol.

Please note that when we are dealing with the atoms of an element; we have to use its 'gram atomic mass' or 'molar mass of element'. But when we are dealing with the molecules of a substance, then we have to use its 'gram molecular mass' or 'molar mass of substance' (The substance containing molecules can be an element or a compound).

Gram Molecular Mass

The amount of a substance whose mass in grams is numerically equal to its molecular mass, is called gram molecular mass of that substance. In other words, the molecular mass of a substance expressed in grams is called its gram molecular mass. To write the gram molecular mass of a substance, we write its molecular mass and then replace the unit 'u' by the word 'gram' or its symbol 'g'. For example :

Molecular mass of oxygen, O_2 = 32 u

So, Gram molecular mass of oxygen, O_2 = 32 grams (or 32 g)

The gram molecular mass of a substance represents the mass of 1 mole of molecules (6.022×10^{23} molecules) of that substance. So, the number of molecules present in 1 gram molecular mass of any substance is 6.022×10^{23} molecules. The molecular mass of hydrogen (H_2) is 2 u, so the gram molecular mass of hydrogen (H_2) is 2 grams; the molecular mass of nitrogen (N_2) is 28 u, so the gram molecular mass of nitrogen (N_2) is 28 grams; the molecular mass of oxygen (O_2) is 32 u, so the gram molecular mass of oxygen (O_2) is 32 grams ; and the molecular mass of water (H_2O) is 18 u, so the gram molecular mass of water (H_2O) is 18 grams.

As discussed above, we can also use the term 'molar mass' of the substance in place of 'gram molecular mass' of substance. **The molar mass of a substance is the mass of 1 mole of its molecules. The molar mass of a substance has 6.022×10^{23} molecules of the substance in it.** The molar mass of a molecular substance is equal to the molecular mass of the substance expressed in the units of g/mol. The molecular mass of hydrogen (H_2) is 2 u, so the molar mass of hydrogen (H_2) is 2 g/mol ; the molecular mass of nitrogen (N_2) is 28 u, so the molar mass of nitrogen (N_2) is 28 g/mol ; the molecular mass of oxygen (O_2) is 32 u, so the molar mass of oxygen (O_2) is 32 g/mol; and the molecular mass of water (H_2O) is 18 u, so the molar mass of water (H_2O) is 18 g/mol.

Figure 80. This is water (H_2O) which is a compound. The molecular mass of water is 18 u. So, the gram molecular mass of water is 18 grams. We can also say that the molar mass of water is 18 gram/mole. 18 grams of water contain 6.022×10^{23} water molecules, or 1 mole of water molecules.

Please note that if an element exists as molecules (such as hydrogen, nitrogen, oxygen, chlorine, etc.), then it can have gram atomic mass as well as gram molecular mass. But if an element does not exist as molecules (such as carbon, sodium, calcium, magnesium, etc.), then it can have only gram atomic mass, it cannot have gram molecular mass. All the compounds, however, have only gram molecular mass. From the above discussion we conclude that :

(*i*) 'Gram atomic mass of an element' and 'Molar mass of an element' are just the same, and

(*ii*) 'Gram molecular mass of a substance' and 'Molar mass of a substance' are also just the same.

We will now solve one problem based on the calculation of molar mass.

Sample Problem. Calculate the molar masses of the following substances :

(*a*) Ethyne, C_2H_2 (*b*) Sulphur molecule, S_8

(*c*) Phosphorus molecule, P_4 (*d*) Hydrochloric acid, HCl

(*e*) Nitric acid, HNO_3

(Atomic masses : C = 12 u ; H = 1 u ; S = 32 u ; P = 31 u ; Cl = 35.5 u ; N = 14 u ; O = 16 u)

(NCERT Book Question)

Solution. The molar masses of all these substances will be equal to the respective molecular masses expressed in g/mol. Now :

(*a*) Molar mass of ethyne, C_2H_2 = Mass of C × 2 + Mass of H × 2
= 12 × 2 + 1 × 2
= 24 + 2
= 26 g/mol

(*b*) Molar mass of sulphur molecule, S_8 = Mass of S × 8
= 32 × 8
= 256 g/mol

(*c*) Molar mass of phosphorus molecule, P_4 = Mass of P × 4
= 31 × 4
= 124 g/mol

(*d*) Molar mass of hydrochloric acid, HCl = Mass of H + Mass of Cl
= 1 + 35.5
= 36.5 g/mol

(*e*) Molar mass of nitric acid, HNO_3 = Mass of H + Mass of N + Mass of O × 3
= 1 + 14 + 16 × 3
= 15 + 48
= 63 g/mol

MOLE CONCEPT

Banks have an extremely large number of coins of various denominations. Counting of such a large number of coins is a difficult job. So, in banks, they weigh coins, rather than count them. The bank people know that a fixed number of a particular coin will always have the same mass. This means that from the mass of a particular type of coins, they can find the number of coins. Thus bank people link the mass of coins to the number of coins present. In chemistry also, scientists link the mass of an element or compound to the number of atoms or molecules present in them. This is done through the 'mole'.

Figure 81. The bank clerk is counting money by weighing the coins. The coins of different denominations are first sorted out and then weighed separately.

Figure 82. Just as banks count the money by weighing coins, in the same way, scientists 'count' atoms and molecules by weighing substances.

Scientists count atoms and molecules by weighing them. It has been found by performing experiments that if we weigh an element equal to its atomic mass in grams, then it contains 6.022×10^{23} atoms of the element. Now, the gram atomic mass of the element as well as 6.022×10^{23} atoms of the element, both represent 1 mole of element. Similarly, if we weigh a compound equal to its molecular mass in grams, then it contains 6.022×10^{23} molecules of the compound. In this case also, the gram molecular mass as well as 6.022×10^{23} molecules represent 1 mole of the compound. Thus, **mole is a link between the mass of atoms (or molecules) and the number of atoms (or molecules)**.

The gram atomic mass of carbon element is 12 grams. Now, when a scientist is performing an experiment by weighing 12 grams of carbon, he knows that he is dealing with 6.022×10^{23} atoms of carbon. In other words, he is working with 1 mole of carbon. The gram molecular mass of water is 18 grams. So, when a scientist is using 18 grams of water in his experiment, he knows that he is carrying out the reaction by using 6.022×10^{23} molecules of water. In other words, the scientist is working with 1 mole of water. In the following discussion, we will start by considering mole as a collection of 6.022×10^{23} particles (atoms, molecules or ions) of a substance. We will give the proper definition of mole after a while.

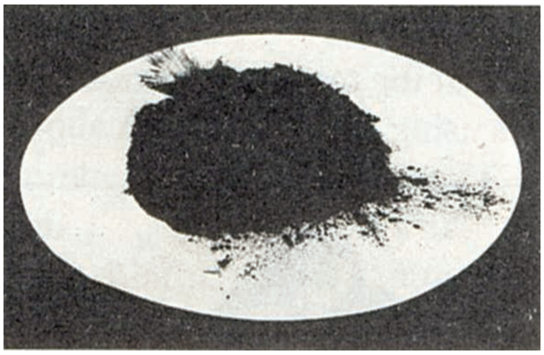


Figure 83. This photograph shows 12 grams of carbon element. It contains 6.022×10^{23} carbon atoms, or 1 mole of carbon atoms.

Figure 84. A mole represents an Avogadro number of particles of a substance. These particles may be atoms, molecules or ions.

Figure 85. The Italian scientist Amedeo Avogadro in whose honour the number of particles (atoms, molecules or ions) in 1 mole of a substance, 6.022×10^{23}, is known as Avogadro number.

A group of 6.022×10^{23} particles (atoms, molecules or ions) of a substance is called a mole of that substance.

Thus, 1 mole of atoms = 6.022×10^{23} atoms

And, 1 mole of molecules = 6.022×10^{23} molecules

It is obvious that **we can have a mole of atoms or a mole of molecules of a substance.** For example, oxygen atom is O and oxygen molecule is O_2. So, we can have a mole of oxygen atoms or a mole of oxygen molecules.

1 mole of oxygen atoms (O) = 6.022×10^{23} oxygen atoms

And, 1 mole of oxygen molecules (O_2) = 6.022×10^{23} oxygen molecules

Thus, mole represents a definite number of particles, atoms or molecules, of a substance. **This number of 6.022×10^{23}, which represents a mole, is known as Avogadro number (L).** We can now say that a mole represents an Avogadro number of particles of a substance. In addition to the definite number of particles of a substance, the mole also represents a definite amount (or mass) of a substance. This point will become more clear from the following discussion.

Mole of Atoms

1 mole of atoms of an element has a mass equal to the gram atomic mass of the element. That is,

1 mole of atoms of an element = Gram atomic mass of the element

Now, the atomic mass of oxygen (O) is 16 u, so gram atomic mass of oxygen will be 16 grams. Thus,

1 mole of oxygen atoms = Gram atomic mass of oxygen
= 16 grams

It should be noted that **the symbol of an element represents 1 mole of atoms of that element.** For example :

Symbol O represents 1 mole of oxygen atoms
and 2 O represents 2 moles of oxygen atoms

Mole of Molecules

1 mole of molecules of a substance has a mass equal to the gram molecular mass of the substance. That is,

1 mole of molecules of a substance = Gram molecular mass of the substance

Now, the molecular mass of oxygen (O_2) is 32 u, so the gram molecular mass of oxygen is 32 grams. Thus,

1 mole of oxygen molecules = Gram molecular mass of oxygen
= 32 grams

It should be noted that **the molecular formula of a substance represents 1 mole of molecules of that substance.** For example :

(*i*) Formula O_2 represents 1 mole of oxygen molecules
and $2O_2$ represents 2 moles of oxygen molecules

(*ii*) Formula H_2O represents 1 mole of water molecules
and $2H_2O$ represents 2 moles of water molecules

Please note that one mole of sulphuric acid, H_2SO_4, contains :

2 moles of hydrogen atoms
1 mole of sulphur atoms
and 4 moles of oxygen atoms

Knowing the mass of 1 mole of a substance we can calculate the mass of any number of moles of that substance. The masses of the moles of some of the substances are given below :

Substance	*Symbol or Formula*	*Mass of 1 mole (Molar mass)*	*This mass (1 mole) contains*
1 mole of hydrogen atoms	H	1 g	6.022×10^{23} hydrogen atoms
1 mole of hydrogen molecules	H_2	$2 \times 1 =$ 2 g	6.022×10^{23} hydrogen molecules
1 mole of water molecules	H_2O	$2 + 16 =$ 18 g	6.022×10^{23} water molecules
1 mole of ammonia molecules	NH_3	$14 + 3 =$ 17 g	6.022×10^{23} ammonia molecules
1 mole of sodium atoms	Na	23 g	6.022×10^{23} sodium atoms

We are now in a position to give the definition of mole as a unit for the amount of substance. **A mole of a substance is that amount of the substance which contains the same number of particles (atoms, molecules or ions) as there are carbon atoms in 12 grams of carbon-12 element.** Since 12 grams of carbon-12 element contain 6.022×10^{23} atoms of carbon, we can also say that : **A mole of a substance is that amount of the**

substance which contains 6.022×10^{23} particles (atoms, molecules or ions) of the substance. Thus, **the SI unit of amount of a substance is mole** which is written in short form as mol. From the above discussion we conclude that :

A mole represents two things :

1. A mole represents a definite amount of the substance. It represents the amount of a substance equal to its gram atomic mass or gram molecular mass.

2. A mole represents a definite number of atoms, molecules or ions of a substance. It represents 6.022×10^{23} atoms, molecules or ions of a substance.

Figure 86. Each watch glass contains 1 mole of the various substances such as glucose, copper sulphate, sulphur, carbon, sodium chloride and iron. The masses of 1 mole of these substances are, however, different. 1 mole of glucose molecules ($C_6H_{12}O_6$) has a mass of 180 g, 1 mole of copper sulphate pentahydrate molecules ($CuSO_4.5H_2O$) has a mass of 249.5 g, 1 mole of sulphur atoms (S) has a mass of 32 g, 1 mole of carbon atoms (C) has a mass of 12 g, 1 mole of sodium chloride molecules (NaCl) has a mass of 58.5 g whereas 1 mole of iron atoms (Fe) has a mass of 56 g.

We will now solve some problems based on the moles of atoms and moles of molecules.

PROBLEMS BASED ON MOLES OF ATOMS

We have just studied that :

1 mole of atoms of an element = Gram atomic mass of the element = 6.022×10^{23} atoms

This gives us three relations :

(*i*) The first relation is :

1 mole of atoms = Gram atomic mass

This relation is used to convert the moles of atoms into mass in grams, and also to convert mass in grams into moles of atoms.

(*ii*) The second relation is :

1 mole of atoms = 6.022×10^{23} atoms

By using this relation we can convert the moles of atoms into number of atoms, and the number of atoms into moles of atoms.

(*iii*) The third relation is :

Gram atomic mass = 6.022×10^{23} atoms

This relation is used to find out the number of atoms in a given mass of the element and also to calculate the mass of a given number of atoms.

We should remember these three relations because they will be used to solve numerical problems based on the moles of atoms. Here are some examples.

Sample Problem 1. How many moles are 5 grams of calcium ? (Atomic mass of calcium = 40 u).

Solution. We know that :

1 mole of atoms = Gram atomic mass

So,1 mole of calcium atoms = Gram atomic mass of calcium

= 40 g

Now, 40 g of calcium = 1 mole of calcium

So, 5 g of calcium = $\frac{1}{40} \times 5$ mole

= $\frac{1}{8}$ mole

= 0.125 mole

Thus, there are 0.125 mole in 5 grams of calcium.

Note. The above problem can also be solved directly by using the formula :

$$\text{Number of moles of atoms} = \frac{\text{Mass of element in grams}}{\text{Gram atomic mass of element}}$$

$$= \frac{5}{40}$$

$$= \frac{1}{8}$$

= 0.125 mole

Thus, 5 grams of calcium constitute 0.125 mole of calcium.

A yet another way of writing the above formula is by using the term 'molar mass' in place of 'gram atomic mass'. That is :

$$\text{Number of moles of atoms} = \frac{\text{Mass of element}}{\text{Molar mass of element}}$$

In the above case, mass of element is 5 grams and molar mass of element is 40 g/mol.

Sample Problem 2. What is the mass of 4 moles of aluminium atoms ?

(Atomic mass of Al = 27 u) **(NCERT Book Question)**

Solution. The atomic mass of aluminium is given to be 27 u. This means that 1 mole of aluminium atoms has a mass of 27 grams.

Now, 1 mole of aluminium atoms = 27 g

So, 4 moles of aluminium atoms = 27 × 4 g

= 108 g

Thus, the mass of 4 moles of aluminium atoms is 108 grams.

Sample Problem 3. Calculate the number of atoms in 0.2 mole of sodium (Na).

Solution. We know that 1 mole of atoms contains 6.022×10^{23} atoms.

Now,

1 mole of sodium atoms = 6.022×10^{23} atoms

So, 0.2 mole of sodium atoms = $6.022 \times 10^{23} \times 0.2$ atoms

= 12.044×10^{22} atoms

Thus, 0.2 mole of sodium element has 12.044×10^{22} atoms in it.

Sample Problem 4. How many moles are 9.033×10^{24} atoms of helium (He) ?

Solution. We know that :

$$6.022 \times 10^{23} \text{ atoms of helium} = 1 \text{ mole}$$

$$\text{So, } 9.033 \times 10^{24} \text{ atoms of helium} = \frac{1}{6.022 \times 10^{23}} \times 9.033 \times 10^{24}$$

$$= 15 \text{ moles} \qquad \text{(or 15 mol)}$$

Thus, 9.033×10^{24} atoms of helium are 15 moles of atoms.

(*a*) A helium gas cylinder (*b*) Helium gas being filled in an ordinary balloon (*c*) Helium gas being filled in a weather balloon (*d*) Helium is filled in advertising balloons like this one

Figure 87. Helium is a very light gas, so it is used to fill various types of balloons.

Sample Problem 5. Calculate the number of iron atoms in a piece of iron weighing 2.8 g (Atomic mass of iron = 56 u).

Solution. 1 mole of iron = Gram atomic mass of iron

= 56 grams

We know that 1 mole of iron element contains 6.022×10^{23} atoms of iron.

Now, 56 g of iron contains = 6.022×10^{23} atoms

$$\text{So, } 2.8 \text{ g of iron contains} = \frac{6.022 \times 10^{23}}{56} \times 2.8$$

$$= \frac{6.022 \times 10^{22}}{2}$$

$$= 3.011 \times 10^{22} \text{ atoms}$$

Thus, a piece of iron metal having a mass of 2.8 grams contains 3.011×10^{22} atoms of iron.

Sample Problem 6. If one mole of carbon atoms weighs 12 grams, what is mass in grams of 1 atom of carbon ? **(NCERT Book Question)**

Solution. 1 mole of carbon atoms means 6.022×10^{23} carbon atoms. In this case 1 mole of carbon atoms weighs 12 grams. This means that the mass of 6.022×10^{23} atoms of carbon is 12 grams.

Now, 6.022×10^{23} atoms of carbon have mass = 12 g

$$\text{So, } 1 \text{ atom of carbon has mass} = \frac{12}{6.022 \times 10^{23}} \text{ g}$$

$$= 1.99 \times 10^{-23} \text{ g}$$

Thus, the absolute mass of 1 atom of carbon is 1.99×10^{-23} gram.

Sample Problem 7. Which has more number of atoms, 100 grams of sodium or 100 grams of iron ? (Atomic masses : Na = 23 u ; Fe = 56 u) **(NCERT Book Question)**

Solution. In order to solve this problem, we should convert 100 grams of sodium into moles of sodium, and also 100 grams of iron into moles of iron. The element having more moles will have more atoms. Please note that since the atomic mass of sodium is 23 u, the molar mass of sodium will be 23 g/mol. Similarly, since the atomic mass of iron is 56 u, the molar mass of iron will be 56 g/mol. We will now calculate the moles of sodium atoms (Na) and iron atoms (Fe), one by one.

(*i*)
$$\text{Moles of sodium} = \frac{\text{Mass of sodium}}{\text{Molar mass of sodium}} = \frac{100}{23} = 4.34$$

(*ii*)
$$\text{Moles of iron} = \frac{\text{Mass of iron}}{\text{Molar mass of iron}} = \frac{100}{56} = 1.78$$

We find that 100 grams of sodium contain 4.34 moles of atoms whereas 100 grams of iron contain 1.78 moles of atoms. Since 100 grams of sodium has more moles, it contains more atoms than 100 grams of iron.

Sample Problem 8. If 1 g of carbon contains x atoms, what will be the number of atoms in 1 g of magnesium ? (C = 12 u, Mg = 24 u)

Solution. The ratio of atoms in carbon and magnesium will be the same as the ratio of their moles. So, first of all we should find out :

(*i*) moles of carbon in 1 gram of carbon, and
(*ii*) moles of magnesium in 1 gram of magnesium

This can be done as follows.

(*a*) 1 mole of carbon = Gram atomic mass of carbon
= 12 grams

Now, 12 g of carbon = 1 mole

So, 1 g of carbon = $\frac{1}{12}$ mole

Thus, we have $\frac{1}{12}$ mole of carbon element and it contains x atoms of carbon. Now, since an equal number of moles of all the elements contain an equal number of atoms, so $\frac{1}{12}$ moles of magnesium will also contain x atoms of magnesium. We will now calculate the moles of magnesium in 1 gram of magnesium.

(*b*) 1 mole of magnesium = Gram atomic mass of magnesium
= 24 grams

Now, 24 g of magnesium = 1 mole

So, 1 g of magnesium = $\frac{1}{24}$ mole

We know that : $\frac{1}{12}$ mole of magnesium contains = x atoms

So, $\frac{1}{24}$ mole of magnesium contains = $\frac{x \times 12}{24}$ atoms
= $\frac{x}{2}$ atoms

Thus, if 1 gram of carbon contains x atoms, then 1 gram of magnesium will have $\frac{x}{2}$ atoms in it.

Figure 88. 1 mole of carbon has a mass of 12 grams (as shown in the above photograph). This 1 mole of carbon (or 12 grams of carbon) contains 6.022×10^{23} atoms of carbon element.

Figure 89. 1 mole of magnesium has a mass of 24 grams (as shown in the above phtograph). This 1 mole of magnesium (or 24 grams of magnesium) contains 6.022×10^{23} atoms of magnesium element.

Sample Problem 9. How many grams of neon will have the same number of atoms as 4 grams of calcium ? (Atomic masses : Ne = 20 u, Ca = 40 u)

Solution. To solve such problems we should remember that "equal number of moles of all the elements contain equal number of atoms".

(*i*) Let us first convert 4 grams of calcium into moles. We have been given that the atomic mass of calcium is 40 u, so 1 mole of calcium is 40 grams.

Now, 40 g of calcium = 1 mole

So, 4 g of calcium = $\frac{1}{40} \times 4$ mole

$= \frac{1}{10}$ mole

Now, $\frac{1}{10}$ mole of calcium will have the same number of atoms as $\frac{1}{10}$ mole of neon. So, we should now convert $\frac{1}{10}$ mole of neon into mass in grams.

(*ii*) The atomic mass of neon is 20 u, so 1 mole of neon will be equal to 20 grams.

Now, 1 mole of neon = 20 g

So, $\frac{1}{10}$ mole of neon = $20 \times \frac{1}{10}$ g

= 2 g

Thus, 2 grams of neon will contain the same number of atoms as 4 grams of calcium.

Sample Problem 10. The mass of a single atom of an element X is 2.65×10^{-23} g. What is its atomic mass ? What could this element be ?

Solution. The atomic mass of an element is numerically equal to the mass of 1 mole of its atoms. Since 1 mole of atoms is 6.022×10^{23} atoms, so it means that the atomic mass of an element is numerically equal to the mass of its 6.022×10^{23} atoms.

Now, 1 atom of element X has mass $= 2.65 \times 10^{-23}$ g

So, 6.022×10^{23} atoms of element X have mass $= 2.65 \times 10^{-23} \times 6.022 \times 10^{23}$

$= 15.96$ g

$\simeq 16$ g

Thus, the atomic mass of the element X is 16 u. The element of atomic mass 16 u is oxygen, having the symbol O.

PROBLEMS BASED ON MOLES OF MOLECULES

We know that :

1 mole of molecules of a substance = Gram molecular mass of the substance = 6.022×10^{23} molecules

This gives us three relations :

(*i*) The first relation is :

1 mole of molecules = Gram molecular mass

This relation can be used to convert the number of moles of molecules into mass in grams, and to convert the mass in grams into moles of molecules.

(*ii*) The second relation is :

1 mole of molecules = 6.022×10^{23} molecules

By using this relation, we can convert the moles of molecules into number of molecules, and the number of molecules can be converted into moles of molecules.

(*iii*) The third relation is :

Gram molecular mass = 6.022×10^{23} molecules

This relation is used to find out the number of molecules in a given mass of the substance and also to calculate the mass of a given number of molecules.

In many of the problems which we are going to solve now, we will need the mass of one mole of molecules of a substance. And to know the mass of one mole of molecules of a substance, we should know its molecular mass. So, first of all we will have to calculate the molecular mass of the substance from its molecular formula by using the atomic masses of the various atoms present in it (This is because the molecular mass of a substance is equal to the atomic masses of all the atoms present in one molecule of the substance).The molecular mass of a substance expressed in grams becomes the "gram molecular mass" of the substance and it gives the mass of 1 mole of the substance (or mass of 6.022×10^{23} molecules of the substance).

The atomic masses of the elements which are required for the calculation of molecular mass are usually given with the problem. But we should also remember the atomic masses of the common elements ourselves because sometimes these are not given in the problem. Keeping these points in mind, we will now solve some problems based on the moles of molecules.

Sample Problem 1. What is the mass of each one of the following ?

(*a*) 1 mole of water (H_2O) (*b*) 1 mole of ethanol (C_2H_6O)

(*c*) 1 mole of glucose ($C_6H_{12}O_6$) (*d*) 1 mole of cane sugar ($C_{12}H_{22}O_{11}$)

(Atomic masses : H = 1 u ; C = 12 u ; O = 16 u)

Solution. The mass of 1 mole of each one of the given substances will be equal to their respective molecular masses expressed in 'grams'. Now :

(*a*) 1 mole of H_2O = Molecular mass of H_2O in grams

= Mass of H × 2 + Mass of O

= 1 × 2 + 16

= 2 + 16

= 18 grams

So, the mass of 1 mole of water (H_2O) is 18 g.

(*b*) 1 mole of C_2H_6O = Molecular mass of C_2H_6O in grams

= Mass of C × 2 + Mass of H × 6 + Mass of O

= 12 × 2 + 1 × 6 + 16

= 24 + 6 + 16

= 46 grams

So, the mass of 1 mole of ethanol (C_2H_6O) is 46 g.

(*c*) 1 mole of $C_6H_{12}O_6$ = Molecular mass of $C_6H_{12}O_6$ in grams

= Mass of C × 6 + Mass of H × 12 + Mass of O × 6

= 12 × 6 + 1 × 12 + 16 × 6

= 72 + 12 + 96

= 180 grams

So, the mass of 1 mole of glucose ($C_6H_{12}O_6$) is 180 g

(*d*) 1 mole of $C_{12}H_{22}O_{11}$ = Molecular mass of $C_{12}H_{22}O_{11}$ in grams

= Mass of C × 12 + Mass of H × 22 + Mass of O × 11

= 12 × 12 + 1 × 22 + 16 × 11

= 144 + 22 + 176

= 342 grams

So, the mass of 1 mole of cane sugar ($C_{12}H_{22}O_{11}$) is 342 g.

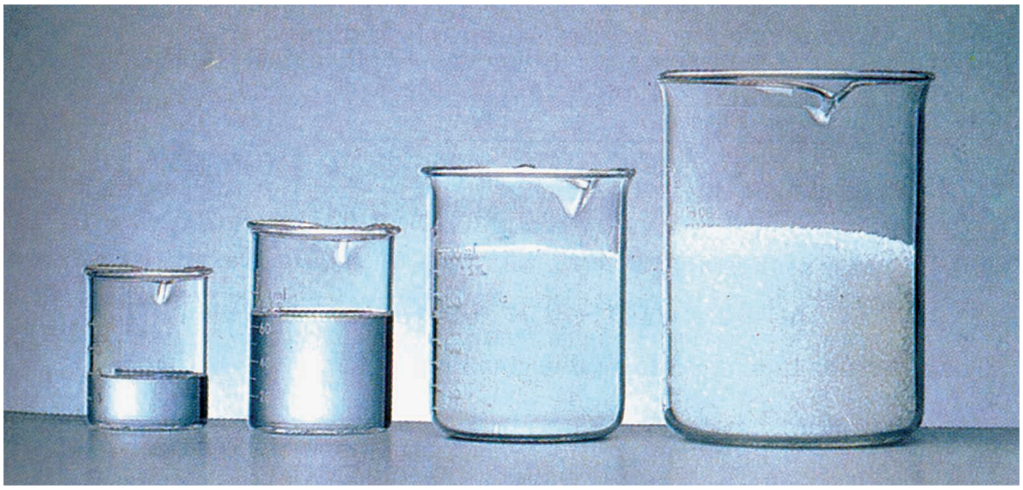


Figure 90. This picture shows 1 mole of all the substances mentioned in Sample Problem 1. The first beaker (from left side) in the above picture contains 1 mole of molecules of water, H_2O (which is 18 g water). The second beaker contains 1 mole of ethanol, C_2H_6O (which is 46 g ethanol). The third beaker from left side contains 1 mole of glucose $C_6H_{12}O_6$ (which is 180 g glucose). And the fourth beaker contains 1 mole of cane sugar or sucrose, $C_{12}H_{22}O_{11}$ (which is 342 g cane sugar).

Sample Problem 2. Convert 22 g of carbon dioxide (CO_2) into moles. (Atomic masses : C = 12 u ; O = 16 u) **(NCERT Book Question)**

Solution. Here we have been given that the atomic mass of carbon (C) is 12 u and the atomic mass of oxygen (O) is 16 u. So, first of all we will calculate the mass of 1 mole of carbon dioxide by using these values of atomic masses. The mass of 1 mole of carbon dioxide (CO_2) will be equal to its molecular mass expressed in grams. That is :

$$\begin{aligned} 1 \text{ mole of } CO_2 &= \text{Molecular mass of } CO_2 \text{ in grams} \\ &= \text{Mass of C + Mass of O} \times 2 \\ &= 12 + 16 \times 2 \\ &= 12 + 32 \\ &= 44 \text{ grams} \end{aligned}$$

So, the mass of 1 mole of carbon dioxide is 44 grams.

$$\begin{aligned} \text{Now, } 44 \text{ g of carbon dioxide} &= 1 \text{ mole} \\ \text{So, } 22 \text{ g of carbon dioxide} &= \frac{1}{44} \times 22 \text{ mole} \\ &= \frac{1}{2} \\ &= 0.5 \text{ mole} \qquad \text{(or 0.5 mol)} \end{aligned}$$

Thus, 22 grams of carbon dioxide are equal to 0.5 mole.

Note. The above problem can also be solved directly by using the formula :

$$\begin{aligned} \textbf{Number of moles of molecules} &= \frac{\textbf{Mass of substance in grams}}{\textbf{Gram molecular mass of substance}} \\ &= \frac{22}{44} \\ &= \frac{1}{2} \\ &= 0.5 \text{ mole} \end{aligned}$$

Thus, 22 grams of carbon dioxide constitute 0.5 mole of carbon dioxide.

A yet another way of writing the above formula is by using the term 'molar mass' in place of 'gram molecular mass'. That is :

$$\textbf{Number of moles of molecules} = \frac{\textbf{Mass of substance}}{\textbf{Molar mass of substance}}$$

In the above case, mass of substance is 22 grams and molar mass of the substance is 44 g/mol.

Sample Problem 3. What is the mass of 0.5 mole of water (H_2O).

(Atomic masses : H = 1 u ; O = 16 u) **(NCERT Book Question)**

Solution. In order to solve this problem, we should know the mass of 1 mole of water. This can be obtained by using the given values of the atomic masses of hydrogen and oxygen as follows :

$$\begin{aligned} 1 \text{ mole of water } (H_2O) &= \text{Molecular mass of } H_2O \text{ in grams} \\ &= \text{Mass of 2H atoms + Mass of O atom} \\ &= 2 \times 1 + 16 \\ &= 2 + 16 \\ &= 18 \text{ grams} \end{aligned}$$

Thus, the mass of 1 mole of water is 18 grams.

Now, Mass of 1 mole of water = 18 g

So, Mass of 0.5 mole of water = 18 × 0.5 g

= 9 g

Thus, the mass of 0.5 mole of water (H_2O) is 9 grams.

Sample Problem 4. What is the number of molecules in 0.25 moles of oxygen ?

Solution. We know that :

1 mole of oxygen contains = 6.022×10^{23} molecules

So, 0.25 mole of oxygen contains = $6.022 \times 10^{23} \times 0.25$

= 1.505×10^{23} molecules

Thus, 0.25 mole of oxygen contains 1.505×10^{23} molecules.

Sample Problem 5. Convert 12.044×10^{22} molecules of sulphur dioxide into moles.

Solution. We know that :

6.022×10^{23} molecules of sulphur dioxide = 1 mole

So, 12.044×10^{22} molecules of sulphur dioxide = $\frac{1}{6.022 \times 10^{23}} \times 12.044 \times 10^{22}$

$= \frac{2}{10}$

= 0.2 mole

Thus, 12.044×10^{22} molecules of sulphur dioxide are 0.2 mole.

Sample Problem 6. What is the number of water molecules contained in a drop of water weighing 0.06 g ?

Solution. We know that 1 mole of water contains 6.022×10^{23} water molecules. So, in order to calculate the number of molecules in 0.06 gram of water, we should first calculate the mass of 1 mole of water in grams.

Now, Molecular mass of water, H_2O = 2 + 16

= 18 u

So, Gram molecular mass of water = 18 grams

(or 1 mole of water)

Thus, 1 mole of water has a mass of 18 grams and it contains 6.022×10^{23} molecules of water.

Now, 18 g water contains = 6.022×10^{23} molecules

So, 0.06 g water contains = $\frac{6.022 \times 10^{23}}{18} \times 0.06$

= 2.007×10^{21} molecules

Thus, a drop of water weighing 0.06 gram contains 2.007×10^{21} molecules of water in it.

Figure 91. A drop of water weighing 0.06 gram contains 2.007×10^{21} molecules of water in it.

Sample Problem 7. Calculate the mass of 3.011×10^{24} molecules of nitrogen gas (N_2). (Atomic mass : N= 14 u)

Solution. First of all we should find out the mass of 1 mole of nitrogen molecules (N_2). Now,

1 mole of N_2 = Molecular mass of N_2 in grams

= Mass of 2 N atoms in grams

= 2 × 14 grams

= 28 grams

Thus, the mass of 1 mole of nitrogen molecules is 28 grams. Now, 1 mole of nitrogen molecules contains 6.022×10^{23} molecules. This means that the mass of 6.022×10^{23} molecules of nitrogen is 28 grams.

Now, Mass of 6.022×10^{23} molecules of N_2 = 28 g

So, Mass of 3.011×10^{24} molecules of N_2 = $\frac{28}{6.022 \times 10^{23}} \times 3.011 \times 10^{24}$

$= \frac{28 \times 10}{2}$

= 140 g

Thus, the mass of 3.011×10^{24} molecules of nitrogen is 140 grams.

Sample Problem 8. The absolute mass of one molecule of a substance is 5.32×10^{-23} g. What is its molecular mass ? What could this substance be ?

Solution. The molecular mass of a substance is numerically equal to the mass of 1 mole of its molecules. Since 1 mole of molecules is equal to 6.022×10^{23} molecules, it means that the molecular mass of a substance is numerically equal to the mass of its 6.022×10^{23} molecules. In this problem we have been given the absolute mass of 1 molecule of the substance, so all that we have to do is to find out the mass of its 6.022×10^{23} molecules.

Now, Mass of 1 molecule of substance = 5.32×10^{-23} g

So, Mass of 6.022×10^{23} molecules of substance = $5.32 \times 10^{-23} \times 6.022 \times 10^{23}$

= 32 g

Thus, the molecular mass of the given substance is 32 u. The substance having a molecular mass of 32 u is oxygen, having the formula O_2.

Sample Problem 9. In which one of the following cases the number of hydrogen atoms is more ?

Two moles of HCl or One mole of NH_3

Solution (*i*) Two moles of HCl can be written as 2HCl. We can see that the two moles of HCl contain 2 moles of H atoms (or hydrogen atoms).

(*ii*) One mole of NH_3 contains 3 moles of H atoms (or hydrogen atoms).

Now, two moles of HCl contain 2 moles of hydrogen atoms whereas one mole of NH_3 contains 3 moles of hydrogen atoms. It is obvious that 1 mole of NH_3 contains more hydrogen atoms.

Sample Problem 10. Calculate the mass of 1 mole of each one of the following :

(*a*) NaCl (*b*) $CaCO_3$ (*c*) $FeSO_4.7H_2O$ (*d*) Na_2O_2

(Atomic masses : H = 1 u ; C = 12 u; O = 16 u ; Na = 23 u ; S = 32 u ; Cl = 35.5 u ; Ca = 40 u ; Fe = 56 u)

Solution. The mass of 1 mole of each one of the given ionic substances will be equal to their respective molecular masses (or formula masses) expressed in grams. In this problem, NaCl is sodium chloride, $CaCO_3$ is calcium carbonate, $FeSO_4.7H_2O$ is ferrous sulphate heptahydrate or iron (II) sulphate heptahydrate and Na_2O_2 is sodium peroxide. Now :

(*a*) 1 mole of NaCl = Formula mass of NaCl in grams

= Mass of Na + Mass of Cl

= 23 + 35.5

= 58.5 g

Thus, the mass of 1 mole of NaCl = 58.5 g

(*b*) 1 mole of $CaCO_3$ = Formula mass of $CaCO_3$ in grams

= Mass of Ca + Mass of C + Mass of O × 3

= 40 + 12 + 16 × 3

= 40 + 12 + 48

= 100 g

Thus, the mass of 1 mole of $CaCO_3$ is 100 g.

(*c*) 1 mole of $FeSO_4.7H_2O$ = Formula mass of $FeSO_4.7H_2O$ in grams

= Mass of Fe + Mass of S + Mass of O × 11 + Mass of H × 14

= 56 + 32 + 16 × 11 + 1 ×14

= 56 + 32 + 176 + 14

= 278 g

Thus, the mass of 1 mole of $FeSO_4.7H_2O$ is 278 g.

(*d*) 1 mole of Na_2O_2 = Formula mass of Na_2O_2 in grams

= Mass of Na × 2 + Mass of O × 2

= 23 × 2 + 16 × 2

= 46 + 32

= 78 g

Thus, the mass of 1 mole of Na_2O_2 is 78 g.

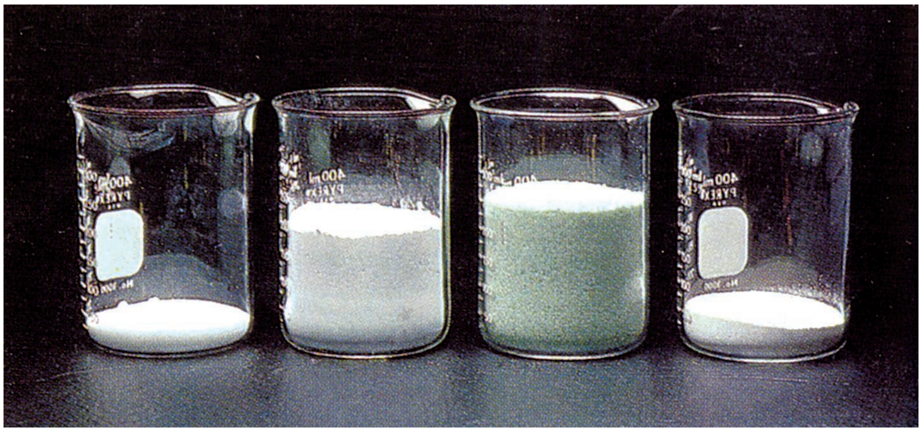


Figure 92. This picture shows 1 mole of all the substances given in Sample Problem 10. The first beaker (from left side) in this picture contains 1 mole of sodium chloride (NaCl) which has a mass of 58.5 g. The second beaker contains 1 mole of calcium carbonate ($CaCO_3$) having a mass of 100 g. The third beaker from left side contains 1 mole of ferrous sulphate heptahydrate ($FeSO_4.7H_2O$) which has a mass of 278 g. And the fourth beaker contains 1 mole of sodium peroxide (Na_2O_2) having a mass of 78 g.

Sample Problem 11. Which contains more molecules, 4 g of methane (CH_4) or 4 g of oxygen (O_2) ? (Atomic masses : C = 12 u, H = 1 u, O = 16 u)

Solution. In this problem, we should convert 4 g of methane into moles and 4 g of oxygen should also be converted into moles by using the respective gram molecular masses. The substance having more moles will contain more molecules in it.

(*i*) Here, Mass of methane (CH_4) = 4 grams

Gram molecular mass of CH_4 = Mass of C + Mass of 4 H

= 12 + 4 × 1

= 16 grams

Now, Number of moles of CH_4 $= \dfrac{\text{Mass of } CH_4 \text{ in grams}}{\text{Gram molecular mass of } CH_4}$

$= \dfrac{4}{16}$

$$= \frac{1}{4}$$

$= 0.250$ mole

(*ii*) Here, Mass of oxygen (O_2) $= 4$ grams

Gram molecular mass of O_2 = Mass of 2 'O' atoms

$= 2 \times 16$

$= 32$ grams

Now, $$\text{Number of moles of } O_2 = \frac{\text{Mass of } O_2 \text{ in grams}}{\text{Gram molecular mass of } O_2}$$

$$= \frac{4}{32}$$

$$= \frac{1}{8}$$

$= 0.125$ mole

We find that 4 g of CH_4 contains more moles of molecules (0.250 moles), whereas 4 g of O_2 contains less moles of molecules (0.125 moles). Since 4 g of methane has more moles, it contains more molecules (than 4 g of oxygen).

Sample Problem 12. If 1 g of sulphur dioxide contains x molecules, what will be the number of molecules in 1 g of methane ? (S = 32 u, O = 16 u, C = 12 u, H = 1 u)

Solution. The ratio of molecules in sulphur dioxide and methane will be the same as the ratio of their moles. So, first of all we should find out the number of moles of sulphur dioxide in 1 gram of sulphur dioxide, and the number of moles of methane in 1 gram of methane. This can be done as follows :

(*i*) The molecular formula of sulphur dioxide is SO_2.

So, 1 mole of SO_2 = Mass of S + Mass of 2 'O'

$= 32 + 2 \times 16$

$= 64$ grams

Now, 64 g of sulphur dioxide = 1 mole

So, 1 g of sulphur dioxide $= \frac{1}{64}$ mole

Thus, we have $\frac{1}{64}$ mole of sulphur dioxide and it contains x molecules in it. Now, since equal moles of all the substances contain equal number of molecules, therefore, $\frac{1}{64}$ mole of methane will also contain x molecules of methane.

We will now calculate the number of moles in 1 gram of methane.

(*ii*) Molecular formula of methane is CH_4.

So, 1 mole of CH_4 = Mass of C + Mass of 4 H

$= 12 + 4 \times 1$

$= 16$ grams

Now, 16 g of methane = 1 mole

So, 1 g of methane $= \frac{1}{16}$ mole

We know that :

$\frac{1}{64}$ mole of methane contains $= x$ molecules

So, $\frac{1}{16}$ mole of methane will contain $= \frac{x \times 64}{16}$ molecules

$= 4x$ molecules

Thus, if 1 g of sulphur dioxide contains x molecules, then 1 g of methane contains $4x$ molecules.

Sample Problem 13. How many grams of oxygen gas contain the same number of molecules as 16 grams of sulphur dioxide gas ? (O = 16 u, S = 32 u)

Solution. This problem will be solved by using the fact that equal moles of all the gases contain equal number of molecules. Let us first convert 16 grams of sulphur dioxide into moles.

1 mole of sulphur dioxide, SO_2 = Mass of S + Mass of 2 'O'

$= 32 + 2 \times 16$

$= 64$ grams

Now, 64 g of sulphur dioxide = 1 mole

So, 16 g of sulphur dioxide $= \frac{1}{64} \times 16$ mole

$= \frac{1}{4}$ mole

Now, $\frac{1}{4}$ mole of sulphur dioxide will have the same number of molecules as $\frac{1}{4}$ mole of oxygen. So, we should now convert $\frac{1}{4}$ mole of oxygen into mass in grams.

1 mole of oxygen, O_2 = Mass of 2 'O' atoms

$= 2 \times 16$

$= 32$ grams

Now, 1 mole of oxygen = 32 grams

So, $\frac{1}{4}$ mole of oxygen $= 32 \times \frac{1}{4}$ grams

$= 8$ grams

Thus, 8 grams of oxygen will contain the same number of molecules as 16 grams of sulphur dioxide.

Sample Problem 14. Calculate the number of aluminium ions present in 0.051 g of aluminium oxide (Al_2O_3). (Atomic masses : Al = 27 u; O = 16 u) **(NCERT Book Question)**

Solution. This problem involves aluminium ions. Please note that the mass of an aluminium ion is the same as that of an aluminium atom. In order to solve this problem, first of all we have to find out the mass of aluminium atoms in 0.051 g of aluminium oxide (which will give us the mass of aluminium ions) This can be done as follows :

1 mole of Al_2O_3 = Formula mass of Al_2O_3 in grams

= Mass of Al × 2 + Mass of O × 3

$= 27 \times 2 + 16 \times 3$

$= 54 + 48$

$= 102$ grams

Now, 1 mole of Al_2O_3 contains 2 moles of Al.

So, Mass of Al in 1 mole of Al_2O_3 = Mass of Al × 2

$= 27 \times 2$

$= 54$ grams

Now, 102 g aluminium oxide contains = 54 g Al

So, 0.051 g aluminium oxide contains = $\frac{54}{102} \times 0.051$ g Al

= 0.027 g Al

The atomic mass of aluminium is given to be 27 u. This means that 1 mole of aluminium atoms (or aluminium ions) has a mass of 27 grams, and it contains 6.022×10^{23} aluminium ions.

Now, 27 g of aluminium has ions = 6.022×10^{23}

So, 0.027 g of aluminium has ions = $\frac{6.022 \times 10^{23}}{27} \times 0.027$

= 6.022×10^{20}

Thus, the number of aluminium ions (Al^{3+}) in 0.051 gram of aluminium oxide is 6.022×10^{20}.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. What is a group of 6.022×10^{23} particles known as ?

2. What name is given to the amount of substance containing 6.022×10^{23} particles (atoms, molecules or ions) of a substance ?

3. What is the numerical value of Avogadro number ?

4. How many atoms are present in one gram atomic mass of a substance ?

5. How many molecules are present in one gram molecular mass of a substance ?

6. What name is given to the number 6.022×10^{23} ?

7. Convert 12 g of oxygen gas into moles.

8. How many moles are 3.6 g of water ?

9. What is the mass of 0.2 mole of oxygen atoms ?

10. Find the mass of 2 moles of nitrogen atoms.

11. Fill in the following blanks :

(*a*) 1 mole contains .... atoms, molecules or ions of a substance.

(*b*) A mole represents an .... number of particles of a substance.

(*c*) 60 g of carbon element are .... moles of carbon atoms.

(*d*) 0.5 mole of calcium element has a mass of ....

(*e*) 64 g of oxygen gas contains .... moles of oxygen atoms.

Short Answer Type Questions

12. (*a*) How many atoms are there in exactly 12 g of carbon-12 element ? (C = 12 u)

(*b*) What name is given to this number ?

(*c*) What name is given to the amount of substance containing this number of atoms ?

13. Calculate the mass of 12.044×10^{25} molecules of oxygen (O_2).

14. What is the number of molecules in 1.5 moles of ammonia ?

15. How many moles of calcium carbonate ($CaCO_3$) are present in 10 g of the substance ? (Ca = 40 u ; C= 12 u; O = 16 u)

16. How many moles of O_2 are there in 1.20×10^{22} oxygen molecules ?

17. If one mole of nitrogen molecules weighs 28 g, calculate the mass of one molecule of nitrogen in grams.

18. How many moles are there in 34.5 g of sodium ? (Atomic mass of Na = 23 u)

19. What is the number of zinc atoms in a piece of zinc weighing 10 g ?
(Atomic mass of Zn = 65 u)

20. Calculate the mass of 3.011×10^{24} atoms of carbon.

21. If 16 g of oxygen contains 1 mole of oxygen atoms, calculate the mass of one atom of oxygen.

22. How many atoms are there in 0.25 mole of hydrogen ?

23. Calculate the number of moles in 12.044×10^{25} atoms of phosphorus.

24. Calculate the number of molecules present in a drop of chloroform ($CHCl_3$) weighing 0.0239 g. (Atomic masses : C = 12 u ; H = 1 u ; Cl = 35.5 u)

25. What is the mass of 5 moles of sodium carbonate (Na_2CO_3) ?
(Atomic masses : Na = 23 u ; C = 12 u ; O = 16 u)

26. Calculate the number of molecules in 4 g of oxygen.

27. How many moles are represented by 100 g of glucose, $C_6H_{12}O_6$? (C = 12 u, H = 1 u, O = 16 u)

28. Calculate the mass in grams of 0.17 mole of hydrogen sulphide, H_2S.
(Atomic masses : H = 1 u, S = 32 u)

29. Show by means of calculations that 5 moles of CO_2 and 5 moles of H_2O do not have the same mass. How much is the difference in their masses ?

30. Calculate the mole ratio of 240 g of calcium and 240 g of magnesium. (Ca = 40 u ; Mg = 24 u)

Long Answer Type Questions

31. (*a*) Define mole. What are the two things that a mole represents.
(*b*) What weight of each element is present in 1.5 moles of sodium sulphite, Na_2SO_3 ?
(Atomic masses : Na = 23 u ; S = 32 u ; O = 16 u)

32. (*a*) What is meant by 'a mole of carbon atoms' ?
(*b*) Which has more atoms, 50 g of aluminium or 50 g of iron ? Illustrate your answer with the help of calculations.
(Atomic masses : Al = 27 u ; Fe = 56 u)

33. (*a*) Define gram atomic mass of a substance. How much is the gram atomic mass of oxygen ?
(*b*) How many moles of oxygen atoms are present in one mole of the following compounds ?
(*i*) Al_2O_3 (*ii*) CO_2 (*iii*) Cl_2O_7 (*iv*) H_2SO_4 (*v*) $Al_2(SO_4)_3$

34. (*a*) Define gram molecular mass of a substance. How much is the gram molecular mass of oxygen ?
(*b*) If sulphur exists as S_8 molecules, calculate the number of moles in 100 g of sulphur. (S = 32 u)

35. (*a*) What is meant by the 'molar mass' of a substance ? State the unit in which molar mass is usually expressed.
(*b*) Calculate the molar masses of the following substances. Write the results with proper units.
(*i*) Ozone molecule, O_3 (*ii*) Ethanoic acid, CH_3COOH

Multiple Choice Questions (MCQs)

36. Which of the following pair of elements represents a mole ratio of 1 : 1 ?
(*a*) 10 g of calcium and 12 g of magnesium (*b*) 12 g of magnesium and 6 g of carbon
(*c*) 12 g of carbon and 20 g of calcium (*d*) 20 g of sodium and 20 g of calcium

37. Which of the following correctly represents 360 g of water ?
(*i*) 2 moles of H_2O (*ii*) 20 moles of water
(*iii*) 6.022×10^{23} molecules of water (*iv*) 1.2044×10^{25} molecules of water
(*a*) (*i*) (*b*) (*i*) and (*iv*) (*c*) (*ii*) and (*iii*) (*d*) (*ii*) and (*iv*)

38. If 32 g of sulphur has x atoms, then the number of atoms in 32 g of oxygen will be :
(*a*) $\frac{x}{2}$ (*b*) $2x$ (*c*) x (*d*) $4x$

39. A student wants to have 3.011×10^{23} atoms each of magnesium and carbon elements. For this purpose, he will have to weigh :
(*a*) 24 g of magnesium and 6 g of carbon (*b*) 12 g of carbon and 24 g of magnesium
(*c*) 20 g of magnesium and 10 g of carbon (*d*) 12 g of magnesium and 6 g of carbon

40. The ratio of moles of atoms in 12 g of magnesium and 16 g of sulphur will be :
(*a*) 3 : 4 (*b*) 4 : 3 (*c*) 1 : 1 (*b*) 1 : 2

41. If 12 gram of carbon has x atoms, then the number of atoms in 12 grams of magnesium will be :
(*a*) x (*b*) $2x$ (*c*) $\frac{x}{2}$ (*d*) $1.5\,x$

42. Which of the following has the maximum number of atoms ?

(*a*) 18 g of H_2O (*b*) 18 g of O_2 (*c*) 18 g of CO_2 (*d*) 18 g of CH_4

Questions Based on High Order Thinking Skills (HOTS)

43. If 1 gram of sulphur dioxide contains *x* molecules, how many molecules will be present in 1 gram of oxygen ? (S = 32 u ; O = 16 u)

44. The mass of one molecule of a substance is 4.65×10^{-23} g. What is its molecular mass ? What could this substance be ?

45. Which contains more molecules, 10 g of sulphur dioxide (SO_2) or 10 g of oxygen (O_2) ?
(Atomic masses : S = 32 u ; O = 16 u)

46. What weight of oxygen gas will contain the same number of molecules as 56 g of nitrogen gas ? (O = 16 u ; N = 14 u)

47. What mass of nitrogen, N_2, will contain the same number of molecules as 1.8 g of water, H_2O ? (Atomic masses : N = 14 u ; H = 1 u ; O = 16 u)

48. If one gram of sulphur contains *x* atoms, calculate the number of atoms in one gram of oxygen element. (Atomic masses : S = 32 u ; O = 16 u)

49. How many grams of magnesium will have the same number of atoms as 6 grams of carbon ?
(Mg = 24 u ; C = 12 u)

50. The mass of one atom of an element X is 2.0×10^{-23} g.

(*i*) Calculate the atomic mass of element X.

(*ii*) What could element X be ?

ANSWERS

1. One mole **2.** One mole **6.** Avogadro number **7.** 0.375 mol **8.** 0.2 mol **9.** 3.2 g **10.** 28 g **11.** (*a*) 6.022×10^{23} (*b*) Avogadro (*c*) 5 (*d*) 20 g (*e*) 4 **12.** (*a*) 6.022×10^{23} atoms (*b*) Avogadro number (*c*) Mole **13.** 6.4 kg **14.** 9.033×10^{23} molecules **15.** 0.1 mol **16.** 0.0199 mol **17.** 4.648×10^{-23} g **18.** 1.5 moles **19.** 9.264×10^{22} atoms **20.** 60 g **21.** 2.656×10^{-23} g **22.** 1.50×10^{23} atoms **23.** 200 mol **24.** 12.044×10^{19} molecules **25.** 530 g **26.** 7.528×10^{22} molecules **27.** 0.55 mol **28.** 5.78 g **29.** 5 moles of $CO_2 = 5 \times 44 = 220$ g ; 5 moles of $H_2O = 5 \times 18 = 90$ g ; Difference = 130 g **30.** 3 : 5 **31.** (*b*) Na = 69 g ; S = 48 g ; O = 72 g **32.** (*b*) 50 g aluminium **33.** (*b*) (*i*) 3 mol (*ii*) 2 mol (*iii*) 7 mol (*iv*) 4 mol (*v*) 12 mol **34.** (*b*) 0.39 mol **35.** (*b*) (*i*) 48 g/mol (*ii*) 60 g/mol **36.** (*b*) **37.** (*d*) **38.** (*b*) **39.** (*d*) **40.** (*c*) **41.** (*c*) **42.** (*d*) **43.** 2*x* **44.** 28 u ; Nitrogen. **45.** 10 g oxygen **46.** 64 g oxygen **47.** 2.8 g **48.** 2*x* **49.** 12 g **50.** (*i*) 12 u (*ii*) Carbon

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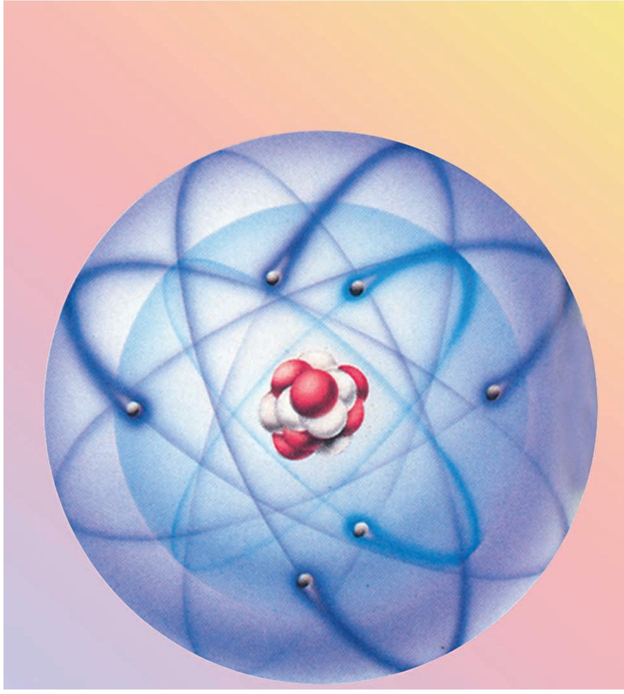


STRUCTURE OF ATOM

Atoms and molecules are the building blocks of matter. The existence of different kinds of matter around us is due to the different types of atoms and molecules present in them. For a long time it was thought that the atoms are indivisible, so they do not have an inner structure. We now know that atoms are divisible and they do have an inner structure. Atoms have smaller particles in them which are called subatomic particles.

Atoms are made up of three subatomic particles : electrons, protons and neutrons. Electron has negative charge, proton has positive charge, whereas neutron has no charge, it is neutral.

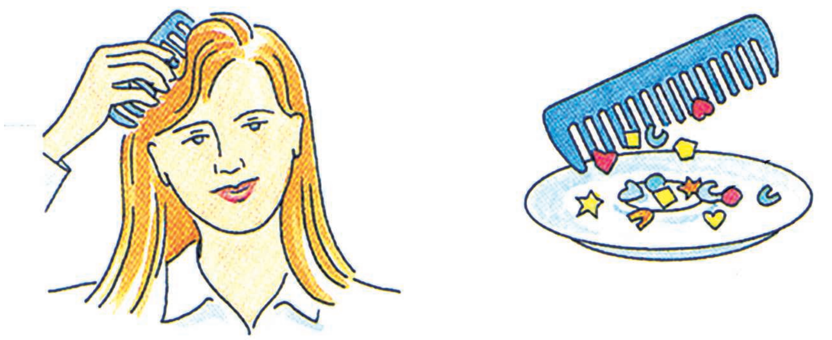
Protons and neutrons are present in a small nucleus at the centre of the atom. Almost the entire mass of the atom is in the nucleus because the electrons, which are outside the nucleus, have very, very small mass. Due to the presence of protons, nucleus has positive charge.

Electrons are outside the nucleus. The electrons in an atom revolve rapidly round the nucleus in fixed circular paths called energy levels or shells. Since an atom on the whole is electrically neutral (having no overall positive or negative charge), therefore, the number of electrons outside the nucleus is equal to the number of protons inside the nucleus.

Atoms of all the elements (except hydrogen) are made up of the three subatomic particles : electrons, protons and neutrons. Hydrogen atom is made up of only one electron and one proton. It does not contain any neutron. **The atoms of different elements differ in the number of electrons, protons and neutrons.** We will now describe how electrons, protons and neutrons were discovered and put together to give the structure of atom.

Charged Particles in Matter

If we rub a comb in dry hair, then this comb attracts small pieces of paper. And if we rub a glass rod with a piece of silk



(*a*) Combing the hair produces electric charge. (*b*) Electrically charged comb then attracts tiny pieces of paper.

Figure 1. The electric charge produced on the comb (on rubbing in hair) comes from the atoms present in the comb. This shows that some charged particles are present in the atoms of comb (and hence of other matter).

cloth and bring it near an inflated balloon, then the glass rod attracts the balloon. We know that an electrically charged object can attract an uncharged object. This means that on rubbing with dry hair, a comb gets an electric charge, and on rubbing with silk cloth, a glass rod also gets an electric charge. Now, the question arises : Where does this electric charge come from ? The obvious answer is : from within the atoms present in the comb and glass rod. These simple experiments tell us that some charged particles are present in the atoms of matter. So, the atom is divisible.

DISCOVERY OF ELECTRON

The existence of electrons in an atom was shown by J.J. Thomson in 1897. Thomson passed electricity at high voltage through a gas at very low pressure taken in a discharge tube. Streams of minute particles were given out by the cathode (negative electrode). These streams of particles are called cathode rays (because they come out of cathode). The mass and charge of the cathode ray particles does not depend on the nature of gas taken in the discharge tube. **Cathode rays consist of small, negatively charged particles called electrons. Since all the gases form cathode rays, it was concluded that all the atoms contain negatively charged particles called electrons.**

Figure 2. J.J. Thomson : The scientist who discovered the negatively charged subatomic particle called electron.

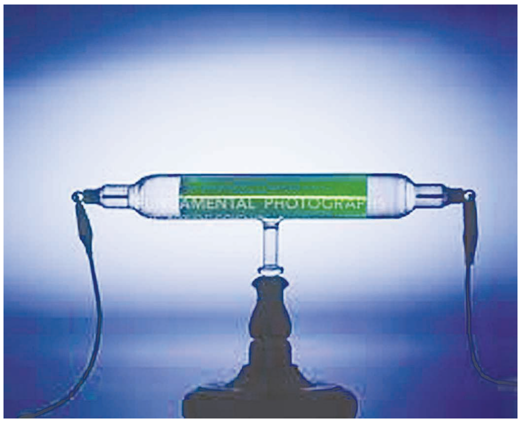


Figure 3. The greenish light in the above gas discharge tube is produced when invisible cathode rays strike on the glass walls of the discharge tube. The stream of cathode rays in the gas discharge tube consists of negatively charged particles called electrons.

Thomson explained the formation of cathode rays as follows. The gas taken in the discharge tube consists of atoms, and all the atoms contain electrons. When high electrical voltage is applied, the electrical energy pushes out some of the electrons from the atoms of the gas. These **fast moving electrons form cathode rays**. Thus, **the formation of cathode rays shows that one of the subatomic particle present in all the atoms is the negatively charged 'electron'.** We can now define an electron as follows.

The electron is a negatively charged particle found in the atoms of all the elements. The electrons are located outside the nucleus in an atom. Only hydrogen atom contains one electron, all other atoms contain more than one electron. An electron is usually represented by the symbol e^- (e for electron and minus sign for negative charge).

Characteristics of an Electron

The two important characteristics of an electron are its mass and charge. These are described below.

1. Mass of an Electron. The mass of an electron is about $\frac{1}{1840}$ of the mass of hydrogen atom (which is the atom of lowest mass). Since the mass of a hydrogen atom is 1 u, we can say that **the relative mass of an electron is $\frac{1}{1840}$ u.** The absolute mass of an electron is, however, 9×10^{-28} gram. The mass of an electron is so small that it is considered to be negligible. This is why the mass of electrons is ignored while calculating the atomic mass of an element.

2. Charge of an Electron. The absolute charge on an electron is 1.6×10^{-19} coulomb of negative charge. Now, 1.6×10^{-19} coulomb has been found to be the smallest negative charge carried by any particle. So, this is taken as the unit of negative charge. This means that an electron has 1 unit of negative charge. In other words, **the relative charge of an electron is, –1 (minus one).**

DISCOVERY OF PROTON

The formation of cathode rays has shown that all the atoms contain negatively charged particles called electrons. Now, an atom is electrically neutral, so it must contain some positively charged particles to balance the negative charge of electrons. It has actually been found by experiments that all the atoms contain positively charged particles called protons.

The existence of protons in the atoms was shown by E. Goldstein. When Goldstein passed electricity at high voltage through a gas at very low pressure taken in a discharge tube, streams of heavy particles were given out by the anode (positive electrode). These streams of particles are called anode rays. Anode rays consist of positively charged particles. The mass and charge of the anode ray particles depends on the nature of gas taken in the discharge tube. Different gases give different types of anode rays which contain positively charged particles having different masses and different charges.

Figure 4. Eugen Goldstein : The scientist who discovered the positively charged subatomic particle called proton.

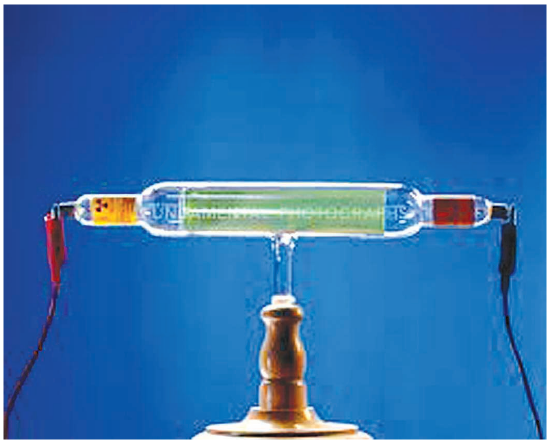


Figure 5. The faint red glow in the above gas discharge tube (seen on the extreme left side in the above picture) is produced when invisible anode rays strike on the glass walls of the discharge tube. The anode rays obtained from hydrogen gas in the discharge tube consist of positively charged particles called protons.

Hydrogen gas is the lightest gas and hydrogen atom is the lightest atom. So, the positive particles obtained from hydrogen gas are the lightest and have the smallest charge. The anode rays obtained from hydrogen gas are made up of the same type of positive particles. These particles are called protons. Thus, **the anode rays obtained from hydrogen gas consist of protons.** *A proton is formed by the removal of an electron from a hydrogen atom.*

Goldstein explained the formation of protons as follows. Hydrogen gas consists of hydrogen atoms. When high electrical voltage is applied to hydrogen gas, the electrical energy removes the electrons from the hydrogen atoms. After the removal of negatively charged electron from a hydrogen atom, a positively charged particle called proton is formed. These **fast moving protons form the anode rays**. Please note that hydrogen atoms are the lightest of all the atoms, so hydrogen atoms form the lightest positively charged particles called protons. The heavier atoms of other gases form heavier positively charged particles which are made up of a number of protons held together. We can now define a proton as follows.

The proton is a positively charged particle found in the atoms of all the elements. The protons are located in the nucleus of an atom. Only hydrogen atom contains one proton in its nucleus, atoms of all other elements contain more than one proton. A proton is usually represented by the symbol p^+ (p for proton and plus sign for positive charge).

Characteristics of a Proton

The two important characteristics of a proton are its mass and charge. These are described below.

1. Mass of a Proton. The proton is actually a hydrogen atom which has lost its electron. Since the mass of an electron is very small, we can say that *the mass of a proton is equal to the mass of a hydrogen atom.* But the mass of a hydrogen atom is 1 u, therefore, **the relative mass of a proton is 1 u.** If, however, we compare the mass of a proton with that of an electron, then the mass of a proton is 1840 times that of an electron. The absolute mass of a proton is 1.6×10^{-24} gram.

2. Charge of a Proton. **The charge of a proton is equal and opposite to the charge of an electron.** So, the absolute charge of a proton is 1.6×10^{-19} coulomb of positive charge. Now, 1.6×10^{-19} coulomb has been found to be the smallest positive charge carried by any particle. So, this is taken as the unit of positive charge. This means that proton carries 1 unit positive charge. In other words, **the relative charge of a proton is +1 (plus one).**

The formation of cathode rays and anode rays on passing electricity through gases at very low pressure tells us that atom is not indivisible, it is made up of smaller particles. Actually, *the formation of cathode rays tells us that atoms contain negatively charged particles (electrons) inside them whereas the formation of anode rays tells us that atoms contain positively charged particles (protons) in them.*

DISCOVERY OF NEUTRON

After the discovery of protons and electrons, it was noticed that all the mass of an atom cannot be accounted for on the basis of only protons and electrons present in it. For example, a carbon atom contains 6 protons and 6 electrons. Now, the mass of electrons is so small that it can be ignored. So, the atomic mass of carbon should be only 6 u, which is the mass of 6 protons. This, however, is wrong because the actual atomic mass of carbon is 12 u. Then, how do we explain this extra mass of 6 units ? This problem was solved by the discovery of another subatomic particle by **James Chadwick** in 1932. This particle is called neutron. **The neutron is a neutral particle found in the nucleus of an atom.** Atoms of all the elements contain neutrons except ordinary hydrogen atom which does not contain any neutron. Thus, **the subatomic particle not present in a hydrogen atom is neutron**. A hydrogen atom contains only one proton and one electron. A neutron is represented by the symbol n.

Figure 6. James Chadwick : The scientist who discovered the neutral subatomic particle called neutron.

Characteristics of a Neutron

The two important characteristics of a neutron are its mass and charge. These are described below.

1. Mass of a Neutron. The mass of a neutron is equal to the mass of a proton. In other words, **the relative mass of a neutron is 1 u.** The absolute mass of a neutron is 1.6×10^{-24} gram.

2. Charge of a Neutron. **Neutron has no charge.** It is electrically neutral.

We are now in a position to explain why the atomic mass of carbon is 12 u. It is now known that a carbon atom contains 6 protons and 6 neutrons, each having a mass of 1 u. Now,

$$\text{Atomic mass of carbon} = \text{Mass of 6 protons} + \text{Mass of 6 neutrons}$$

$$= 6 \times 1 + 6 \times 1$$
$$= 12 \text{ u}$$

Thus, the atomic mass is given by the sum of the masses of protons and neutrons present in the nucleus of an atom. The mass of electrons present in an atom is very, very small, so it is ignored.

We will now compare a proton, a neutron and an electron in respect of their relative masses and charges.

Comparison between Proton, Neutron and Electron

Subatomic particle	*Relative mass*	*Relative charge*	*Location in the atom*
(*i*) Proton	1 u	+1	In the nucleus
(*ii*) Neutron	1 u	0	In the nucleus
(*iii*) Electron	$\frac{1}{1840}$ u	–1	Outside nucleus

STRUCTURE OF ATOM

Dalton's atomic theory suggested that atom was indivisible – which could not be broken down into smaller particles. But the discovery of subatomic particles such as electrons and protons inside the atom disproved this postulate of Dalton's atomic theory. **The discovery of electrons and protons suggested that atoms are divisible and they do have an inner structure.** After the discovery that atoms contain electrons and protons, it became necessary to find out how these electrons and protons were arranged inside the atom (Please note that the third subatomic particle neutron had not been discovered at that time). J.J. Thomson was the first scientist to propose a model for the structure of atom. This is described below.

THOMSON'S MODEL OF THE ATOM

When J.J. Thomson proposed his model of the atom in 1903, then only electrons and protons were known to be present in the atom. According to Thomson's model of the atom :

1. An atom consists of a sphere (or ball) of positive charge with negatively charged electrons embedded in it.
2. The positive and negative charges in an atom are equal in magnitude, due to which an atom is electrically neutral. It has no overall positive or negative charge.

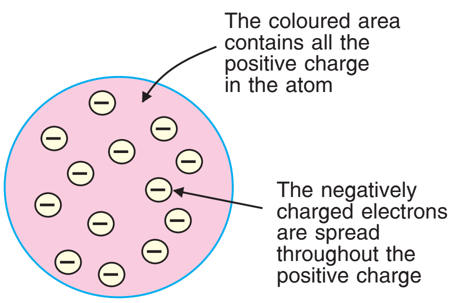


Figure 7. Thomson's model of the atom.

Figure 8. Thomson's model of the atom is similar to a Christmas pudding.

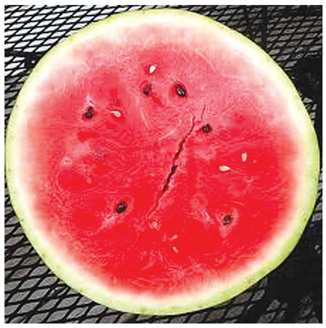


Figure 9. We can also compare Thomson's model of the atom to a watermelon.

Thomson's model of the atom is shown in Figure 7. The coloured area in the sphere (or ball) contains all the positive charge in the atom. The negatively charged electrons are spread throughout the positive charge. The total negative charge of electrons is equal to the total positive charge of the sphere. These equal and opposite charges balance each other due to which an atom becomes electrically neutral on the whole.

Thomson's model of the atom is similar to that of a Christmas pudding. The electrons embedded in a sphere of positive charge are like the currants (dry fruits) in a spherical Christmas pudding. We can also compare Thomson's model of atom to a watermelon. The red, edible part of watermelon represents the sphere of positive charge whereas the black seeds embedded in watermelon are like the electrons. Although Thomson's model of atom explained the electrically neutral nature of atom but it could not explain the results of various experiments carried out by other scientists such as Rutherford's experiments.

Before we describe Rutherford's experiment which led to the discovery of a positively charged nucleus in the atom, we should know the meaning of alpha particles (also written as α-particles). **Alpha particle is a positively charged particle having 2 units of positive charge and 4 units of mass**. It is actually a helium

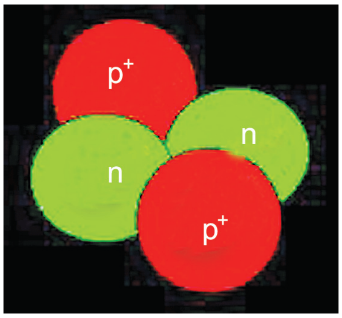


Figure 10. An alpha particle is made of two protons and two neutrons.

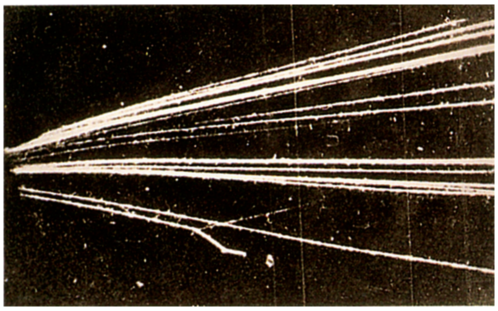


Figure 11. This picture shows the fast moving alpha particles being emitted by a radioactive element (like radium or polonium).

Figure 12. This is a gold foil. It is a very thin sheet of gold metal. Such a gold foil was used in Rutherford's alpha particle scattering experiment which led to the discovery of nucleus.

ion, He^{2+}. Alpha particles are emitted by radioactive elements like radium and polonium. **The fast moving alpha particles have a considerable amount of energy. They can penetrate through matter to some extent.** We will also be using a gold foil in this experiment. A gold foil is a very thin sheet of gold. Alpha particles are much smaller than the gold atoms present in the gold foil. We will now describe Rutherford's experiment.

Rutherford's Experiment – Discovery of Nucleus

After the discovery of electrons, protons and neutrons, it became clear that an atom is made up of these three subatomic particles. Experiments were then carried out to find out how electrons, protons and neutrons were arranged in an atom. It was Rutherford's alpha particle scattering experiment which led to the discovery of a small positively charged nucleus in the atom containing all the protons and neutrons.

When fast moving alpha particles are allowed to strike a very thin gold foil in vacuum, it is found that :

1. Most of the alpha particles pass straight through the gold foil without any deflection from their original path (see Figure 13).
2. A few alpha particles are deflected through small angles and a few are deflected through large angles.

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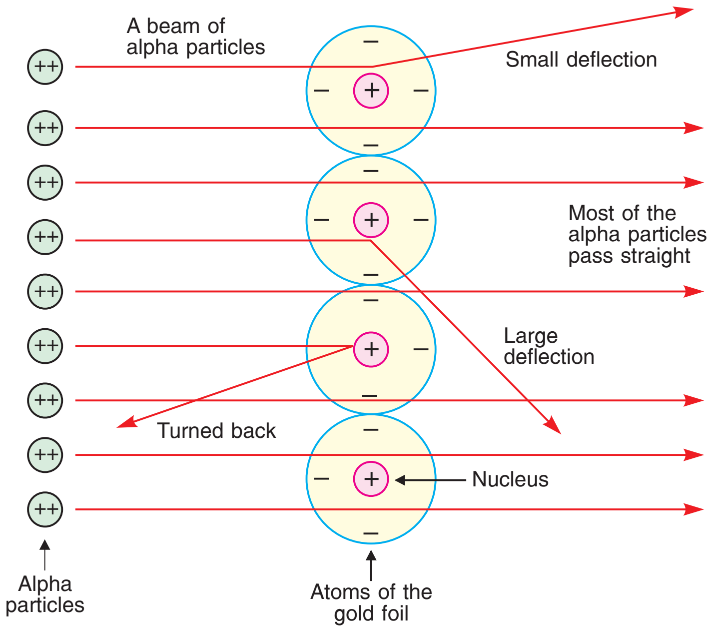


Figure 13. Scattering of alpha particles by the atoms of a gold foil.

3. A very few alpha particles completely rebound on hitting the gold foil and turn back on their path (just as a ball rebounds on hitting a hard wall).

Rutherford explained these observations in the following way :

Gold foil is made up of atoms. If the atoms were solid throughout their volume, then every alpha particle striking them should have changed its path and got deflected. **Since most of the alpha particles pass straight through the gold foil without any deflection, it shows that there is a lot of empty space in the atom.**

We know that similar charges repel each other. So, a positively charged body will repel another positively charged body. **The observation that some of the alpha particles are deflected through small and large angles shows that there is a 'centre of positive charge' in the atom which repels the positively charged alpha particles and deflects them from their original path.** This centre of positive charge in the atom is known as *nucleus*. Thus, the scattering of alpha particles by a thin gold foil shows the existence of a positively charged nucleus in the atom.

A very few of the alpha particles are turned back on their path. This fact cannot be explained only on the basis of repulsion due to positive charge of the nucleus. It can, however, be explained by assuming that the nucleus is very dense and hard. So, **the observation that a very few alpha particles completely rebound on hitting the gold foil shows that the nucleus is very dense and hard which does not allow the alpha particles to pass through it.** Since the nucleus is very dense, practically the whole mass of an atom is centred at its nucleus. As the number of alpha particles which are deflected is very small, we conclude that the size of the nucleus must be very small as compared to the size of the atom as a whole. In fact, the radius of nucleus has been found to be about 10^5 times smaller than the radius of the atom.

Figure 14. The nucleus of an atom is extremely small as compared to the size of the atom as a whole. The relative size of the nucleus in an atom is roughly the same as that of a pea in the middle of this large stadium.

From the above discussion we conclude that **Rutherford's alpha-particle scattering experiment shows the presence of a nucleus in the atom.** It also gives the following important information about the nucleus of an atom :

(*i*) Nucleus of an atom is positively charged.

(*ii*) Nucleus of an atom is very dense and hard.

(*iii*) Nucleus of an atom is very small as compared to the size of the atom as a whole.

Nucleus

The nucleus is a small positively charged part at the centre of an atom. The nucleus contains all the protons and neutrons, therefore, **almost the entire mass of an atom is concentrated in the nucleus** (the electrons, which are outside the nucleus, have negligible mass). The positive charge on the nucleus is due to the presence of protons in it. The number of protons in the nucleus determines the number of positive charges on the nucleus. The neutrons which are also present in the nucleus have no charge, they are neutral. **Protons and neutrons taken together are known as nucleons** (because they are present in the nucleus). **The volume of the nucleus of an atom is very small as compared to the volume of the extranuclear part of the atom.** The existence of positively charged nucleus in an atom was shown by the alpha particle scattering experiment of Rutherford.

Please note that when Rutherford put forward his nuclear model of atom in 1911, even then only electrons and protons were known to be present in the atom. This is because neutron was discovered much later in 1932. So, the original model of an atom given by Rutherford contained only protons in the nucleus. It contained no neutrons. Rutherford's model of the atom was improved later on by including neutrons in the nucleus. We will study this improved model of atom now.

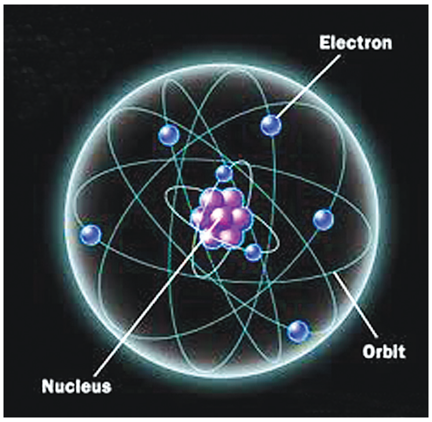


Figure 15. The nucleus is a small positively charged part at the centre of an atom. It contains all the protons and neutrons.

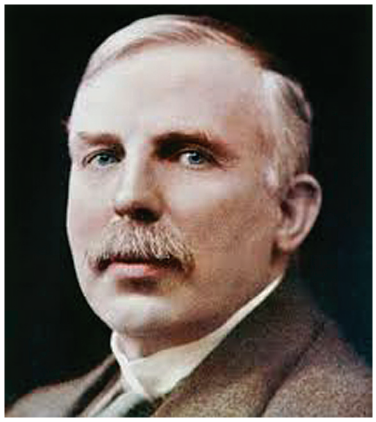


Figure 16. Ernest Rutherford : The scientist who discovered positively charged nucleus at the centre of an atom.

RUTHERFORD'S MODEL OF THE ATOM

On the basis of alpha particle scattering experiment, Rutherford gave a nuclear model of the atom. Rutherford's model of atom (or structure of atom) can be described as follows :

1. An atom consists of a positively charged, dense and very small nucleus containing all the protons and neutrons (protons have positive charge whereas neutrons have no charge). Almost the entire mass of an atom is concentrated in the nucleus.
2. The nucleus is surrounded by negatively charged electrons. The electrons are revolving round the nucleus in circular paths at very high speeds. The circular paths of the electrons are called orbits.
3. The electrostatic attraction between the positively charged nucleus and negatively charged electrons holds the atom together.
4. An atom is electrically neutral. This is because the number of protons and electrons in an atom is equal.
5. Most of the atom is empty space.

We will now describe the structures of some atoms on the basis of Rutherford's model of atom.

The simplest atom is that of hydrogen. It contains one proton and one electron. According to Rutherford's theory, a hydrogen atom consists of a small nucleus containing one proton, and one electron revolving around it (Figure 17). The nucleus is almost at the centre of the atom. Since the hydrogen atom contains an equal number of protons and electrons (1 each), it is electrically neutral. Please note that **the nucleus of an ordinary hydrogen atom does not contain any neutrons in it.**

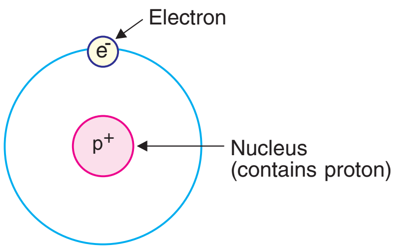


Figure 17. Structure of a hydrogen atom.
Here p^+ = proton
e^- = electron

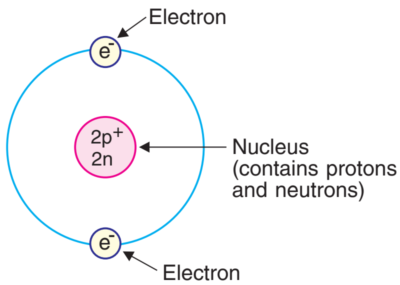


Figure 18. Structure of a helium atom.
p^+ = proton, n = neutron
e^- = electron

The next simplest atom is that of helium. A helium atom consists of a small central nucleus containing 2 protons and 2 neutrons, and there are 2 electrons revolving around this nucleus (Figure 18). Since the helium atom contains an equal number of protons and electrons (2 each), therefore, it is electrically neutral.

Drawback of Rutherford's Model of the Atom

A major drawback (or defect) of Rutherford's model of the atom is that it does not explain the stability of the atom. This point will become more clear from the following discussion.

In the Rutherford's model of an atom, the negatively charged electrons are revolving around the positively charged nucleus in circular paths. Now, we know that if an object moves in a circular path, then its motion is said to be accelerated. This means that the motion of an electron revolving around the nucleus is accelerated.

According to the electromagnetic theory of physics, if a charged particle undergoes accelerated motion, then it must radiate energy (or lose energy) continuously. Now, if we apply this electromagnetic theory to the Rutherford's model of an atom, it will mean that the negatively charged electrons revolving around the nucleus with accelerated motion, will lose their energy continuously by radiation. Thus, the energy of revolving electrons will decrease gradually and their speed will also go on decreasing. The electrons will then be attracted more strongly by the oppositely charged nucleus due to which they will come more and more close to the nucleus. And ultimately the electrons should fall into the nucleus by taking a spiral path (as shown in Figure 19). This should make the atom very unstable and hence the atom should collapse.

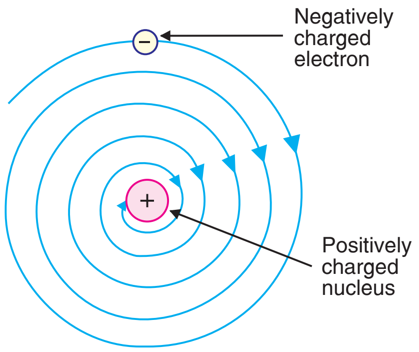


Figure 19. Diagram to show how an energy losing electron could fall into the nucleus.

But this does not happen at all. We know that the electrons do not fall into the nucleus of an atom. Rather, atoms are very stable and do not collapse on their own. The Rutherford's model, however, does not explain the stability of an atom.

Neils Bohr Explained the Stability of Atom

In order to explain the stability of atom and overcome the objection against Rutherford's model of atom, Neils Bohr gave a new arrangement of electrons in the atom in 1913. According to Neils Bohr :

1. The electrons could revolve around the nucleus in only "certain orbits" (or "certain energy levels"), each orbit having a different radius. The electrons in each orbit have a characteristic amount of energy. The electrons which are in orbits close to the nucleus have low energy while those in orbits farther from the nucleus have higher energy.

2. When an electron is revolving in a particular orbit or particular energy level around the nucleus, the electron does not radiate energy (does not lose energy), even though it has accelerated motion around the nucleus. And since the electrons do not lose energy while revolving in certain permitted orbits, they do not fall into the nucleus, and hence the atom remains stable. Please note that the circular paths or orbits around the nucleus (where the movement of electrons takes place), are also known as "energy levels" or "electron shells".

BOHR'S MODEL OF THE ATOM

The present concept of atom was given by Neils Bohr. The Bohr's model of atom can be described as follows :

1. **An atom is made up of three particles : electrons, protons and neutrons.** Electrons have negative charge, protons have positive charge whereas neutrons have no charge, they are neutral. Due to the presence of equal number of negative electrons and positive protons, the atom on the whole is

Figure 20. Neils Bohr : The scientist who gave the present concept of the structure of atom.

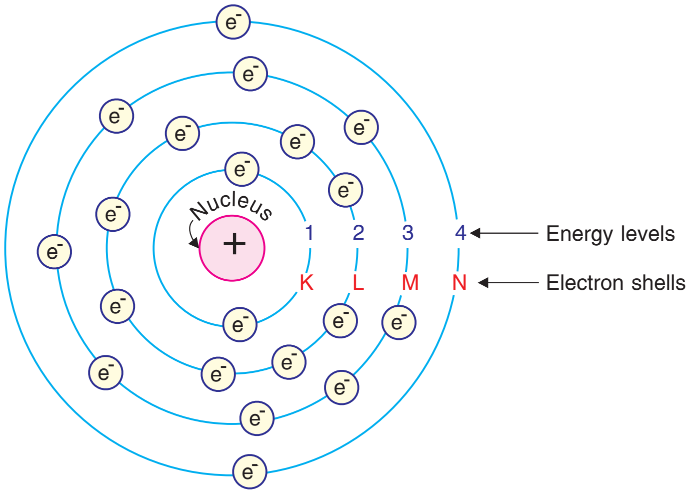


Figure 21. Bohr's model of the atom : Nucleus is at the centre. Electrons revolve round the nucleus in 'fixed' energy levels or electron shells (only first four energy levels are shown in the above diagram).

electrically neutral.

2. **The protons and neutrons are located in a small nucleus at the centre of the atom.** Due to the presence of protons, nucleus is positively charged.
3. **The electrons revolve rapidly round the nucleus in fixed circular paths called energy levels or shells.** The energy levels or shells are represented in two ways : either by the numbers 1, 2, 3, 4, 5 and 6 or by the letters K, L, M, N, O and P (see Figure 21). The energy levels are counted from the centre outwards.
4. **There is a limit to the number of electrons which each energy level (or shell) can hold.** For example, the first energy level (or K shell) can hold a maximum of 2 electrons; second energy level (or L shell) can hold a maximum of 8 electrons; third energy level (or M shell) can hold a maximum of 18 electrons and fourth energy level (or N shell) can hold a maximum of 32 electrons.
5. **Each energy level (or shell) is associated with a fixed amount of energy,** the shell nearest to the nucleus having minimum energy and the shell farthest from the nucleus having the maximum energy.
6. **There is no change in the energy of electrons as long as they keep revolving in the same energy level, and the atom remains stable.** The change in the energy of an electron takes place only when it jumps from a lower energy level to a higher energy level or when it comes down from a higher energy level to a lower energy level. When an electron gains energy, it jumps from a lower energy level to a higher energy level, and when an electron comes down from a higher energy level to a lower energy level, it loses energy.

ATOMIC NUMBER

We know that protons are present in the nucleus of an atom. It is the number of protons present in an atom which determines its atomic number. We can define atomic number as follows : **The number of protons in one atom of an element is known as atomic number of that element.** That is :

Atomic number of an element = Number of protons in one atom of element

For example, one atom of sodium element has 11 protons in it, so the atomic number of sodium is 11. Similarly, one atom of carbon element has 6 protons in it, so the atomic number of carbon is 6. And a hydrogen atom has just 1 proton in its nucleus, therefore the atomic number of hydrogen is 1. **The atomic**

number of an element is denoted by the letter *Z*. The atomic number of sodium is 11, so we can say that for sodium, $Z = 11$. The atomic number of carbon is 6, so for carbon, $Z = 6$. And the atomic number of hydrogen is 1, therefore, for hydrogen, $Z = 1$.

All the atoms of the same element have the same number of protons in their nuclei, and hence they have the same atomic number. Atoms of different elements have different number of protons in their nuclei, so they have different atomic numbers. **No two elements can have the same atomic number.** Since each element has its own fixed atomic number, therefore, **atomic number can be used to identify an element.** For example, atomic number 6 tells us that it is carbon element. No other element can have atomic number of 6. Thus, **it is the number of protons (or atomic number) which distinguishes the atoms of one element from the atoms of another element.** The atoms of various elements are different because they have different atomic numbers (because of different number of protons in them).

In a normal atom (or neutral atom), the number of protons is equal to the number of electrons in it. So, we can also say that **the atomic number of an element is equal to the number of electrons in a neutral atom of that element.** That is,

Atomic number of an element = Number of electrons in one neutral atom

For example, one neutral atom of sodium contains 11 electrons, so the atomic number of sodium is 11. **It is very important to note here that the atomic number of an element is equal to the number of electrons only in a neutral atom, and not in an ion** because only a neutral atom contains an equal number of protons and electrons. On the other hand, an ion is formed by the removal of electrons from a normal atom or by the addition of electrons to a normal atom and, therefore, contains either less or more electrons than protons.

Only the electrons of an atom take part in chemical reactions, the protons do not take part in a chemical reaction. So, during a chemical reaction, the number of electrons in the atoms may change, but the number of protons remains the same. Thus, **the atomic number of an element does not change during a chemical reaction, it remains the same.**

It is clear from the above discussion that **the atomic number of an element tells us two things :**

1. It tells us the number of protons in one atom of the element.

2. It tells us the number of electrons in one normal atom of the element.

For example, the atomic number of sodium is 11. It tells us that a sodium atom contains 11 protons. It also tells us that a normal sodium atom contains 11 electrons. We will now discuss the mass number of an element.

MASS NUMBER

An atom consists of protons, neutrons and electrons. Since the mass of electrons is negligible, the real mass of an atom is determined by the protons and neutrons only. **The total number of protons and neutrons present in one atom of an element is known as its mass number.** That is,

Mass number = No. of protons + No. of neutrons

For example, one atom of sodium element contains 11 protons and 12 neutrons, so the mass number of sodium is 11 + 12 = 23. Similarly, a normal carbon atom has 6 protons and 6 neutrons, so the mass number of carbon is 6 + 6 = 12. And an ordinary hydrogen atom has 1 proton but 0 neutron (no neutron), therefore, the mass number of ordinary hydrogen is just 1. **The mass number of an element is denoted by the letter *A***. The mass number of sodium is 23, so we can say that for sodium, $A = 23$. The mass number of carbon is 12, so for carbon, $A = 12$. And the mass number of ordinary hydrogen is 1, so for ordinary hydrogen, $A = 1$. Please note that protons and neutrons present in a nucleus, taken together, are known as nucleons. So, we can also say that the total number of nucleons present in one atom of an element is known as its mass number.

The mass number of an atom also gives us the atomic mass. This can be explained as follows. We have just seen that :

Mass number = No. of protons + No. of neutrons

Now, Mass of a proton = 1 u

And, Mass of a neutron = 1 u

So, Mass number = No. of protons × 1 + No. of neutrons × 1

or Mass number = Mass of protons + Mass of neutrons

But the total mass of protons and neutrons is called atomic mass, so :

Mass number = Atomic mass

Thus, the mass number of an atom gives us the atomic mass of the atom. Actually, the atomic mass of an atom is numerically equal to its mass number. For example, if the mass number of an atom is 23, then its atomic mass will be 23 u.

Relationship Between Mass Number and Atomic Number

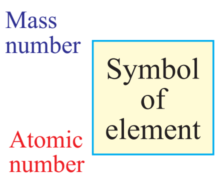
We will now derive a relationship between mass number and atomic number of an element. We have just seen that :

Mass number = No. of protons + No. of neutrons

Since the number of protons in an atom is equal to the atomic number of the element, we can rewrite the above relation by putting "Atomic number" in place of "No. of protons". Thus :

Mass number = Atomic number + No. of neutrons

The atomic number and mass number can be indicated on the symbol of an element. The atomic number is written on the lower left side of the symbol whereas mass number is written on the upper left side of the symbol of the element. This is shown below :



For example, an atom of carbon whose atomic number is 6 and mass number 12 is represented as :

$${}^{12}_{6}C$$

The lower figure (6) indicates the atomic number and the upper figure (12) indicates the mass number of carbon. Let us solve some problems now.

Sample Problem 1. Calculate the atomic number of an element whose atomic nucleus has mass number 23 and neutron number 12. What is the symbol of the element ?

Solution. We know that :

Mass number = Atomic number + No. of neutrons

So, 23 = Atomic number + 12

And, Atomic number = 23 – 12

= 11

The element having atomic number 11 is sodium and its symbol is Na. If, however, we indicate the atomic number and mass number also, then the symbol becomes ${}^{23}_{11}Na$, where 11 is the atomic number and 23 is the mass number.

Sample Problem 2. The number of electrons in an atom is 8 and the number of protons is also 8.

(*a*) What is the atomic number of the atom ?

(*b*) What is the charge on the atom ? **(NCERT Book Question)**

Solution. (*a*) Atomic number is equal to the number of protons in one atom. Since this atom contains 8 protons, so the atomic number is 8.

(*b*) This atom contains an equal number of positively charged protons and negatively charged electrons (8 each), so it has no overall charge. That is, the charge on this atom is 0 (zero).

Sample Problem 3. Helium atom has an atomic mass of 4 u and two protons in its nucleus. How many neutrons does it have ? **(NCERT Book Question)**

Solution. We know that atomic mass is numerically equal to mass number of an atom. Since the helium atom has an atomic mass of 4 u, therefore, the mass number of helium atom will be 4. And the number of protons in the helium nucleus has been given to be 2. Now,

Mass number = No. of protons + No. of neutrons

So, 4 = 2 + No. of neutrons

And, No. of neutrons = 4 – 2

= 2

Thus, the helium atom has 2 neutrons.

ARRANGEMENT OF ELECTRONS IN THE ATOMS

Electrons are negatively charged, so they form a cloud of negative charges outside the nucleus. In this cloud, the electrons are arranged according to their potential energy in different energy levels or shells. The energy levels of the electrons are denoted by the numbers 1, 2, 3, 4, 5 and 6 whereas shells are represented by the letters K, L, M, N, O and P.

1st energy level is K shell

2nd energy level is L shell

3rd energy level is M shell

4th energy level is N shell, and so on.

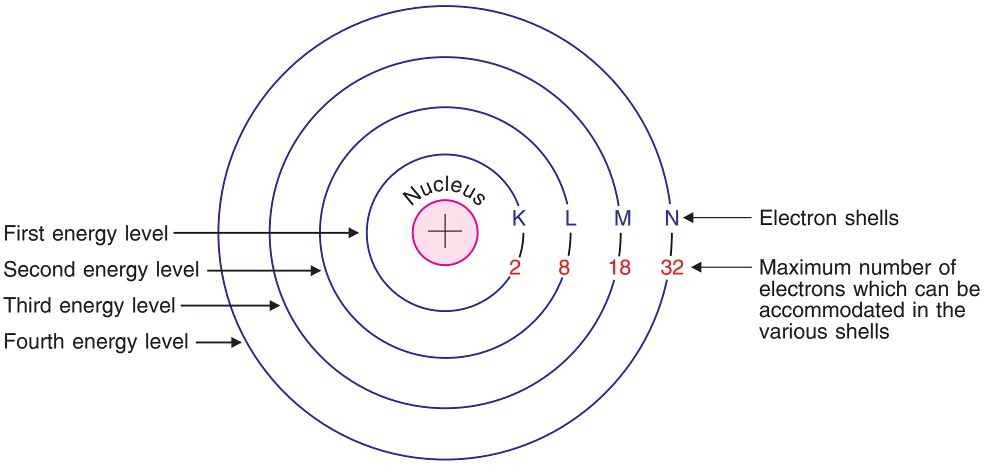


Figure 22. Energy levels or electron shells in an atom. (This figure shows only first four shells K, L, M and N)

The energy levels or shells are represented by circles around the nucleus. The shells are counted from the centre outwards (see Figure 22). For example, K shell having the minimum energy is nearest to the nucleus ; L shell which has a little more energy is a bit farther away from the nucleus, and so on. It is obvious that **the outermost shell of an atom is at the highest energy level**.

We will now describe how the electrons fill up the various energy levels or shells in an atom. It is a well known fact that a system is most stable when it has the minimum energy. So, the electrons occupy the low energy levels first (this will make the atoms more stable). Now, K shell is at the lowest energy level, so first of all the electrons fill K shell, then L shell, M shell, N shell, and so on.

Electronic Configurations of Elements

The arrangement of electrons in the various shells (or energy levels) of an atom of the element is known as electronic configuration of the element. In other words, electronic configuration is the distribution of electrons in various shells (or energy levels) of an atom such as K shell, L shell, M shell, etc.

In order to write down the electronic configuration of an element, we should know two things :

(*i*) We should know the number of electrons in one atom of the element.

(*ii*) We should know the maximum number of electrons that can be accommodated in different shells of the atom.

The number of electrons in an atom of the element is given by the atomic number of the element, because **the number of electrons in an atom of the element is equal to the atomic number of the element.** For example, if the atomic number of an element is 12, then its atom contains 12 electrons.

The maximum number of electrons which can be put in a particular energy level or shell was given by Bohr and Bury. According to Bohr-Bury scheme :

1. The maximum number of electrons which can be accommodated in any energy level of the atom is given by $2n^2$ (where n is the number of that energy level). Let us calculate the maximum number of electrons which can be put in the first four energy levels of an atom.

(*i*) For 1st energy level, $n = 1$

So, The maximum number of electrons in 1st energy level $= 2n^2$

$= 2 \times (1)^2$

$= 2 \times 1$

$= 2$

(*ii*) For 2nd energy level, $n = 2$

So, The maximum number of electrons in 2nd energy level $= 2n^2$

$= 2 \times (2)^2$

$= 2 \times 4$

$= 8$

(*iii*) For 3rd energy level, $n = 3$

So, The maximum number of electrons in 3rd energy level $= 2n^2$

$= 2 \times (3)^2$

$= 2 \times 9$

$= 18$

(*iv*) For 4th energy level, $n = 4$

So, The maximum number of electrons in 4th energy level $= 2n^2$

$= 2 \times (4)^2$

$= 2 \times 16$

$= 32$

Thus, the maximum number of electrons that can be accommodated in the first energy level is 2, for second energy level is 8, for third energy level is 18, and for the fourth energy level is 32. Now, the first energy level is called K shell, the second energy level is called L shell, the third energy level is called M shell and the fourth energy level is known as N shell. So, we can also say that **the maximum number of electrons which can be accommodated in K shell is 2, for L shell is 8, for M shell is 18 and for N shell is 32.** This can be put in the tabular form as follows :

Electron shell	*Maximum capacity*
K shell	2 electrons
L shell	8 electrons
M shell	18 electrons
N shell	32 electrons

2. The outermost shell of an atom cannot accommodate more than 8 electrons, even if it has the capacity to accommodate more electrons. (If, however, the outermost shell of an atom is the first shell or K shell, then it cannot accommodate more than 2 electrons)

This means that normally, the outermost shell of an atom can take a maximum of 8 electrons only. For example, if M shell is the outermost shell of an atom then it can hold a maximum of 8 electrons only, though its maximum rated capacity is 18 electrons. This is due to the fact that "having 8 electrons in the outermost shell" makes the atoms very stable. If, however, the outermost shell is the first shell or K shell, then it can hold a maximum of 2 electrons only. This is because having 2 electrons in the outermost shell when it is first shell or K shell (there being no other electron shells in the atom) also makes the atom very stable. This happens in the case of helium element which has only one shell (K shell) in its atom.

3. Electrons in an atom do not occupy a new shell unless all the inner shells are completely filled with electrons

This means that the electron shells in an atom are filled in a step-wise manner. First of all the electrons fill K shell, then L shell, M shell, N shell, and so on. There are, however, some exceptions to this rule (which apply to elements having atomic numbers more than 18). We will study this in higher classes.

Keeping these points in mind, let us learn to write the electronic configurations of the elements.

Sample Problem 1. Write the electronic configuration of an element X whose atomic number is 12.

Solution. Atomic number of the element X is 12 which means that one atom of X has 12 electrons. First of all the electrons will go to K shell which can take a maximum of 2 electrons. Thus, the first 2 electrons will occupy K shell and we write $\underset{2}{\mathrm{K}}$ for it. After filling the K shell, the electrons will go to L shell. Now, L shell can take a maximum of 8 electrons for which we write $\underset{8}{\mathrm{L}}$. In this way 2 + 8 = 10 electrons have been accommodated, and we are left with 2 more electrons. The remaining 2 electrons go to M shell and we write $\underset{2}{\mathrm{M}}$ for it. Writing all the electron shells together, the electronic configuration of the element X becomes :

K L M
2, 8, 2

Please note that it is not necessary to write the shells K, L and M, etc., while writing the electronic configurations of the elements. For example, **the electronic configuration of the element X of atomic number 12 can be simply written as 2, 8, 2.** It is, however, better to indicate their shells also. Another point to be noted is that we have given so many details in the solution of this problem just to make you understand the things clearly. There is no need to write so many details in the exam. The arrangement of electrons in the atom of element X has been shown in Figure 23.

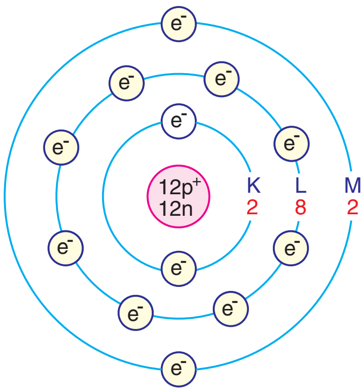


Figure 23. Figure for sample problem 1.

Sample Problem 2. Write the distribution of electrons in a carbon atom. (Atomic number of carbon = 6) **(NCERT Book Question)**

Solution. The atomic number of carbon is 6, so a carbon atom has 6 electrons in it. Out of 6 electrons :

(*i*) the first 2 electrons will occupy K shell. For this we write $\underset{2}{\mathrm{K}}$.

(*ii*) the remaining 6 – 2 = 4 electrons will go to L shell. For this we write $\underset{4}{L}$.

So, the distribution of electrons in a carbon atom (or the electronic configuration of a carbon atom) will be :

$$\underset{2,}{K}\ \underset{4}{L} \quad \text{or} \quad 2,\ 4$$

Sample Problem 3. Write the electronic configuration of sodium atom (Atomic number of sodium = 11)

(NCERT Book Question)

Solution. The atomic number of sodium is 11. This means that a normal sodium atom contains 11 electrons. Out of 11 electrons of sodium atom, the first 2 electrons will occupy K shell, the next 8 electrons will occupy L shell and the remaining 1 electron will go to M shell. So, the electronic configuration of sodium atom will be :

$$\underset{2,}{K}\ \underset{8,}{L}\ \underset{1}{M} \quad \text{or} \quad 2,\ 8,\ 1$$

Sample Problem 4. What would be the electronic configuration of a positively charged sodium ion, Na^+ ? What would be its atomic number ?

Solution. The atomic number of sodium is 11. So, a neutral sodium atom (Na) has 11 electrons in it.

(*i*) A positively charged sodium ion (Na^+) is formed by the removal of 1 electron from a sodium atom. So, a sodium ion has 11 – 1 = 10 electrons in it. Thus, the electronic configuration of a sodium ion will be $\underset{2,}{K}\ \underset{8}{L}$ or 2, 8.

(*ii*) The atomic number of an element is equal to the number of protons in its atom. Since a sodium atom as well as a sodium ion contain the same number of protons, therefore, the atomic number of sodium ion is the same as that of a sodium atom, which is 11.

Sample Problem 5. Explain why, sodium ion, Na^+, has completely filled K and L shells.

(NCERT Book Question)

Solution. A sodium ion, Na^+, has 10 electrons in it. Now, the maximum capacity of K shell is 2 electrons and that of L shell is 8 electrons. Taken together, the maximum capacity of K and L shells is 2 + 8 = 10 electrons. A sodium ion Na^+ has completely filled K and L shells because its 10 electrons can completely fill up K and L shells.

Sample Problem 6. If both K and L shells of an atom are full, what is the total number of electrons in the atom ? **(NCERT Book Question)**

Solution. K shell becomes full with 2 electrons and L shell becomes full with 8 electrons. So, if the K and L shells of an atom are full, then it will have a total of 2 + 8 = 10 electrons in it.

Sample Problem 7. An element has 2 electrons in the M shell. What is the atomic number of the element ?

Solution. There are 2 electrons in the M shell of the atom of this element. This means that the K and L shells of the atom of this element (which come before M shell) are completely filled with electrons. Now, K shell can accommodate 2 electrons, L shell can accommodate 8 electrons and we have been given that M shell has 2 electrons. So, the electronic configuration of this element becomes 2, 8, 2. Thus, the number of electrons in its atom is 2 + 8 + 2 = 12. Since the number of electrons in a neutral atom is equal to the number of protons, therefore, the atomic number of this element is 12.

Electronic Configurations of First 20 Elements

The electronic configurations (electron distribution in various shells of the atoms) of the first twenty elements having atomic numbers from 1 to 20 are given on the next page.

Electronic Configurations of First Twenty Elements

Element	*Symbol*	*Atomic number*	*Electronic configuration (or Electron distribution)* K L M N
1. Hydrogen	H	1	1
2. Helium	**He**	**2**	**2**
3. Lithium	Li	3	2, 1
4. Beryllium	Be	4	2, 2
5. Boron	B	5	2, 3
6. Carbon	C	6	2, 4
7. Nitrogen	N	7	2, 5
8. Oxygen	O	8	2, 6
9. Fluorine	F	9	2, 7
10. Neon	**Ne**	**10**	**2, 8**
11. Sodium	Na	11	2, 8, 1
12. Magnesium	Mg	12	2, 8, 2
13. Aluminium	Al	13	2, 8, 3
14. Silicon	Si	14	2, 8, 4
15. Phosphorus	P	15	2, 8, 5
16. Sulphur	S	16	2, 8, 6
17. Chlorine	Cl	17	2, 8, 7
18. Argon	**Ar**	**18**	**2, 8, 8**
19. Potassium	K	19	2, 8, 8, 1
20. Calcium	Ca	20	2, 8, 8, 2

Before we end this discussion, we would like to say a few words about the electronic configurations of potassium (2, 8, 8, 1) and calcium (2, 8, 8, 2) having atomic numbers 19 and 20 respectively. We know that M shell can accommodate up to 18 electrons but in the case of potassium and calcium, the M shell has only 8 electrons when the next electrons enter the N shell. That is, the fourth energy shell N has started to fill up even before the third energy shell M is complete with 18 electrons. This abnormal behaviour of potassium and calcium will be explained in higher classes. Before we go further and discuss valence electrons (or valency electrons) **please answer the following questions :**

Very Short Answer Type Questions

1. Which subatomic particle is not present in an ordinary hydrogen atom ?
2. Name the scientists who described the arrangement of electrons in an atom.
3. What is the maximum number of electrons which can be accommodated in the K shell of an atom ?
4. What is the maximum number of electrons which can be accommodated in the L shell of an atom ?
5. What is the maximum number of electrons an M shell of the atom can accommodate ?
6. What is the maximum number of electrons that can go into the N shell of an atom ?
7. What is the maximum number of electrons which can be accommodated in the :
   (*a*) innermost shell of an atom ?
   (*b*) outermost shell of an atom ?
8. Name the three subatomic particles present in an atom.
9. Name the negatively charged particle present in the atoms of all the elements.
10. Name the scientist who discovered electron.
11. What is the usual symbol for (*a*) an electron (*b*) a proton, and (*c*) a neutron ?

12. State whether the following statements are true or false :
(*a*) Thomson proposed that the nucleus of an atom contains protons and neutrons.
(*b*) The cathode rays obtained from all the gases consist of negatively charged particles called electrons.
(*c*) The anode rays obtained from all the gases consist of positively charged particles called protons.

13. Name the central part of an atom where protons and neutrons are held together.

14. What are the various letters used by Bohr to represent electron shells in an atom ?

15. Name the particles which actually determine the mass of an atom.

16. Name the positively charged particle present in the atoms of all the elements.

17. What is the electronic configuration of a hydrogen atom ?

18. How many times is a proton heavier than an electron ?

19. Name the gas which produces anode rays consisting of protons in the discharge tube experiment.

20. Which part of an atom was discovered by Rutherford's alpha particle scattering experiment ?

21. What is the positive charge on the nucleus of an atom due to ?

22. State the number of electrons present in the outermost shell of the atoms of the following elements :
(*i*) Neon (*ii*) Chlorine

23. Which shell of an atom can accommodate a maximum of :
(*a*) 8 electrons ? (*b*) 32 electrons ?

24. Name the shell of an atom which can accommodate a maximum of :
(*a*) 2 electrons (*b*) 18 electrons

25. Which subatomic particle was discovered by :
(*i*) Chadwick ? (*ii*) Thomson ? (*iii*) Goldstein ?

26. Name the subatomic particle whose relative charge is :
(*a*) +1 (*b*) –1 (*c*) 0

27. Fill in the blanks in the following statements :
(*a*) The number of protons in the nucleus of an atom is called its ....
(*b*) The total number of protons and neutrons in the nucleus of an atom is called its ....
(*c*) An atom has atomic mass number 23 and atomic number 11. The atom has .... electrons.
(*d*) An atom of an element has 11 protons, 11 electrons and 12 neutrons. The atomic mass of the atom is ....
(*e*) If the nucleus of an atom has atomic number 17, mass number 37 and there are 17 electrons outside the nucleus, the number of neutrons in it is ....
(*f*) Almost all the mass of an atom is concentrated in a small region of space called the ....
(*g*) Cathode rays are a beam of fast moving ....
(*h*) The anode rays obtained from hydrogen gas consist of particles called ....
(*i*) The maximum number of electrons that can be accommodated in L shell are ....
(*j*) The maximum number of electrons that can go into the M shell is ....
(*k*) The subatomic particle not present in a hydrogen atom is ....
(*l*) The electron has ....charge, the proton has .... charge, and the neutron has .... charge.

Short Answer Type Questions

28. What is an electron ? State its relative mass and charge.

29. What is the absolute mass and charge of an electron ?

30. Give the evidence for the existence of nucleus in an atom.

31. What important information is furnished about the nucleus of an atom by the alpha particle scattering experiment of Rutherford ?

32. How was it shown that an atom has a lot of empty space within it ?

33. Why is an atom neutral inspite of the presence of charged particles in it ?

34. (*a*) Which of the nuclear particles is present in the same fixed number in the atoms of any particular element ?
(*b*) What do we call this number which is characteristic of a particular element ?

35. What is a proton ? State its relative mass and charge.
36. What is the absolute mass and charge of a proton ?
37. How does a proton differ from an electron ?
38. State two observations which show that atom is not indivisible.
39. All the gases form cathode rays and anode rays when electricity is passed through them :
(*i*) What does the formation of cathode rays tell us about the atoms ?
(*ii*) What does the formation of anode rays tell us about the atoms ?
40. What do you understand by the term ''electronic configuration'' of an element ? Write down the electronic configuration of oxygen (At. No. = 8).
41. An element has an atomic number 12. How many electrons will be present in the K, L and M energy shells of its atom ?
42. (*a*) What is the nucleus of an atom and what is the nature of charge on it ?
(*b*) Name the scientist who discovered the nucleus of atom.
43. Name the particles used by Rutherford in his experiment on the discovery of nucleus. Also state the charge on these particles.
44. An element has atomic number 13 and an atomic mass of 27.
(*a*) How many electrons are there in each atom of the element ?
(*b*) How are these electrons distributed in the various energy levels ?
45. Write the distribution of electrons in an atom of element whose atomic number is 18. What is special about the outermost electron shell (or valence shell) of the atom of this element ?
46. What is a neutron ? State its relative mass and charge.
47. Compare an electron, a proton and a neutron in respect of their relative masses and charges.
48. What is a proton ? How does it differ from a neutron ?
49. Compare an electron and a proton in respect of mass and charge.
50. Compare a proton and a neutron in respect of mass and charge.
51. How does an electron differ from a neutron ?
52. State the location of electrons, protons and neutrons in an atom.
53. Fill in the following blanks :

Atomic number	*Mass number*	*Protons*	*Neutrons*	*Electrons*	*Symbol*
10	22	....	....	....	....

54. Fill in the following blanks in respect of an atom of an element :

No. of protons	*No. of neutrons*	*Mass number*	*Atomic number*	*No. of electrons*	*Symbol*
11	12	....	....	....	....

Long Answer Type Questions

55. (*a*) What are cathode rays ? What is the nature of charge on cathode rays ?
(*b*) Explain how, cathode rays are formed from the gas taken in the discharge tube.
(*c*) What conclusion is obtained from the fact that all the gases form cathode rays ?
56. (*a*) Describe Thomson's model of the atom. Which subatomic particle was not present in Thomson's model of the atom ?
(*b*) The mass number of an element is 18. It contains 7 electrons. What is the number of protons and neutrons in it ? What is the atomic number of the element ?
57. (*a*) Describe the Rutherford's model of an atom. State one drawback of Rutherford's model of the atom.
(*b*) The mass number of an element is 23 and it contains 11 electrons. What is the number of protons and neutrons in it ? What is the atomic number of the element ?
58. (*a*) Describe Bohr's model of the atom. How did Neils Bohr explain the stability of atom ?
(*b*) An element has an atomic number of 11 and its mass number is 23. What is the arrangement of electrons in the shells ? State nuclear composition of an atom of the element.

59. (*a*) What is meant by (*i*) atomic number, and (*ii*) mass number, of an element ? Explain with the help of an example.
(*b*) What is the relation between the atomic number and mass number of an element ?
(*c*) If an element M has mass number 24 and atomic number 12, how many neutrons does its atom contain ?

Multiple Choice Questions (MCQs)

60. Rutherford's alpha particle scattering experiment led to the discovery of :
(*a*) Nucleus (*b*) Electrons (*c*) Protons (*d*) Neutrons

61. Which of the following is the correct electronic configuration of sodium ?
(*a*) 2, 8, 1 (*b*) 8, 2, 1 (*c*) 2, 1, 8 (*d*) 2, 8, 2

62. The particle not present in an ordinary hydrogen atom is :
(*a*) proton (*b*) neutron (*c*) nucleus (*d*) electron

63. The subatomic particle called electron was discovered by :
(*a*) J.J. Thomson (*b*) Neils Bohr (*c*) James Chadwick (*d*) E. Goldstein

64. Which of the following represents the correct electron distribution in magnesium ion ?
(*a*) 2, 8 (*b*) 2, 8, 1 (*c*) 2, 8, 2 (*d*) 2, 8, 3

65. The correct electronic configuration of a chloride ion is :
(*a*) 2, 8 (*b*) 2, 8, 4 (*c*) 2, 8, 8 (*d*) 2, 8, 7

66. Goldstein's experiments which involved passing high voltage electricity through gases at very low pressure resulted in the discovery of :
(*a*) electron (*b*) proton (*c*) nucleus (*b*) neutron

67. The number of electrons in the atom of an element X is 15 and the number of neutrons is 16. Which of the following is the correct representation of an atom of this element ?
(*a*) $^{31}_{15}X$ (*b*) $^{31}_{16}X$ (*c*) $^{16}_{15}X$ (*d*) $^{15}_{16}X$

68. The ion of an element has 3 positive charges. The mass number of atom of this element is 27 and the number of neutrons is 14. What is the number of electrons in the ion ?
(*a*) 13 (*b*) 10 (*c*) 14 (*d*) 16

69. The first model of an atom was given by :
(*a*) Neils Bohr (*b*) Ernest Rutherford (*c*) J.J. Thomson (*d*) Eugen Goldstein

70. Which of the following statement is always correct ?
(*a*) an atom has equal number of electrons and protons
(*b*) an atom has equal number of electrons and neutrons
(*c*) an atom has equal number of protons and neutrons
(*d*) an atom has equal number of electrons, protons and neutrons

Questions Based on High Order Thinking Skills (HOTS)

71. From the symbol $^{31}_{15}P$, state :
(*i*) mass number of phosphorus,
(*ii*) atomic number of phosphorus, and
(*iii*) electron configuration of phosphorus.

72. The atom of an element X has 7 electrons in its M shell.
(*a*) Write the electronic configuration of element X.
(*b*) What is the atomic number of element X ?
(*c*) Is it a metal or a non-metal ?
(*d*) What type of ion will be formed by an atom of element X ? Write the symbol of the ion formed.
(*e*) What could element X be ?

73. An atom of element E contains 3 protons, 3 electrons and 4 neutrons :
(*a*) What is its atomic number ?

(*b*) What is its mass number ?
(*c*) Write the electronic configuration of the element E.
(*d*) State whether element E is a metal or non-metal. Why ?
(*e*) What type of ion, cation or anion, will be formed by an atom of element E ? Why ?
(*f*) Write the symbol of the ion formed by an atom of element E.
(*g*) What could element X be ?

74. An atom of an element X may be written as ${}^{9}_{4}X$.
(*a*) What does the figure 9 indicate ?
(*b*) What does the figure 4 indicate ?
(*c*) What is the number of protons in atom X ?
(*d*) What is the number of neutrons in atom X ?
(*e*) What is the number of electrons in atom X ?
(*f*) How many electrons are there in the outermost shell of an atom of element X ?
(*g*) Write the symbol of ion formed by an atom of element X.

75. The electronic configuration of an element Z is 2, 8, 8.
(*a*) What is the atomic number of the element ?
(*b*) State whether element Z is a metal or a non-metal.
(*c*) What type of ion (if any) will be formed by an atom of element Z ? Why ?
(*d*) What is special about the outermost electron shell of the atom of this element ?
(*e*) Give the name and symbol of element Z.
(*f*) Name the group of elements to which Z belongs.

ANSWERS

1. Neutron **7.** (*a*) 2 (*b*) 8 **12.** (*a*) False (*b*) True (*c*) False **19.** Hydrogen gas **20.** Nucleus **22.** (*i*) 8 (*ii*) 7 **27.** (*a*) atomic number (*b*) mass number (*c*) 11 (*d*) 23 (*e*) 20 (*f*) nucleus (*g*) electrons (*h*) protons (*i*) 8 (*j*) 18 (*k*) neutron (*l*) negative ; positive ; no **34.** (*a*) Protons (*b*) Atomic number **40.** $\begin{matrix} K & L \\ 2, & 6 \end{matrix}$ **41.** K : 2 ; L : 8 ; M : 2 **44.** (*a*) 13 (*b*) $\begin{matrix} K & L & M \\ 2, & 8, & 3 \end{matrix}$ **45.** $\begin{matrix} K & L & M \\ 2, & 8, & 8 \end{matrix}$; The outermost electron shell (M shell) of the atom of this element is completely filled with electrons **53.** 10 ; 12 ; 10 ; Ne **54.** 23 ; 11 ; 11 ; Na **56.** (*b*) 7 ; 11; 7 **57.** (*b*) 11 ; 12 ; 11 **58.** (*b*) $\begin{matrix} K & L & M \\ 2, & 8, & 1 \end{matrix}$; 11 protons and 12 neutrons **59.** (*c*) 12 **60.** (*a*) **61.** (*a*) **62.** (*b*) **63.** (*a*) **64.** (*a*) **65.** (*c*) **66.** (*b*) **67.** (*a*) **68.** (*b*) **69.** (*c*) **70.**(*a*) **71.** (*i*) 31 (*ii*) 15 (*iii*) $\begin{matrix} K & L & M \\ 2, & 8, & 5 \end{matrix}$ **72.** (*a*) $\begin{matrix} K & L & M \\ 2, & 8, & 7 \end{matrix}$ (*b*) 17 (*c*) Non-metal (*d*) Anion (Negative ion) ; X^- (*e*) Chlorine (Cl) **73.** (*a*) 3 (*b*) 7 (*c*) $\begin{matrix} K & L \\ 2, & 1 \end{matrix}$ (*d*) Metal ; Because it has 1 valence electron (1 outermost electron) (*e*) Cation (Positive ion) ; Because an atom of E has 1 outermost electron which it can lose easily to form a positively charged ion (having 1 unit positive charge) (*f*) E^+ (*g*) Lithium (Li) **74.** (*a*) Mass number (*b*) Atomic number (*c*) 4 (*d*) 5 (*e*) 4 (*f*) 2 (*g*) X^{2+} **75.** (*a*) 18 (*b*) Non-metal (*c*) The atom of element Z will not form any ion because it has a completely filled outermost shell (having 8 electrons) due to which it can neither lose electrons nor gain electrons to form an ion (*d*) The outermost electron shell of the atom of this element is completely filled with electrons (*e*) Argon, Ar (*f*) Noble gases (or Inert gases)

VALENCE ELECTRONS (OR VALENCY ELECTRONS)

The outermost electron shell of an atom is known as valence shell. **The electrons present in the outermost shell of an atom are known as valence electrons (or valency electrons) because they decide the valency (combining capacity) of the atom.** Only the valence electrons of an atom take part in chemical reactions because they have more energy than all the inner electrons of the atom. Let us take the example of sodium atom to understand the meaning of valence electrons clearly.

The atomic number of sodium is 11, which means that one sodium atom has 11 electrons in it. So, the electronic configuration of sodium atom will be K L M (2, 8, 1). In the sodium atom, M shell is the outermost shell or valence shell (see Figure 24). There is 1 electron in the outermost shell of sodium atom, therefore, sodium atom has 1 valence electron.

When a sodium atom combines with other atoms, only its one valence electron (in the M shell) takes part in chemical reactions. The electrons of two inner shells (K shell and L shell) of the sodium atom never take part in chemical reactions.

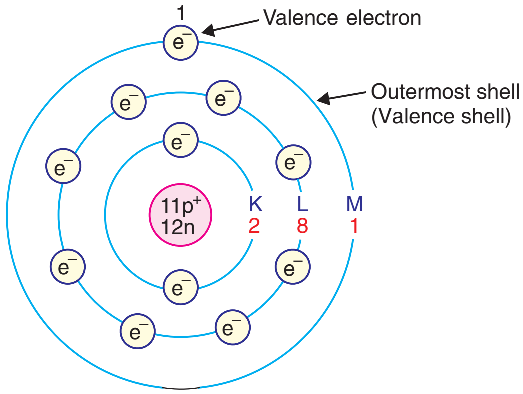


Figure 24. Sodium atom has one valence electron (which has been marked 1 in the above figure).

We can now say that **those electrons of an atom which take part in chemical reactions are called valence electrons. Valence electrons are located in the outermost shell of an atom**. In a chemical reaction, valence electrons of an atom are either transferred to the valence electrons of another atom, or shared with the valence electrons of another atom.

(*i*) The elements Hydrogen, Lithium, Sodium and Potassium have 1 valence electron each in their atoms.

(*ii*) The elements Helium, Beryllium, Magnesium and Calcium have 2 valence electrons each in their atoms.

(*iii*) The elements Boron and Aluminium have 3 valence electrons each in their atoms.

(*iv*) The elements Carbon and Silicon have 4 valence electrons each in their atoms.

(*v*) The elements Nitrogen and Phosphorus have 5 valence electrons each in their atoms.

(*vi*) The elements Oxygen and Sulphur have 6 valence electrons each in their atoms.

(*vii*) The elements Fluorine and Chlorine have 7 valence electrons each in their atoms.

(*viii*) The elements Neon and Argon have 8 valence electrons each in their atoms.

In order to find out the number of valence electrons in an atom of the element, we should write down the electronic configuration of the element by using its atomic number. The outermost shell will be the valence shell and the number of electrons present in it will give us the number of valence electrons. This point will become more clear from the following example.

Sample Problem. What is the number of valence electrons in the atom of an element X having atomic number 17 ? Name the valence shell of this atom.

Solution. In order to find out the number of valence electrons, we should write down the electronic configuration of element X. The atomic number of element X is 17, so one atom of X contains 17 electrons. The electronic configuration will be :

K L M
2, 8, 7

Here M shell is the outermost shell or valence shell of the atom and it has 7 electrons in it. Thus, there are 7 valence electrons in the atom of element X.

Before we can understand valency (or combining capacity) of elements, it is necessary to know why the elements called noble gases (or inert gases) are chemically unreactive and why atoms of elements combine with one another. This is discussed below.

Inertness of Noble Gases

There are some elements which do not combine with other elements. These elements are : Helium, Neon, Argon, Krypton, Xenon and Radon. They are known as noble gases or inert gases because they do not react with other elements to form compounds. **We know that only the outermost electrons of an atom take part in a chemical reaction. Since the noble gases are chemically unreactive, we must conclude that**

the electron arrangements in their atoms are very stable which do not allow the outermost electrons to take part in chemical reactions. We will now write down the electronic configurations of the noble gases to find out the exact reason for their inert nature.

Electronic Configurations of Noble Gases (or Inert Gases)

Noble gas (Inert gas)	*Symbol*	*Atomic number*	*Electronic configuration* K L M N O P	*Number of electrons in outermost shell (Valence shell)*
1. Helium	He	2	2	2
2. Neon	Ne	10	2, 8	8
3. Argon	Ar	18	2, 8, 8	8
4. Krypton	Kr	36	2, 8, 18, 8	8
5. Xenon	Xe	54	2, 8, 18, 18, 8	8
6. Radon	Rn	86	2, 8, 18, 32, 18, 8	8

If we look at the number of electrons in the outermost shells of the inert gases in the above table, we find that only one inert gas helium has 2 electrons in its outermost shell, all other inert gases have 8 electrons in the outermost shells of their atoms. We know that the outermost shell of an atom can accommodate a maximum of 8 electrons (except when the outermost shell is K shell and it can hold only a maximum of 2 electrons). This means that **all the noble gases have completely filled outermost shells**. Since the atoms of inert gases are very stable and have 8 electrons in their outermost shells, therefore, to have 8 electrons in the outermost shell of an atom is considered to be the most stable arrangement of electrons. To have '8 electrons' in the outermost shell of an atom is known as 'octet' of electrons. Most of the inert gases have octet of electrons in their valence shells. From this discussion we conclude that **the atoms having 8 electrons (or octet of electrons) in their outermost shell are very stable and hence chemically unreactive**.

Please note that **2 electrons in the outermost shell is considered to be a stable arrangement of electrons only when the atom has just one shell, K shell, and there are no other electron shells in the atom**. To have '2 electrons' in the outermost K shell is known as 'duplet' of electrons. Helium is the only inert gas having a duplet of electrons in its outermost shell. It is very important to note here that **though 8 electrons in the outermost shell always impart stability to an atom, but 2 electrons in the outermost shell impart stability only when the outermost shell is the first shell (K shell), and no other shells are present in the atom.**

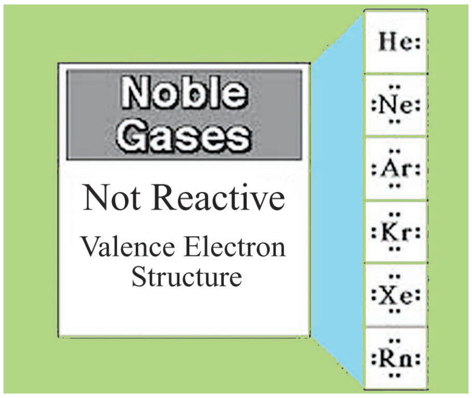


Figure 25. Only one noble gas helium (He) has 2 valence electrons (2 outermost electrons). All other noble gases have 8 electrons each in their valence shells.

Figure 26. Neon is a noble gas. Neon gas is used in advertising signs (called neon signs) because it glows red when electricity is passed through it.

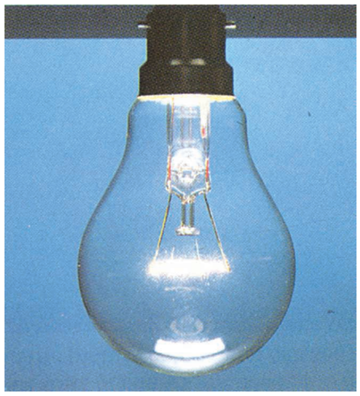


Figure 27. Argon is also a noble gas. Argon gas is used to fill light bulbs to prevent the tungsten filament from reacting with oxygen in air.

It should be noted that noble gases are unreactive because they have very stable electron arrangements with 8 (or 2) electrons in their outermost shells. In other words, the noble gas atoms have completely filled outermost shells. It is not possible to remove electrons from the outermost shell of a noble gas atom or to add electrons to the outermost shell of a noble gas atom. Due to this the outermost electrons of a noble gas atom cannot take part in chemical reactions. **Since the atoms of inert gases are very stable or unreactive they can exist in the free state as individual atoms.** So, the inert gases are monoatomic, that is, inert gases exist as single atoms. Their atoms and molecules are just the same. For example, helium, neon, argon, etc., all exist in the form of monoatomic molecules He, Ne, Ar, etc.

Cause of Chemical Combination

Everything in this world wants to become more stable. For atoms, stability means having the electron arrangement of an inert gas. **The atoms combine with one another to achieve the inert gas electron arrangement and become more stable.** So, when atoms combine to form chemical compounds, they do so in such a way that each atom gets 8 electrons in its outermost shell or 2 electrons in the outermost K shell. In other words, the atoms having less than 8 electrons (or less than 2 electrons) in their outermost shell are unstable. So, all the atoms have a tendency to achieve the inert gas electron arrangement of 8 electrons (or 2 electrons) in their outermost shells and become more stable.

An atom can achieve the inert gas (or noble gas) electron arrangement in three ways :

(*i*) by ***losing*** one or more electrons (to another atom)
(*ii*) by ***gaining*** one or more electrons (from another atom)
(*iii*) by ***sharing*** one or more electrons (with another atom)

If an element has 1, 2 or 3 electrons in the outermost shell of its atom, then it loses these electrons to achieve the inert gas electron arrangement of eight valence electrons and forms positively charged ion or cation (It is not possible to add 7, 6 or 5 electrons to an atom due to energy considerations).

If an element has 5, 6 or 7 electrons in the outermost shell of its atom, then it gains (accepts) electrons to achieve the stable, inert gas configuration of eight valence electrons, and forms negatively charged ion called anion (It is not possible to remove 5, 6 or 7 electrons from an atom due to very high energy required).

If, however, an element has 4 electrons in the outermost shell of its atom, then it can neither lose 4 electrons nor gain 4 electrons due to energy considerations. An element having 4 electrons in the outermost shell of its atom can achieve the inert gas electron arrangement of eight valence electrons only by sharing its 4 outermost electrons with the 4 electrons of the other atoms.

VALENCY OF ELEMENTS

When atoms of one element combine with the atoms of another element to form a compound, they do so in fixed numbers depending upon the capacities of the atoms to form bonds. **The capacity of an atom of an element to form chemical bonds is known as its valency.** The valency of an element decides the number of other atoms which can combine with one atom of that element. For example, the valency of carbon is 4 and that of hydrogen is 1. So, one atom of carbon can combine with four atoms of hydrogen to form a methane molecule, CH_4. The valency of an element is also known as "valence" of the element, ''combining capacity" of the element or "combining number" of the element. **The valency of an element is decided by the "number of valence electrons" in its atom.** In other words, the valency of an element is decided by the "number of outermost electrons" in its atom. This is discussed below.

Relation Between Valency and Valence Electrons

The valency of an element depends on the number of valence electrons (outermost electrons) in its atom because only the valence electrons take part in chemical bonding. **The valency of an element is either equal to the number of valence electrons in its atom or equal to the number of electrons required to complete eight electrons in the valence shell.** For example, sodium has 1 valence electron and the valency of sodium is also 1. So, in the case of sodium, the valency is equal to the number of valence electrons in its atom. In general, **the valency of a metal element is equal to the number of valence electrons in its atom.** That is,

Valency of a metal = No. of valence electrons in its atom

Let us discuss the case of non-metals now. Chlorine has 7 valence electrons but its valency is not 7. Chlorine atom requires 1 electron to complete the 8 electron structure, so the valency of chlorine is 1. Thus, in the case of chlorine, valency is equal to the number of electrons required to complete 8 electrons in the valence shell. In general, **the valency of a non-metal element is usually equal to eight minus the number of valence electrons in its atom.** That is,

Valency of a non-metal = 8 – No. of valence electrons in its atom

There is one exception to this rule and that is the valency of hydrogen. The valency of hydrogen is equal to the number of valence electrons, which is 1 (though hydrogen is a non-metal element).

Types of Valency

There are two types of valency : Electrovalency and Covalency. If an element combines by the loss or gain of electrons to form electrovalent compounds (or ionic compounds), its valency is known as electrovalency, and if an element combines by the sharing of electrons to form covalent compounds (or molecular compounds), its valency is known as covalency. We will now discuss these two types of valency in detail. Let us take the case of electrovalency first.

1. ELECTROVALENCY

In the formation of an electrovalent compound (or ionic compound), **the number of electrons lost or gained by one atom of an element to achieve the nearest inert gas electron configuration is known as its electrovalency.** The elements which lose electrons form positive ions, so they have *positive electrovalency*. The elements which gain electrons form negative ions, so they have *negative electrovalency*. The following examples will make it more clear.

(*a*) Valency of Sodium

The atomic number of sodium is 11, so its electronic configuration is 2, 8, 1. It has 1 electron in its outermost shell. Sodium atom can lose this electron to form a sodium ion, Na^+, having an inert gas electron arrangement of 2, 8. **Since a sodium atom loses 1 electron to achieve the inert gas electron configuration, therefore, the valency of sodium is 1 (or 1+).** The atomic number of potassium is 19 and its valency is also 1. Similarly, the atomic number of lithium is 3 and its valency is also 1. Explain these two cases yourself.

(*b*) Valency of Magnesium

The atomic number of magnesium is 12, and its electronic configuration is 2, 8, 2. It has 2 electrons in its valence shell. The magnesium atom can lose these two outermost electrons to form a magnesium ion, Mg^{2+}, having an inert gas electron configuration of 2, 8. **Since one magnesium atom loses 2 electrons to achieve the inert gas electron configuration, therefore, the valency of magnesium is 2 (or 2+).** The atomic number of calcium is 20 and its valency is also 2. Similarly, the atomic number of beryllium (Be) is 4 and its valency is also 2. Explain these two cases yourself.

(*c*) Valency of Aluminium

The atomic number of aluminium is 13, so its electronic configuration is 2, 8, 3. It has 3 electrons in its outermost shell. The aluminium atom can lose these 3 electrons to form the aluminium ion, Al^{3+}, having an inert gas electron configuration of 2, 8. **Since one atom of aluminium loses 3 electrons to achieve the inert gas electron configuration, so the valency of aluminium is 3 (or 3+).** The atomic number of boron (B) is 5 and its valency is also 3. Explain it yourself.

(*d*) Valency of Chlorine

The atomic number of chlorine is 17, so its electronic configuration is 2, 8, 7. The chlorine atom has 7 electrons in its outermost shell and it needs 1 more electron to achieve the 8-electron configuration. So, the chlorine atom gains (accepts) 1 electron to form a chloride ion, Cl^-, having an inert gas electron arrangement of 2, 8, 8. **Since one chlorine atom gains 1 electron to achieve the inert gas electron configuration, so the electrovalency of chlorine is 1 (or 1–).** Fluorine has atomic number 9, and its electrovalency is also 1 (or 1–). Explain it yourself. The other halogens bromine and iodine also have 7 valence electrons each and need 1 electron each to achieve the inert gas electron arrangements. So, bromine and iodine also have the valency of 1 (or 1–).

(*e*) Valency of Oxygen

The atomic number of oxygen is 8, so its electronic configuration is 2, 6. The oxygen atom has 6 valence electrons, so it needs 2 more electrons to complete the 8-electron structure. The oxygen atom gains (accepts) 2 electrons to form an oxide ion, O^{2-}, having an inert gas electron arrangement of 2, 8. **Since one atom of oxygen requires 2 electrons to achieve the nearest inert gas electron arrangement, so the electrovalency of oxygen is 2 (or 2–).** The atomic number of sulphur is 16 and its valency is also 2. Explain it yourself.

(*f*) Valency of Nitrogen

The atomic number of nitrogen is 7, so its electronic configuration is 2, 5. Nitrogen atom has 5 electrons in its outermost shell and it needs 3 more electrons to complete the 8-electron structure. Thus, the nitrogen atom gains 3 electrons to form a nitride ion, N^{3-}, having an inert gas electron configuration of 2, 8. **Since one nitrogen atom needs 3 electrons to achieve the nearest inert gas electron arrangement, so the electrovalency of nitrogen is 3 (or 3 –).** The atomic number of phosphorus is 15, and its valency is also 3. Explain it yourself.

The atoms of inert gases like helium, neon, argon, etc., have completely filled outermost shells, so they can neither lose electrons nor gain electrons. Due to this, **inert gases have "zero valency"** and are chemically unreactive. We will discuss the covalency now.

2. COVALENCY

In the formation of a covalent compound (or molecular compound), **the number of electrons shared by one atom of an element to achieve the nearest inert gas electron configuration is known as its covalency.** If an atom shares 1 electron, its covalency will be 1, if it shares 2 electrons, then its valency will be 2, and so on. This point will become more clear from the following examples.

(*a*) Covalency of Hydrogen

The atomic number of hydrogen is 1, so its electronic configuration is 1. A hydrogen atom has 1 electron in its outermost shell, which is K shell, so it needs 1 more electron to achieve the 2-electron inert gas electron arrangement of helium and become stable. Hydrogen atom gets this electron by sharing. **Since one atom of hydrogen shares 1 electron to achieve the nearest inert gas electron configuration, therefore, the covalency (or just valency) of hydrogen is 1**. For example, in the formation of a hydrogen molecule H_2, two hydrogen atoms share 1 electron with each other to achieve the nearest inert gas electron arrangement, so the valency of hydrogen in H_2 molecule is 1. Please note that the shared electrons are counted with both the combining atoms for the purpose of determining their inert gas electron configuration.

Figure 28. Look at these girls ! They appear to form a hydrogen molecule (H–H or H_2).

(*b*) Covalency of Chlorine

A chlorine atom has 7 electrons in its outermost shell, so it can share its 1 electron with one electron of another atom to achieve the 8-electron inert gas electron arrangement. **Since one chlorine atom shares 1 electron to achieve the nearest inert gas electron arrangement, therefore, the covalency (or just valency) of chlorine is 1**. For example, in the formation of a chlorine molecule, Cl_2, each chlorine atom shares its 1 electron with the other atom, so the valency of chlorine in Cl_2 molecule is 1.

(*c*) Covalency of Oxygen

An oxygen atom has 6 valence electrons, so it can share its 2 electrons with two electrons of another atom to achieve the 8-electron inert gas electron arrangement and become stable. **Since one oxygen atom shares 2 electrons to achieve the nearest inert gas electron arrangement, therefore, the covalency (or just valency) of oxygen is 2**. For example, in the formation of an oxygen molecule, O_2, each oxygen atom shares its 2 electrons with the other atom, so the valency of oxygen in the O_2 molecule is 2.

(*d*) Covalency of Nitrogen

A nitrogen atom has 5 valence electrons, so it can share its 3 electrons with three electrons of another atom to attain the 8-electron inert gas electron configuration. **Since one nitrogen atom shares 3 electrons to achieve the nearest inert gas electronic configuration, therefore, the covalency (or just valency) of nitrogen is 3**. For example, in the formation of a nitrogen molecule, N_2, each nitrogen atom shares its 3 electrons with the other atom, so the valency of nitrogen in the N_2 molecule is 3.

(*e*) Covalency of Carbon

The atomic number of carbon is 6, so its electronic configuration is 2, 4. Thus, a carbon atom has 4 valence electrons and it requires 4 more electrons to complete the 'octet'. It gets these electrons by sharing. So, a carbon atom shares its 4 electrons with the four electrons of other atoms to attain the 8-electron inert gas electron arrangement. **Since one carbon atom shares its 4 electrons to attain the inert gas electron arrangement, therefore, the covalency (or just valency) of carbon is 4**. For example, in the formation of a methane molecule, CH_4, the carbon atom shares its 4 electrons with four electrons of four hydrogen atoms, so the valency of carbon in CH_4 molecule is 4. The atomic number of silicon is 14 and its valency is also 4. Explain it yourself.

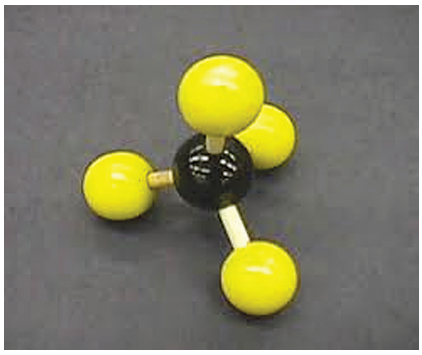


Figure 29. Model of methane molecule (CH_4).

The elements like fluorine, chlorine, bromine, iodine, oxygen, and sulphur, etc., form electrovalent compounds as well as covalent compounds, so they show electrovalency as well as covalency. Please note that **the electrovalency and covalency of an element are numerically the same.** So, we usually talk of just valency and not electrovalency or covalency. Let us now solve some problems based on valency.

Sample Problem 1. What valency will be shown by an element having atomic number 12 ?

Solution. To find out the valency of the element, we will have to write down its electronic configuration. Now, the atomic number of this element is 12, so its electronic configuration will be $\begin{matrix} K & L & M \\ 2, & 8, & 2 \end{matrix}$. It has 2 electrons in its outermost shell (M shell). So, one atom of this element can lose 2 electrons to achieve the nearest inert gas electron arrangement of 2, 8. Since one atom of the element loses 2 electrons to achieve the inert gas electron configuration, so its valency is 2. It is divalent. (The element having atomic number 12 is actually magnesium).

Sample Problem 2. What valency will be shown by an element having atomic number 15 ?

Solution. The atomic number of this element is 15, so its electronic configuration will be $\begin{matrix} K & L & M \\ 2, & 8, & 5 \end{matrix}$. It has 5 electrons in its outermost shell, so it needs 3 more electrons to complete the eight electron, inert gas configuration. Since one atom of this element needs 3 electrons to achieve the inert gas electron configuration, therefore, its valency is 3. (The element having atomic number 15 is actually phosphorus).

Sample Problem 3. If Z = 3, what would be the valency of the element ? Also name the element.

(NCERT Book Question)

Solution. The symbol Z stands for the atomic number of an element. By saying that Z = 3, we mean that the atomic number of this element is 3. The electronic configuration of the element having atomic number 3 is $\underset{2,}{K}\ \underset{1}{L}$. It has 1 electron in its outermost shell (L shell). So, one atom of this element can lose 1 electron to achieve the nearest inert gas electron arrangement of $\underset{2}{K}$ (which is the same as that of helium gas). Since one atom of this element loses 1 electron to achieve the inert gas electron configuration, therefore, its valency is 1. The element having atomic number 3 is lithium.

Sample Problem 4. The number of valence electrons in a chloride ion, Cl^-, are :

(*a*) 16 (*b*) 8 (*c*) 17 (*d*) 18

Choose the correct answer. **(NCERT Book Question)**

Solution. A chlorine atom (Cl) has 7 valence electrons. A chloride ion is formed by the addition of 1 more electron to a chlorine atom. So, the number of valence electrons in a chloride ion (Cl^-) will be 7 + 1 = 8.

ISOTOPES

In nature, most of the elements have a number of atoms which have the 'same atomic number' but 'different mass numbers'. Such atoms of an element are called 'isotopes'. Thus : **Isotopes are atoms of the same element having the same atomic number but different mass numbers.** Isotopes of an element have the same atomic number because they contain the same number of protons (and electrons). Isotopes of an element have different mass numbers because they contain different number of neutrons. It is clear that **the isotopes of an element differ in the number of neutrons in their nuclei.** Let us take an example to understand the meaning of isotopes more clearly.

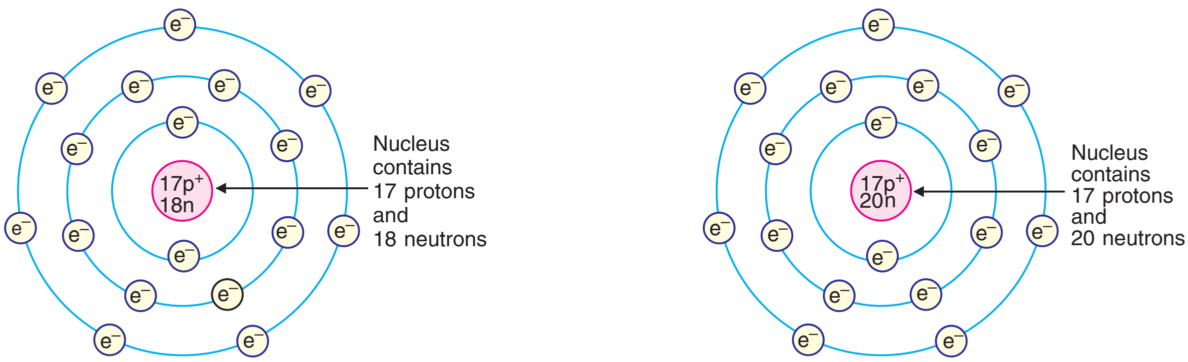
All the chlorine atoms contain 17 protons, so the atomic number of all the chlorine atoms is 17. Now, some chlorine atoms have 18 neutrons whereas other chlorine atoms contain 20 neutrons. Chlorine atoms can, therefore, have mass numbers of 17 + 18 = 35 or 17 + 20 = 37. Thus, chlorine has two isotopes of mass numbers 35 and 37 respectively. The two isotopes of chlorine can be written as :

$$^{35}_{17}Cl \quad \text{and} \quad ^{37}_{17}Cl$$

Both of these chlorine isotopes have the same atomic number of 17 but different mass numbers of 35 and 37 respectively. The complete composition of the two isotopes of chlorine is given below :

Isotope	*Protons*	*Neutrons*	*Electrons*
$^{35}_{17}Cl$	17	18	17
$^{37}_{17}Cl$	17	20	17

The diagrams of the two isotopes of chlorine are given below :

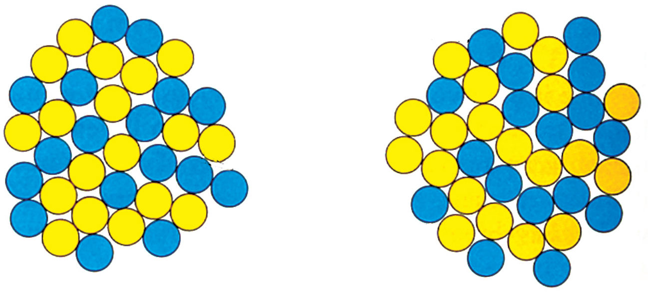


(*i*) Cl-35 isotope (Mass number or Atomic mass = 35)

(*ii*) Cl-37 isotope (Mass number or Atomic mass = 37)

Figure 30. Diagrams of the two isotopes of chlorine.

It should be noted that the mass number of an atom is equal to its atomic mass. So, we can also use the term ''atomic mass'' in place of "mass number" in the definition of isotopes and say that : **isotopes are atoms of the same element having the same atomic number but different atomic masses.** Please note that **the difference in the masses of isotopes of an element is due to the different number of neutrons in their nuclei.** For example, the two isotopes of chlorine contain different number of 18 and 20 neutrons, and hence they have different atomic masses of 35 u and 37 u respectively. It should be clear by now that whether we use the term "mass number" or "atomic mass" in the definition of isotopes, it means the same thing. Another point to be noted is that if they ask the nuclear composition of isotopes in the examination, then we should give the number of protons and neutrons present in the nucleus of each isotope. For example,



(*a*) ${}^{35}_{17}Cl$ contains 17 protons and 18 neutrons

(*b*) ${}^{37}_{17}Cl$ contains 17 protons and 20 neutrons

Figure 31. Nuclear composition of the two isotopes of chlorine (The blue balls represent protons whereas yellow balls represent neutrons).

(*i*) Nuclear composition of ${}^{35}_{17}Cl$ isotope = 17 protons + 18 neutrons

(*ii*) Nuclear composition of ${}^{37}_{17}Cl$ isotope = 17 protons + 20 neutrons

Please note that the isotopes of an element can also be represented by writing their mass numbers with the name of the element or symbol of the element. For example :

(*i*) The isotope of chlorine having mass number 35 can also be represented as chlorine-35 (or just Cl-35), and

(*ii*) The isotope of chlorine having mass number 37 can also be represented as chlorine-37 (or just Cl-37).

We will now give some more examples of isotopes of the various elements such as hydrogen, carbon, oxygen and neon.

1. Isotopes of Hydrogen. The hydrogen element has three isotopes having the same atomic number of 1 but different mass numbers of 1, 2 and 3 respectively. The three isotopes of hydrogen can be represented as :

$${}^{1}_{1}H, \quad {}^{2}_{1}H \quad \text{and} \quad {}^{3}_{1}H$$

The three isotopes of hydrogen, ${}^{1}_{1}H$, ${}^{2}_{1}H$ and ${}^{3}_{1}H$ have been given the special names of protium, deuterium and tritium respectively.

(*i*) Protium is the ordinary hydrogen isotope of mass number 1. Protium is represented as ${}^{1}_{1}H$. Protium does not have a special symbol.

(*ii*) Deuterium is the heavy hydrogen isotope of mass number 2. Deuterium is represented as ${}^{2}_{1}H$. The special symbol of deuterium is D.

(*iii*) Tritium is the very heavy hydrogen isotope of mass number 3. Tritium is represented as ${}^{3}_{1}H$. The special symbol of tritium is T.

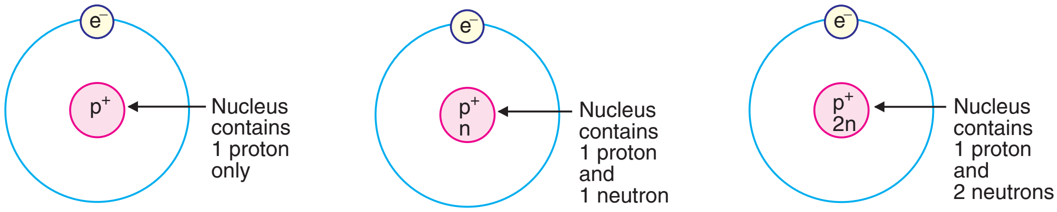
Thus, we can now say that **hydrogen element has three isotopes : protium, deuterium and tritium, having the same atomic number of 1 but different mass numbers of 1, 2 and 3 respectively.**

The complete composition of the three isotopes of hydrogen is given below :

Name	*Isotope*	*Protons*	*Neutrons*	*Electrons*
Protium	${}^{1}_{1}H$	1	0	1
Deuterium	${}^{2}_{1}H$	1	1	1
Tritium	${}^{3}_{1}H$	1	2	1

It is clear from the above table that all the isotopes of hydrogen contain 1 proton and 1 electron each but they contain 0, 1 and 2 neutrons respectively. Please note that the ordinary hydrogen isotope (protium) does not contain any neutron ; the heavy hydrogen isotope (deuterium) contains 1 neutron ; whereas the very heavy hydrogen isotope (tritium) contains 2 neutrons.

The diagrams of the three isotopes of hydrogen are given below :



(*i*) Ordinary hydrogen (or Protium) Atomic mass = 1 u

(*ii*) Heavy hydrogen (or Deuterium) Atomic mass = 2 u

(*iii*) Very heavy hydrogen (or Tritium) Atomic mass = 3 u

Figure 32. Diagrams to show the three isotopes of hydrogen.

2. Isotopes of Carbon. The carbon element has three isotopes having the same atomic number of 6 but different mass numbers of 12, 13 and 14. The three isotopes of carbon can be written as :

$^{12}_{6}C$, $^{13}_{6}C$ and $^{14}_{6}C$

These three isotopes of carbon contain 6 protons and 6 electrons each but they contain an unequal number of neutrons. The C-12 isotope contains 12 – 6 = 6 neutrons, C-13 isotope contains 13 – 6 = 7 neutrons whereas the C-14 isotope contains 14 – 6 = 8 neutrons.

3. Isotopes of Oxygen. The oxygen element has three isotopes :

$^{16}_{8}O$, $^{17}_{8}O$ and $^{18}_{8}O$

All the isotopes of oxygen have the same atomic number of 8 but they have different mass numbers (or atomic masses) of 16, 17 and 18 respectively.

4. Isotopes of Neon. The neon element has also three isotopes which can be written as :

$^{20}_{10}Ne$, $^{21}_{10}Ne$ and $^{22}_{10}Ne$

It is obvious from the above symbols that all the isotopes of neon have the same atomic number of 10 but they have different mass numbers (or atomic masses) of 20, 21 and 22 respectively. We will now discuss why all the isotopes of an element have identical chemical properties.

All the Isotopes of an Element Have Identical Chemical Properties

The chemical properties of an atom of the element depend on the number of protons and electrons, not on the number of neutrons. Since all the isotopes of an element contain the same number of protons and electrons, therefore, the chemical properties of all the isotopes of an element are identical (or same). **We can explain the identical chemical properties of all the isotopes of an element on the basis of their electronic configurations as follows.**

All the isotopes of an element contain the same number of electrons because of which they have identical electronic configurations having the same number of valence electrons. **Since all the isotopes of an element have identical electronic configurations containing the same number of valence electrons, therefore, all the isotopes of an element show identical chemical properties.** For example, the two isotopes of chlorine, $^{35}_{17}Cl$ and $^{37}_{17}Cl$, both have the same number of 17 electrons in them due to which both of them have the same electronic configuration of 2, 8, 7. Since both the isotopes of chlorine, Cl-35 and Cl-37, have identical electronic configurations (having the same number of 7 valence electrons), they show identical chemical properties.

The Physical Properties of the Isotopes of an Element are Different

The physical properties of an element depend on the mass of the atoms. Now, due to the presence of different number of neutrons, the masses of all the isotopes of an element are slightly different. **Since the masses of the isotopes of an element are slightly different, therefore, the physical properties of the isotopes of an element are slightly different.** Thus, the various isotopes of an element can have slightly different physical properties such as densities, melting points and boiling points, etc. (because all these physical properties depend on the masses of the isotopes). For example, the two isotopes of chlorine, ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$, have slightly different physical properties because they have slightly different atomic masses of 35 u and 37 u, respectively.

Reason for the Fractional Atomic Masses of Elements

The atomic masses of many elements are in fractions and not whole numbers. For example, the atomic mass of chlorine is 35.5 u whereas that of copper is 63.5 u. **The fractional atomic masses of elements are due to the existence of their isotopes having different masses.** Most of the elements have more than one natural isotope having different masses. Since the atomic mass of an element is the average relative mass of all the natural isotopes of that element, most elements have fractional atomic masses. For example, chlorine has two isotopes ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$ with abundance of 75% and 25% respectively. In other words, natural chlorine consists of two types of atoms, one having a mass of 35 u and the other having a mass of 37 u in the proportion of 75% and 25% respectively. Thus, the average mass of a chlorine atom will be 75% of 35 and 25% of 37, which is 35.5 u. This gives us the atomic mass of chlorine as 35.5 u. The calculation of average atomic mass of chlorine will become more clear from the following discussion.

Figure 33. This flask contains chlorine. Chlorine consists of two types of atoms, one having a mass of 35 u and the other having a mass of 37 u in the proportion of 75 per cent and 25 per cent respectively.

(*i*) The chlorine isotope ${}^{35}_{17}Cl$ has a mass of 35 u and its abundance (or proportion) in nature is 75%.

(*ii*) The chlorine isotope ${}^{37}_{17}Cl$ has a mass of 37 u and its abundance (or proportion) in nature is 25%.

This means that the isotope of mass 35 u will contribute 75 per cent to the average atomic mass of chlorine whereas the isotope of mass 37 u will contribute 25 per cent to the average atomic mass of chlorine. So,

$$\begin{aligned}\text{Average atomic mass of chlorine} &= 35\times\frac{75}{100} + 37\times\frac{25}{100}\\ &= \frac{2625}{100}+\frac{925}{100}\\ &= 26.25 + 9.25\\ &= 35.5 \text{ u}\end{aligned}$$

Thus, the average atomic mass of chlorine is 35.5 u.

All the naturally occurring isotopes of an element are present in a fixed proportion, so the average atomic mass of an element is fixed (or constant).

We will now solve some problems based on isotopes. In order to find out whether two (or more) atoms are isotopes of the same element or not, we should look at the number of protons and neutrons in them. If they contain the same number of protons but different number of neutrons, they will be isotopes of the same element. The number of electrons in them will also be the same. This point will be helpful in solving the following problems.

Sample Problem 1. The number of protons, neutrons and electrons in species A to E are given in the following table :

Species	*Protons*	*Neutrons*	*Electrons*
A	6	6	4
B	18	22	18
C	17	20	17
D	9	10	11
E	17	18	17

Indicate from the above table the species that represent a pair of isotopes.

Solution. Those species which contain the same number of protons but different number of neutrons will be a pair of isotopes. In the above table only two species C and E have the same number of protons (17 each) but different number of neutrons (20 and 18 respectively). Thus, C and E are a pair of isotopes. (Please note that the atomic number 17 is of chlorine, so C and E are actually the two isotopes of chlorine).

Sample Problem 2. Composition of the nuclei of two atomic species X and Y is given as under :

	X	Y
Protons :	6	6
Neutrons :	6	8

Give the mass numbers of X and Y. What is the relation between the two species and which element or elements they represent ? **(NCERT Book Question)**

Solution. We know that :

$$\text{Mass number} = \text{No. of protons} + \text{No. of neutrons}$$

So,
$$\text{Mass number of X} = 6 + 6 = 12$$
$$\text{Mass number of Y} = 6 + 8 = 14$$

Thus, the mass number of X is 12 and that of Y is 14.

Now, X contains 6 protons, therefore, the atomic number of X is 6. Y contains 6 protons, therefore, the atomic number of Y is also 6. Since X and Y have the same atomic number (of 6) but different mass numbers (of 12 and 14), they are a pair of isotopes. Atomic number 6 is of carbon element. So, both X and Y represent carbon element.

Sample Problem 3. Bromine occurs in nature mainly in the form of two isotopes $^{79}_{35}\text{Br}$ and $^{81}_{35}\text{Br}$. If the abundance of $^{79}_{35}\text{Br}$ isotope is 49.7% and that of $^{81}_{35}\text{Br}$ isotope is 50.3%, calculate the average atomic mass of bromine. **(NCERT Book Question)**

Solution. We know that upper digit in the symbol of an isotope represents its mass (which is the same as its mass number). Now :

(*i*) The mass of $^{79}_{35}\text{Br}$ isotope is 79 u and its abundance is 49.7%.

(*ii*) The mass of $^{81}_{35}\text{Br}$ isotope is 81 u and its abundance is 50.3%.

So, Average atomic mass of bromine $= 79 \times \dfrac{49.7}{100} + 81 \times \dfrac{50.3}{100}$

$$= \frac{3926.3}{100} + \frac{4074.3}{100}$$

$$= 39.263 + 40.743$$
$$= 80.006$$
$$= 80 \text{ u}$$

Thus, the average atomic mass of bromine is 80 u.

Sample Problem 4. A sample of an element X contains two isotopes ${}^{16}_{8}X$ and ${}^{18}_{8}X$. If the average atomic mass of this sample of the element be 16.2 u, calculate the percentage of the two isotopes in this sample.

(NCERT Book Question)

Solution. In order to solve this problem, we will have to suppose that the percentage of one of the isotopes in the sample is x, so that the percentage of the other isotope in the sample will be $(100 - x)$. Now :

(*i*) The mass of ${}^{16}_{8}X$ isotope is 16 u. Suppose its percentage in the sample is x %.

(*ii*) The mass of ${}^{18}_{8}X$ isotope is 18 u. Its percentage in the sample will be $(100 - x)$ %.

So, Average atomic mass of X $= 16 \times \frac{x}{100} + 18 \times \frac{(100 - x)}{100}$

But the average atomic mass of X has been given to be 16.2 u. Therefore,

$$16.2 = 16 \times \frac{x}{100} + 18 \times \frac{(100 - x)}{100}$$

or $$16.2 = \frac{16x + 1800 - 18x}{100}$$

or $$16.2 \times 100 = 1800 - 2x$$

or $$2x = 1800 - 1620$$

or $$2x = 180$$

And $$x = \frac{180}{2}$$

or $$x = 90$$

Thus, the percentage of the isotope ${}^{16}_{8}X$ in the sample is 90%. The percentage of the other isotope ${}^{18}_{8}X$ in the sample will be 100 – 90 = 10%.

RADIOACTIVE ISOTOPES

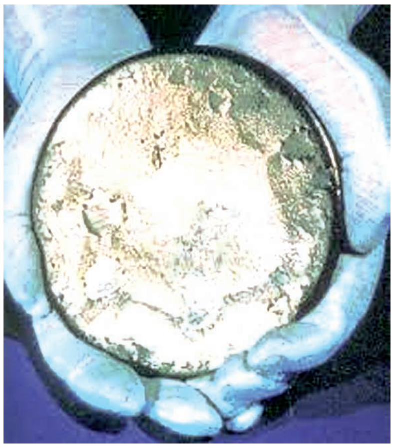
There are two types of isotopes : those which are stable and those which are unstable. **The isotopes which are unstable (due to the presence of extra neutrons in their nuclei) and emit various types of radiations, are called radioactive isotopes (or just radioisotopes).** The radiations (such as alpha particles, beta particles and gamma rays) are emitted by the unstable nuclei of the radioactive isotopes. Some of the common radioactive isotopes are : Carbon-14, Arsenic-74, Sodium-24, Iodine-131, Cobalt-60 and Uranium-235. **The high energy radiations emitted by radioactive isotopes are harmful to human beings.** So, radioactive isotopes have to be used very, very carefully by taking suitable precautions and at proper concentrations to avoid damage.

Applications of Radioactive Isotopes

Radioactive isotopes are widely used in medicine to diagnose, study and treat various ailments. They are also used in power plants and in industry. Some of the important applications (or uses) of radioactive isotopes are given below.

1. Radioactive isotopes are used as a fuel in nuclear reactors of nuclear power plants for generating electricity.

Uranium-235 isotope is used as a fuel in the reactors of nuclear power plants for generating electricity. This is done as follows : When uranium-235 atoms are bombarded with slow moving neutrons, the heavy uranium nuclei break up to form two smaller nuclei and a tremendous amount of heat energy is produced. This heat energy is used to boil water in big boilers to form steam. The high pressure steam turns the



(*a*) Uranium-235

(*b*) A nuclear power plant

Figure 34. Radioactive isotopes (such as uranium-235) are used as a fuel in the nuclear power plants for generating electricity.

turbines. The turbines run the generators to produce electricity. The process in which big uranium-235 nuclei are broken into smaller nuclei to obtain energy is called nuclear fission.The radioactive isotopes such as uranium-235 and plutonium-239 are also used for making atom bombs (or nuclear bombs).

2. Radioactive isotopes are used as 'tracers' in medicine to detect the presence of tumors and blood clots, etc., in the human body.

A small amount of the low activity radioactive compound (called tracer) is either injected into the body of a person or given orally. This radioactive compound moves through the body and accumulates in the area of tumor, blood clot, etc. The exact position of the accumulated radioactive tracer can be found with the help of a device called Geiger counter. This gives the exact position of the tumor or blood clot and is of great help to the doctors for deciding further treatment. Arsenic-74 tracer is used to detect the presence of tumors and sodium-24 tracer is used to detect the presence of blood clots.

3. Radioactive isotopes are used in the treatment of cancer.

Cobalt-60 radioisotope is used to cure cancer. When the high energy gamma radiations emitted by cobalt-60 radioisotopes are directed at the cancerous tumor in the human body, the cancerous cells get

(*a*) This is cobalt-60 radioisotope. It produces high energy gamma rays

(*b*) A carefully controlled beam of gamma rays is used to kill cancer cells in the human body. It is called radiotherapy

Figure 35. Radioactive isotopes are used in the treatment of cancer.

burnt. The treatment of cancer by using radioactive radiations is called radiotherapy.

4. Radioactive isotopes are used to determine the activity of thyroid gland which helps in the treatment of diseases like goitre.

Doctors use iodine-131 radioisotope as a tracer to find how and at what rate the thyroid gland in our body takes up iodine (which is essential for making thyroxine hormone). This helps in the treatment of diseases like goitre.

5. Radioactive isotopes are used in industry to detect the leakage in underground oil pipelines, gas pipelines and water pipes.

To check the leakage in a metal pipeline, a solution of the radioactive substance is introduced in the pipeline. At the place of crack in the pipeline, the radioactive solution will leak out, and the radioactive detector (called Geiger counter) will indicate a higher level of radiations.

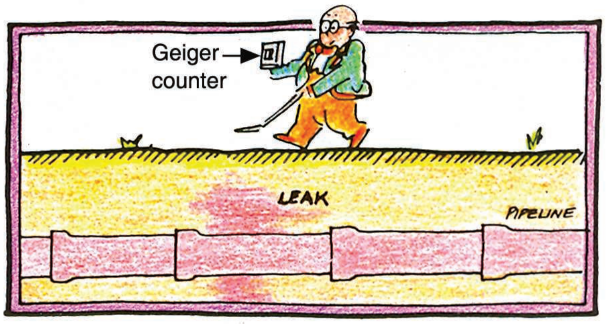


Figure 36. Radioactive isotopes being used for detecting leakage in underground pipeline carrying oil or gas. This prevents digging up of the whole pipeline to plug the leakage.

ISOBARS

We have just studied isotopes which are atoms of the same element having the same atomic number but different mass numbers. It is, however, also possible that in some cases, the atoms of different elements having different atomic numbers may have the same mass number. Such atoms are called isobars. We can now say that : **Isobars are the atoms of different elements having different atomic numbers but the same mass number (or same atomic mass)**. Isobars have different number of protons in their nuclei but the total number of nucleons (protons + neutrons) in them is the same. An example of isobars is argon, $^{40}_{18}Ar$, and calcium, $^{40}_{20}Ca$. This is because argon and calcium are atoms of different elements having different atomic numbers of 18 and 20 respectively but the same mass number of 40. The complete nuclear composition of the isobars $^{40}_{18}Ar$ and $^{40}_{20}Ca$ is given below :

Isobar	*Protons*	*Neutrons*	*Mass number*
$^{40}_{18}Ar$	18	22	18 + 22 = 40
$^{40}_{20}Ca$	20	20	20 + 20 = 40

Here is another example of isobars. The radioactive sodium, $^{24}_{11}Na$, and magnesium $^{24}_{12}Mg$, are isobars. This is because radioactive sodium and magnesium are different elements having different atomic numbers of 11 and 12 respectively but the same mass number of 24.

In order to find out isobars from among a number of given species, we should look at their atomic numbers and mass numbers. The atomic species having different atomic numbers but same mass number will be isobars. We will now solve some problems based on isobars.

Sample Problem 1. Which two of the following atomic species are isotopes of each other and which two are isobars ?

$$^{231}_{90}Z, \quad ^{230}_{91}Z, \quad ^{230}_{88}Z, \quad ^{233}_{90}Z$$

Solution (*a*). The isotopes of an element have the same atomic number but different mass numbers. The lower figures in the above given symbols indicate the atomic numbers. Now, in this case there are two atoms having the same atomic number of 90. So, the two isotopes will be :

$$^{231}_{90}Z \quad \text{and} \quad ^{233}_{90}Z$$

(*b*) The isobars have different atomic numbers but same mass numbers. The upper figures in the given symbols indicate the mass numbers. In this case there are two atoms having the same mass number of 230. So, the two isobars will be :

$$^{230}_{91}Z \quad \text{and} \quad ^{230}_{88}Z$$

Sample Problem 2. Write the electronic configurations of any one pair of (*a*) isotopes, and (*b*) isobars. **(NCERT Book Question)**

Solution. (*a*) A pair of isotopes of chlorine is $^{35}_{17}Cl$ and $^{37}_{17}Cl$. The atomic number of both the isotopes is the same, 17. So, the electronic configuration of both these isotopes will be 2, 8, 7.

(*b*) A pair of isobars is $^{40}_{18}Ar$ and $^{40}_{20}Ca$. The atomic number of argon (Ar) is 18, so its electronic configuration will be 2, 8, 8. The atomic number of calcium (Ca) is 20, so its electronic configuration will be 2, 8, 8, 2.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. The total number of electrons in a nitrogen atom is 7. Find the number of valence electrons in it.
2. What is the general name of the elements having 8 electrons in the valence shell of their atoms ?
3. Which noble gas has less than 8 electrons in the valence shell of its atom ? What is this number ?
4. State one use of radioactive isotopes in medicine.
5. Give one example of a radioactive isotope which is used as a fuel in the reactors of nuclear power plants.
6. Name the radioactive isotope which is used in the treatment of cancer.
7. Which radioactive isotope is used to determine the activity of thyroid gland ?
8. State one use of radioactive isotopes in industry.
9. State whether the following statement is true or false :
   Radioactive isotope of iodine is used for making the medicine called tincture iodine.
10. What name is given to those atoms which contain the same number of protons and electrons but different number of neutrons ?
11. What is the relationship between an atom containing 11 protons, 11 electrons and 11 neutrons, and another atom containing 11 protons, 11 electrons and 12 neutrons ?
12. What name is given to the pair of atoms such as $^{14}_{7}N$ and $^{15}_{7}N$?
13. What name is given to those isotopes which have unstable nuclei and emit various types of radiations ?
14. Fill in the following blanks in respect of an atom of an element :

Number of protons	*Number of neutrons*	*Mass number*	*Atomic number*	*Number of electrons*	*Valency*
11	12	....	....	....	....

15. Complete the following statements :
   (*a*) Magnesium has 2 valence electrons in the .... shell.
   (*b*) The valency of nitrogen in N_2 molecule is ....
   (*c*) Isotopes have different mass numbers because their nuclei contain different number of ....
   (*d*) Some boron atoms have mass number 10 and some have mass number 11. These boron atoms with different mass numbers are called ....

Short Answer Type Questions

16. The nucleus of an atom has 5 protons and 6 neutrons. What would be the (*a*) atomic number, (*b*) mass number, (*c*) the number of electrons, and (*d*) the number of valence electrons, per atom of this element ?
17. Write the electronic configuration of the element with atomic number 17. Indicate the valency of the element.
18. The atomic number of an element X is 16.
   (*a*) Write down the electronic configuration of X.
   (*b*) What will be the valency of X ?

19. What valencies will be shown by the elements A, B, C, D and E having atomic numbers 2, 4, 8, 10, and 13 respectively.

20. Give one use each of the following radioactive isotopes :
(*a*) Uranium-235 (*b*) Cobalt-60

21. Explain why $^{3}_{1}H$ and $^{3}_{2}He$ are not considered isotopes.

22. What is the reason for the different atomic masses of the isotopes of an element ?

23. What is the reason for the identical chemical properties of all the isotopes of an element ? Explain with the help of an example.

24. What is the reason for the slightly different physical properties of all the isotopes of an element ?

25. Explain why, the atomic masses of many elements are in fractions and not whole numbers.

26. Which of the following are isotopes and which are isobars ?
Argon, Deuterium, Calcium, Tritium, Protium

27. Hydrogen has three isotopes written as :
$^{1}_{1}H$, $^{2}_{1}H$, $^{3}_{1}H$
Explain why :
(*i*) these isotopes have almost identical chemical properties.
(*ii*) they are electrically neutral.

28. Given that the percentage abundance of the isotope $^{20}_{10}Ne$ is 90% and that of the isotope $^{22}_{10}Ne$ is 10%, calculate the average atomic mass of neon.

29. What are isobars ? Explain with an example.

30. For the symbols H, D and T, write the subatomic particles (protons, neutrons and electrons) found in each one of them.

31. An element has Z = 7. What is the valency of the element ? Also name the element.

Long Answer Type Questions

32. (*a*) What are valence electrons ? Where are valence electrons situated in an atom ?
(*b*) What is the number of valence electrons in the atoms of an element having atomic number 13 ? Name the valence shell of this atom.

33. (*a*) What are isotopes ? Explain by giving an example.
(*b*) Give one similarity and one difference between a pair of isotopes.
(*c*) Give the number of protons, neutrons and electrons per atom in the two isotopes of chlorine $^{35}_{17}Cl$ and $^{37}_{17}Cl$.

34. (*a*) What are radioactive isotopes ? Give two examples of radioactive isotopes.
(*b*) Give any two uses of radioactive isotopes.
(*c*) An element Z contains two naturally occurring isotopes $^{35}_{17}Z$ and $^{37}_{17}Z$. If the average atomic mass of this element be 35.5 u, calculate the percentage of two isotopes.

35. (*a*) Define valency of an element. What valency will be shown by an element having atomic number 14 ?
(*b*) What is the relation between the valency of an element and the number of valence electrons in its atoms ? Explain with examples.

Multiple Choice Questions (MCQs)

36. The mass number of two atoms X and Y is the same (40 each) but their atomic numbers are different (being 20 and 18 respectively). X and Y are examples of :
(*a*) chemically similar atoms (*b*) isotopes
(*c*) solid and liquid metals (*d*) isobars

37. Which of the following statement is correct about the atom of an element ?
(*a*) an atom can have only protons and neutrons but no electrons.
(*b*) an atom can have only electrons and neutrons but no protons
(*c*) an atom can have only electron and proton but no neutron
(*d*) an atom must always have a proton, neutron and electron

38. There are two species represented as ^{35}Cl and ^{37}Cl. Which of the following statement is correct regarding these species ?
(*a*) they have different chemical properties
(*b*) their physical properties are the same
(*c*) they have the same number of protons
(*d*) they are isobars of the same element

39. The radioactive isotope used in the treatment of cancer is :
(*a*) plutonium-239 (*b*) arsenic-74 (*c*) cobalt-60 (*d*) iodine-131

40. Elements having valency 'one' are :
(*a*) always metals
(*b*) always non-metals
(*c*) always metalloids
(*d*) either metals or non-metals

41. In a sample of ethyl ethanoate ($CH_3COOC_2H_5$), the two oxygen atoms have the same number of electrons but different number of neutrons. Which of the following is the correct reason for it ?
(*a*) one of the oxygen atoms has gained electrons
(*b*) one of the oxygen atoms has gained protons
(*c*) the two oxygen atoms are isotopes
(*d*) the two oxygen atoms are isobars

42. Which of the following elements does not exhibit electrovalency ?
(*a*) calcium (*b*) chromium (*c*) carbon (*d*) cadmium

43. The number of valence electrons in a graphite atom is :
(*a*) 2 (*b*) 4 (*c*) 3 (*d*) 5

44. The atomic numbers of four elements A, B, C and D are 12, 13, 15 and 3 respectively. The element which cannot form a cation is :
(*a*) A (*b*) B (*c*) C (*d*) D

45. The number of valence electrons in a sulphide ion, S^{2-}, is :
(*a*) 16 (*b*) 10 (*c*) 9 (*d*) 8

46. For an element, Z = 9. The valency of this element will be :
(*a*) 4 (*b*) 2 (*c*) 1 (*d*) 3

47. Four elements W, X, Y and Z contain 8, 11, 9 and 17 protons per atom respectively. The element which cannot form an anion is most likely to be :
(*a*) W (*b*) X (*c*) Y (*d*) Z

48. The four atomic species can be represented as follows. Out of these, the two species which can be termed isobars are :
(*i*) $^{201}_{60}X$ (*ii*) $^{200}_{61}X$ (*iii*) $^{200}_{58}X$ (*iv*) $^{203}_{60}X$
(*a*) (*i*) and (*ii*) (*b*) (*ii*) and (*iii*) (*c*) (*i*) and (*iii*) (*d*) (*i*) and (*iv*)

49. There are four elements P, Q, R and S having atomic numbers of 4, 18, 10 and 16 respectively. The element which can exhibit covalency as well as electrovalency will be :
(*a*) P (*b*) Q (*c*) R (*d*) S

50. The atomic number of an element X is 8 and that of element Y is 4. Both these elements can exhibit a valency of :
(*a*) 1 (*b*) 2 (*c*) 3 (*d*) 4

51. The isotopes of an element contain :
(*a*) same number of neutrons but different number of protons
(*b*) same number of neutrons but different number of electrons
(*c*) different number of protons as well as different number of neutrons
(*d*) different number of neutrons but same number of protons

Questions Based on High Order Thinking Skills (HOTS)

52. What is the number of valence electrons in :
(*a*) sodium ion, Na^+ (*b*) oxide ion, O^{2-}

53. Atom A has a mass number 209 and atomic number 82.
Atom B has a mass number 209 and atomic number 83.
(*i*) How many protons atom A has ?
(*ii*) How many protons atom B has ?
(*iii*) Are atoms A and B isotopes of the same element ?

54. Which of the following pairs are isotopes ? Give reasons for your choice :

(*i*) ${}^{58}_{26}A$, ${}^{58}_{28}B$ or (*ii*) ${}^{79}_{35}X$, ${}^{80}_{35}Y$

55. Three different atoms of oxygen are represented as :

${}^{16}_{8}O$, ${}^{17}_{8}O$ and ${}^{18}_{8}O$

(*i*) What do the subscripts (lower figures) and superscripts (upper figures) represent ?

(*ii*) What factor is responsible for the change in the superscripts 16, 17 and 18, though the element is the same ?

(*iii*) What is the usual name for such atoms of an element ?

(*iv*) Give the nuclear composition of ${}^{18}_{8}O$

56. The atomic species *A* and *B* have different number of protons but the same number of nucleons. On the other hand, the atomic species *X* and *Y* have the same number of protons but different number of nucleons. Which pair is an example of isobars ? Why ?

57. Composition of the nuclei of two atomic species A and B is given as under :

	A	B
Protons :	18	20
Neutrons :	22	20

Give the mass numbers of A and B. What is the relation between the two species and which element or elements they represent ?

58. Which of the following pairs are isobars ?

(*i*) ${}^{58}_{26}A$, ${}^{58}_{28}B$ (*ii*) ${}^{79}_{35}X$, ${}^{80}_{35}Y$

Give reasons for your choice.

59. The number of protons, neutrons and electrons in particles A to E are given below :

Particle	*Protons*	*Neutrons*	*Electrons*
A	17	18	17
B	3	4	2
C	18	22	18
D	17	20	17
E	9	10	10

Giving reasons, find a pair of isotopes from the above particles.

60. The composition of two atomic particles is given below :

	X	Y
Protons :	8	8
Neutrons :	8	9
Electrons :	8	8

(*i*) What is the mass number of X ?

(*ii*) What is the mass number of Y ?

(*iii*) What is the relation between X and Y ?

(*iv*) Which element/elements do they represent ?

ANSWERS

1. 5 **2.** Noble gases **3.** Helium ; 2 **9.** False **10.** Isotopes **11.** Isotopes **12.** Isotopes **13.** Radioactive isotopes **14.** 23 ; 11 ; 11; 1 **15.** (*a*) M (*b*) 3 (*c*) neutrons (*d*) isotopes **16.** (*a*) 5 (*b*) 11 (*c*) 5 (*d*) 3 **18.** (*a*) 2, 8, 6 (*b*) 2 **19.** A = 0; B = 2 ; C = 2 ; D = 0 ; E = 3 **26.** Isotopes : Deuterium , Tritium and Protium ; Isobars : Argon and Calcium **28.** 20.2 u **31.** 3 ; Nitrogen **32.** (*b*) 3 ; M shell **34.** (*c*) 75% ; 25% **35.** (*a*) 4 **36.** (*d*) **37.** (*c*) **38.** (*c*) **39.** (*c*) **40.** (*d*) **41.** (*c*) **42.**(*c*) **43** (*b*) **44.** (*c*) **45.** (*d*) **46.**(*c*) **47.** (*b*) **48.** (*b*) **49.** (*d*) 3 **50.** (*b*) **51.** (*d*) **52.** (*a*) 8 (*b*) 8 **53.** (*i*) 82 (*ii*) 83 (*iii*) No **54.** ${}^{79}_{35}X$. ${}^{80}_{35}Y$; Same atomic number of 35 **55.** (*i*) Atomic number ; Mass number (*ii*) No. of neutrons (*iii*) Isotopes (*iv*) Protons 8 ; Neutrons 10 **56.** A and B ; Due to different number of protons, they have different atomic numbers and due to same number of nucleons, they have the same mass number **57.** Mass number of A = 40 ; B = 40 ; Isobars : A is Argon, B is Calcium **58.** ${}^{58}_{26}A$, ${}^{58}_{28}B$ **59.** A and D ; Same number of protons but different number of neutrons **60.** (*i*) 16 (*ii*) 17 (*iii*) Isotopes (*iv*) Oxygen

Multiple Choice Questions (MCQs)

(Based on Practical Skills in Science)

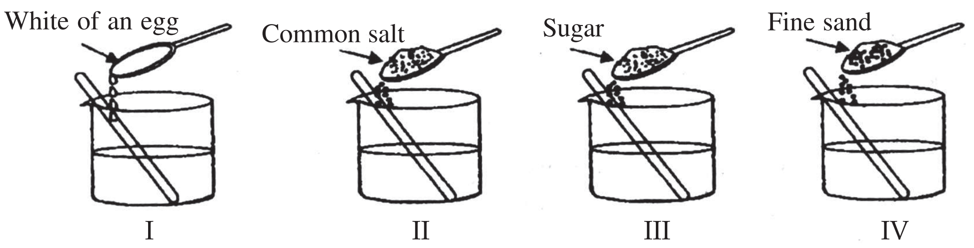
1. Four students, (A), (B), (C) and (D) observed the colour and solubility of iron, sulphur and iron sulphide in carbon disulphide. The tick mark (✓) represents 'soluble', and cross mark (×) represents 'insoluble', in carbon disulphide. Their observations are tabulated below.

Student	Colour			Solubility in carbon disulphide		
	Fe	S	FeS	Fe	S	FeS
(A)	Yellow	Silvery	Greyish silver	(✓)	(×)	(✓)
(B)	Silvery	Orange	Reddish brown	(×)	(✓)	(✓)
(C)	Grey	Yellow	Greyish black	(×)	(✓)	(×)
(D)	Silvery	White	Silvery white	(✓)	(×)	(×)

The student, who correctly reported the observations, is student :

(1) (A) (2) (B) (3) (C) (4) (D)

2. The white of an egg, common salt, sugar and fine sand are added to water separately in beakers as shown below. The mixture is stirred well. A suspension will be formed in the beaker :



(1) I (2) II (3) III (4) IV

3. The correct procedure of heating iron-sulphur mixture to prepare iron sulphide is :

(1) heat the powder mixture at the base of the test tube using a blue flame throughout.

(2) heat the iron filings and sulphur mixture in the middle of the test tube using yellow flame throughout.

(3) heat the powder mixture at the top of the test tube using an orange flame throughout.

(4) heat the iron filings-sulphur mixture at 3/4 quarters of the test tube using a red flame throughout.

4. A student while heating solid lead nitrate taken in a test tube would observe :

(1) white residue of PbO_2 (2) green residue of NO_2

(3) yellow residue of PbO (4) brown residue of NO

5. The following precautions were listed for the experiment on determination of melting point of ice. The incorrect precaution is :

(1) The bulb of the thermometer should be kept surrounded with crushed ice.

(2) Ice should be stirred regularly to keep a uniform temperature throughout.

(3) The final temperature should be noted by keeping the eyes in line with the level of mercury.

(4) Only the tip of the bulb of the thermometer should just touch the crushed ice.

6. The correct procedure for preparing a colloidal solution of egg albumin in water is :

(1) to break the egg shell, take only the white portion and to add it to water with constant stirring.

(2) to break the egg shell, take only the yellow portion and to add it to boiling water with constant stirring.

(3) to boil the egg first, to break the egg shell, to add the white portion to ice cold water and to mix.
(4) to boil the egg first, to break the egg shell, to add the yellow portion to water and to mix.

7. Four students (A), (B), (C) and (D) independently observed the evaporation of water under different conditions, and recorded the temperature of water at regular intervals as shown below.

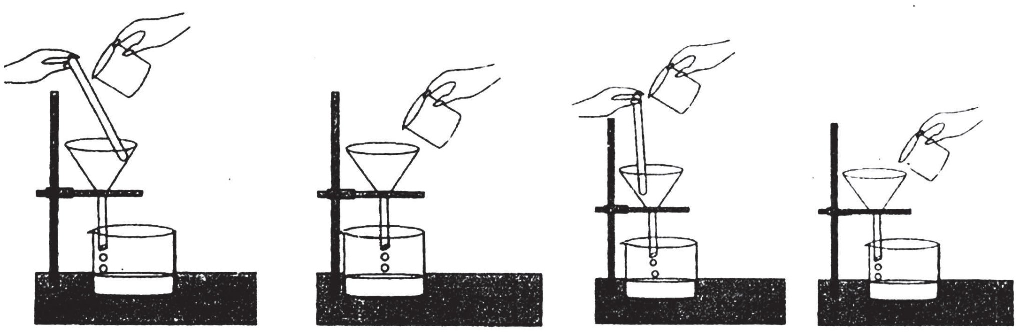
Student	Placing of experimental set up in/under	Temperature recording for 15 minutes
(A)	sun	increased gradually
(B)	open air	decreased gradually
(C)	a fan	initially increased, then became constant
(D)	a corner of the room	initially increased, then gradually decreased

The correct recording of observations is that of the student :
(1) (A) (2) (B) (3) (C) (4) (D)

8. A student takes a mixture of sand and ammonium chloride in a china dish and heats it under a funnel fitted with a plug over a flame. He would observe that :
(1) solid sand gets deposited on the lower cooler parts of the funnel while solid ammonium chloride remains in the china dish.
(2) sand and ammonium chloride get deposited on hotter parts of the funnel.
(3) ammonium chloride gets deposited on the cooler parts of the funnel and sand remains in the china dish.
(4) sand collects on cooler parts of the funnel while ammonium chloride melts in the china dish.

9. A student takes some water in a beaker and heats it over a flame for determining its boiling point. He keeps on taking its temperature readings. He would observe that the temperature of water :
(1) keeps on increasing regularly
(2) keeps on increasing irregularly
(3) first increases slowly, then decreases rapidly and eventually becomes constant
(4) first increases gradually and then becomes constant.

10. Which of the following is the correct set of apparatus to separate common salt and sand by filtration process :

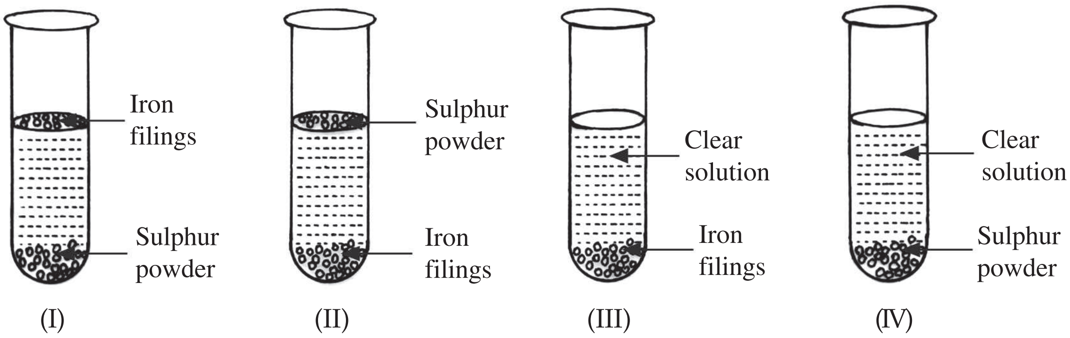


I II III IV

(1) I (2) II (3) III (4) IV

11. A student added the following substances to water kept in four separate beakers. He stirred the mixture well and filtered each one of them through a filter paper. He would obtain a solid residue on the filter paper in the case of :
(1) egg albumin (2) common salt (3) chalk powder (4) alum

12. In an experiment, carbon disulphide was added to a test-tube containing a mixture of iron filings and sulphur powder as shown in the given diagrams :



The correct observation is represented in diagram :

(1) I (2) II (3) III (4) IV

13. The colour of insoluble product formed when sodium sulphate solution and barium chloride solution are mixed together is :

(1) blue (2) yellow (3) white (4) red-brown

14. A student, by mistake, mixed sulphur powder with iron filings. The following techniques were suggested to separate the sulphur from the mixture out of which he has to choose one :

A. dissolving in carbon disulphide, filtration, evaporation

B. dissolving in water at room temperature and filtration

C. dissolving in hot water, filtration and evaporation

D. dissolving in ice cold water and filtration

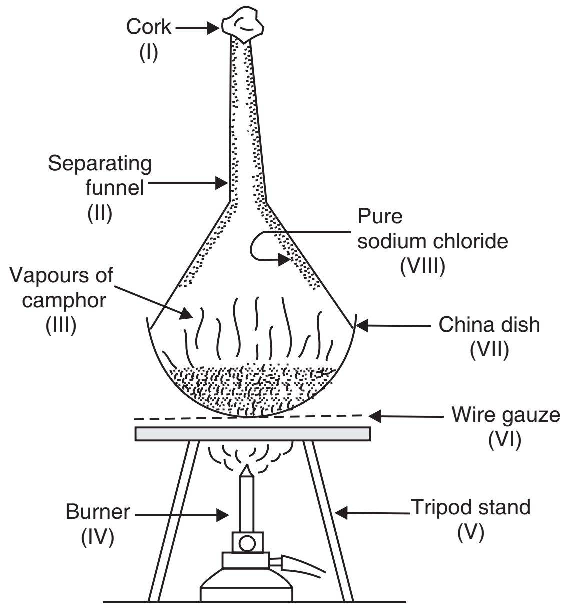
The correct technique is :

(1) A (2) B (3) C (4) D

15. A student has done the labelling for the experimental set-up for separating a mixture of sodium chloride and camphor as indicated in the diagram given here. The parts/substances that have been incorrectly labelled are :

(1) I, III, VIII (2) II, III, VII

(3) I, II, VIII (4) III, V, VII



16. A teacher gave an impure sample of alum containing fine sand as impurity to a student. He asked him to recover pure alum from this sample. The correct procedure to be followed would be to :

(1) dissolve the impure sample of alum in water, filter and evaporate the filtrate

(2) dissolve the impure sample of alum in alcohol and filter

(3) move a magnet over the impure sample of alum

(4) dissolve the impure sample of alum in carbon disulphide, filter and evaporate the filtrate

17. The colour of residue left behind on heating lead nitrate when it is still hot is :

(1) green (2) yellow (3) black (4) reddish-brown

18. A student took some lead nitrate compound in a boiling tube and heated it strongly. The gas/gases evolved on heating this compound is/are :

(1) NO_2 (2) $NO_2 + CO_2$ (3) $NO_2 + O_2$ (4) $N_2 + O_2$

19. When a student heated a colourless solid compound, then brown fumes of a gas are evolved. The colourless solid is most likely to be :

(1) ferrous sulphate (2) lead carbonate

(3) lead nitrate (4) lead sulphate

20. When dilute sulphuric acid is added to granulated zinc placed in a test-tube, the observation made is :
(1) the surface of the metal turns shiny (2) the reaction mixture turns milky
(3) odour of sulphur dioxide is observed (4) a colourless and odourless gas evolves with bubbles

21. What is the correct order of the methods you would apply to separate the components of a mixture of ammonium chloride, common salt and sand ?
(1) dissolving in water, filtration, evaporation and sublimation
(2) dissolving in water, evaporation and sublimation
(3) sublimation, dissolving in water, filtration and evaporation
(4) moving a magnet, dissolving in water and sublimation

22. Four students took separately the mixture of sand, common salt and ammonium chloride in beakers, added water, stirred the mixture well and then filtered. They reported their observations as shown below.

Student	*As residue*	*In the filtrate*
I	Ammonium chloride	Sand, Common salt
II	Common salt, Sand	Ammonium chloride
III	Sand, Ammonium chloride	Common salt
IV	Sand	Ammonium chloride, Common salt

Who reported the observations in the correct order of the components as residue and in the filtrate ?
(1) I (2) IV (3) III (4) II

23. When zinc metal reacts with dilute sulphuric acid, a gas is evolved. Which one is a correct statement about the nature of this gas ?
(1) colourless with suffocating odour (2) reddish brown and odourless
(3) colourless and sweet smelling (4) colourless and odourless

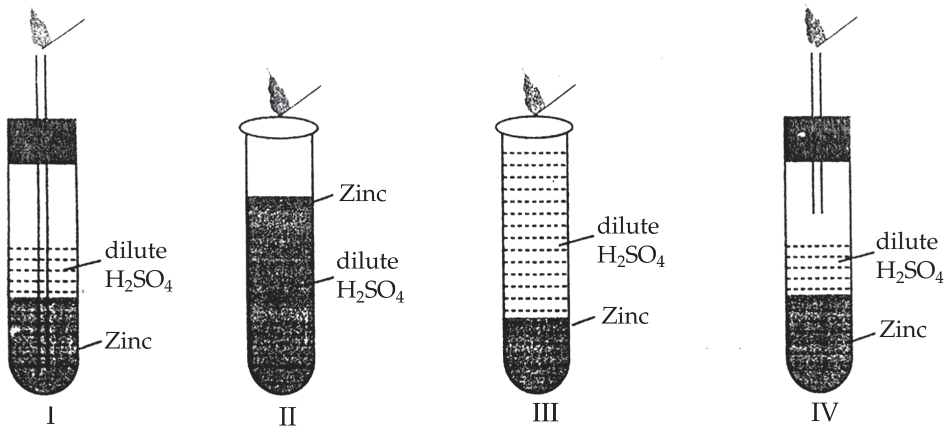
24. The reaction between iron and copper sulphate solution represents which type of reaction ?
(1) decomposition (2) combination
(3) single displacement (4) double decomposition

25. When a burning magnesium ribbon is introduced in a gas jar containing oxygen, it will burn with :
(1) a reddish flame (2) a pale blue flame
(3) a golden yellow flame (4) a dazzling white flame

26. A student heats calculated amounts of iron filings and sulphur powder together in a boiling tube. He will obtain :
(1) a homogeneous mixture of Fe and S (2) a heterogeneous compound of Fe and S
(3) a homogeneous compound of FeS (4) a heterogeneous mixture of FeS, Fe and S

27. Which of the following mixture can be separated completely by the process of sublimation ?
(1) fine sand and cane sugar
(2) sodium chloride and potassium permanganate
(3) potassium chloride and ammonium chloride
(4) barium chloride and sodium sulphate

28. Four set ups as given here were arranged to identify the gas evolved when dilute sulphuric acid was added to zinc granules. The most appropriate set up is :
(1) I (2) II
(3) III (4) IV



29. An iron nail was dropped into copper sulphate solution. After some time, the colour of the solution changed from :

(1) light green to blue (2) blue to light green (3) light green to colourless (4) blue to yellow

30. A student was asked by her science teacher to prepare a true solution. She dissolved the solute in water but forgot to record its name. What may be the correct name of the solute ?

(1) barium sulphate (2) sulphur powder
(3) alum (4) egg albumin

31. A student placed a clean iron nail in blue coloured copper sulphate solution for a considerable time. He observes that :

(1) iron nail gets green coating (2) iron nail gets brown coating
(3) iron nail gets no coating (4) iron nail gets blue coating

32. When a student added a few drops of barium chloride solution to sodium sulphate solution, he obtained a white precipitate instantly. Which of the following type of chemical reaction has been carried out by the student ?

(1) combination (2) double displacement (3) displacement (4) decomposition

33. A student was asked to carry out a chemical reaction by placing four different metal strips in $CuSO_4$ solution for a considerable time, one by one. Which of the following metal strip will turn the blue $CuSO_4$ solution to a light green solution in due course of time ?

(1) Fe (2) Au (3) Mg (4) Ag

34. We can show that iron is more reactive than copper :

(1) by preparing copper sulphate solution and dipping iron strip in it
(2) by dipping both the strips in water for some time
(3) by preparing iron sulphate solution and dipping copper strip in it
(4) by heating both iron and copper strips

35. A student sets up an apparatus to determine the melting point of ice. He takes a beaker half filled with crushed ice and dips a mercury thermometer with an initial reading of room temperature (25°C) in such a way that the bulb of thermometer is surrounded by ice. The correct observation obtained by the student is that :

(1) mercury in the thermometer keeps on falling till it reads, –1°C and becomes constant thereafter
(2) temperature falls, reaches 0°C, then it remains constant even after the whole of the ice has melted
(3) the temperature falls in the beginning but starts rising as soon as the ice starts melting
(4) temperature falls, reaches 0°C and remains constant only as long as both ice and water are present in it

ANSWERS

1. 3	**2.** 4	**3.** 1	**4.** 3	**5.** 4
6. 1	**7.** 2	**8.** 3	**9.** 4	**10.** 1
11. 3	**12.** 3	**13.** 3	**14.** 1	**15.** 3
16. 1	**17.** 4	**18.** 3	**19.** 3	**20.** 4
21. 3	**22.** 2	**23.** 4	**24.** 3	**25.** 4
26. 3	**27.** 3	**28.** 4	**29.** 2	**30.** 3
31. 2	**32.** 2	**33.** 1	**34.** 1	**35.** 4

NCERT BOOK QUESTIONS AND EXERCISES
(with answers)

Chapter : MATTER IN OUR SURROUNDINGS

NCERT Book, Page 3

Q.1. Which of the following are matter ?
Chair, air, love, smell, hate, almonds, thought, cold, cold-drink, smell of perfume

Ans. Chair, air, smell, almonds, cold drink and smell of perfume are matter (because they occupy space and have mass). It should be noted that 'smell' is a matter because it is due to the presence of some volatile substances in air which occupy space and have mass.

Q.2. Give reasons for the following observations :
The smell of hot sizzling food reaches you several metres away but to get the smell from cold food, you have to go close.

Ans. The smell of food reaches us by the process of diffusion of gases (released by the food) into the air. The rate of diffusion of hot gases into air is faster than that of cold gases. So, the smell of hot sizzling food reaches us quickly even when we are several metres away because the rate of diffusion of hot gases (released by the hot sizzling food) is much faster than the rate of diffusion of cold gases released by the cold food.

Q.3. A diver is able to cut through water in a swimming pool. Which property of matter does this observation show ?

Ans. Water is a liquid form of matter. The observation that a diver is able to cut through water in a swimming pool shows that though there is a quite strong force of attraction between the particles of a liquid (like water) which holds them together but the force is not strong enough to hold the particles of the liquid in fixed positions. So, by applying somewhat greater force, a diver is able to overcome the forces of attraction present among the particles of water and hence cut through water in the swimming pool.

Q. 4. What are the characteristics of the particles of matter ?

Ans. The important characteristics of the particles of matter (like atoms or molecules) are the following :

(*i*) The particles of matter are very, very small.
(*ii*) The particles of matter have spaces between them.
(*iii*) The particles of matter are constantly moving.
(*iv*) The particles of matter attract one another.

NCERT Book, Page 6

Q.1. The mass per unit volume of a substance is called density (density = mass / volume). Arrange the following in order of increasing density :
Air, Exhaust from chimneys, Honey, Water, Chalk, Cotton and Iron

Ans. The order of increasing densities of the given substances is :

Air < Exhaust from chimneys < Cotton < Water < Honey < Chalk < Iron

Explanation :

(*i*) Air is mainly a mixture of comparatively light gases like nitrogen, and oxygen, etc., so it has the lowest density.
(*ii*) Exhaust gases from chimneys, in addition to air, also contain heavier gases like carbon dioxide, sulphur dioxide and nitrogen dioxide, etc., so they have slightly higher density than air.
(*iii*) Cotton is a fluffy solid which has a lot of air trapped in its pores. Due to lot of trapped air, solid cotton has higher density than exhaust gases from chimneys.
(*iv*) Water is a liquid having quite closely packed particles, so the density of water is higher than that of cotton.
(*v*) Honey is a thick liquid having closely packed heavy particles, so the density of honey is higher than that of water.

(*vi*) Chalk is a porous solid in which the particles are comparatively less closely packed but it has higher density than honey (which is a liquid).

(*vii*) Iron is a highly compact solid in which the particles are very, very closely packed due to which its density is much higher than that of chalk.

Q.2. (*a*) Tabulate the differences in the characteristics of the three states of matter.

(*b*) Comment upon the following :
Rigidity, Compressibility, Fluidity, Filling a gas container, Shape, Kinetic energy and Density.

Ans. (*a*) The main differences in the characteristics of the three states of matter, solids, liquids and gases are given below :

Solids	*Liquids*	*Gases*
(*i*) Solids have a fixed shape and a fixed volume.	(*i*) Liquids have a fixed volume but they have no fixed shape. Liquids take the shape of the container in which they are placed.	(*i*) Gases have neither a fixed shape nor a fixed volume. Gases acquire the shape and volume of the container in which they are kept.
(*ii*) Solids cannot be compressed much.	(*ii*) Like solids, liquids cannot be compressed much.	(*ii*) Gases can be compressed easily (into a small volume).
(*iii*) Solids have high densities. They are heavy.	(*iii*) Liquids have moderate to high densities. They are usually less dense than solids.	(*iii*) Gases have very low densities. They are very, very, light. A gas is much lighter than the same volume of a solid or a liquid.
(*iv*) Solids do not fill their container completely.	(*iv*) Liquids do not fill their container completely.	(*iv*) Gases fill their container completely.
(*v*) Solids do not flow.	(*v*) Liquids generally flow easily.	(*v*) Gases flow easily.

(*b*) (*i*) **Rigidity.** Rigidity refers to the property of a solid to resist change in its shape (or resist deformation) when an outside force is applied. In most simple terms, rigidity means 'stiffness'. The particles in a solid are very closely packed and there are very strong forces of attraction between them, so solids possess high rigidity. Liquids and gases are not rigid because the positions of their particles are not fixed.

(*ii*) **Compressibility.** Compressibility is the property of a fluid (or a solid) due to which its volume decreases when pressure is applied. The particles in gases have large spaces between them due to which their volume decreases too much when pressure is applied on them. So, gases have high compressibility. On the other hand, the particles in solids and liquids are closely packed, so solids and liquids do not have much compressibility.

(*iii*) **Fluidity.** The property of flowing easily is called fluidity. Gases and liquids exhibit the property of fluidity, so they are called fluids. Due to large interparticle distances and very weak forces of attraction, gases can flow extremely easily. So, the gases have very high fluidity . And because of comparatively smaller interparticle distances and stronger forces of attraction between their particles, the fluidity of liquids is less than that of gases. Solids are not fluids, they have no fluidity.

(*iv*) **Filling a gas container.** A gas fills its container completely because due to high kinetic energy and negligible interparticle forces of attraction, the particles in a gas move with high speeds in all directions and occupy all the space in the container.

(*v*) **Shape.** The external form or appearance of a substance is called its shape. A solid has a fixed shape because the particles in a solid are closely packed and their positions are fixed due to strong forces of attraction between them. The liquids and gases do not have fixed shapes because the positions of particles in them are not fixed due to comparatively weaker forces of attraction between them.

(*vi*) **Kinetic energy**. The energy possessed by a material due to the motion of its particles is called kinetic energy. At a given temperature, the particles in a gas have the maximum kinetic energy because they move with high speeds due to weakest forces of attraction among them. Liquids have lesser kinetic energy (than gases) whereas solids have the the least kinetic energy at a given temperature.

(*vii*) **Density.** The mass per unit volume of a material is called its density. Solids have high densities because their particles are very close together. Liquids have usually lower densities than solids because their particles are somewhat more loosely packed than that in solids. Gases have the lowest densities because their particles are very far apart from one another.

Q.3. Give reasons :

(*a*) A gas fills completely the vessel in which it is kept.

(*b*) A gas exerts pressure on the walls of the container.

(*c*) A wooden table should be called a solid.

(*d*) We can easily move our hand in air but to do the same through a solid block of wood, we need a karate expert.

Ans. (*a*) The particles of a gas have high kinetic energy and negligible forces of attraction amongst them. Due to this the particles of a gas are constantly moving with high speeds in all the directions and the gas completely fills the vessel in which it is kept.

(*b*) Because of high kinetic energy and negligible forces of attraction, the particles of a gas move with high speeds in all directions. When the fast moving gas particles hit the walls of its container from inside, they exert a pressure (called gas pressure). Thus, the pressure exerted by a gas is due to the constant collisions of the fast moving gas particles against the inner walls of the container.

(*c*) A wooden table is a rigid object having a definite shape and a definite volume. Since a wooden table has these basic characteristics of solid state (rigidity, definite shape and definite volume), it should be called a solid.

(*d*) Air is a gas (or a mixture of gases) whose particles are very far apart and there are very weak forces of attraction between them. The extremely weak forces between particles of air can be overcome easily due to which we can easily move our hand in air. On the other hand, the particles of a solid block of wood are very closely packed and there are very strong forces of attraction between the particles of wood. It needs a huge outside force to overcome the strong interparticle attractions of a block of wood and break it apart by moving hand which only a karate expert can apply.

Q.4. Liquids generally have lower density as compared to solids. But you must have observed that ice floats on water. Find out why ?

Ans. Ice is formed by the freezing of water. When water freezes to form ice, then a number of empty spaces are created in solid ice (which were not present in liquid water) giving it a cage-like structure. Due to the presence of some empty spaces, the volume of ice becomes more than an equal mass of water. Because of its greater volume, the density (mass per unit volume) of ice decreases. And due to its lower density than water, ice floats on water (even though it is a solid).

NCERT Book, Page 9

Q.1. Convert the following temperatures to celsius scale :

(*a*) 300 K (*b*) 573 K

Ans. (*a*) See Sample Problem 2 on page 24 of this book.

(*b*)

$$\text{Temp. on Kelvin scale} = \text{Temp. on Celsius scale} + 273$$

$$573 = \text{Temp. on Celsius scale} + 273$$

$$\text{And, Temp. on Celsius scale} = 573 - 273$$

$$= 300°C$$

Q.2. What is the physical state of water at :

(*a*) 250°C ? (*b*) 100°C ?

Ans. (*a*) The boiling point of water is 100°C. So, the physical state of water at a temperature of 250°C (which is much above its boiling point) will be 'gaseous state'.

(*b*) The physical state of water at its boiling point temperature of 100°C will be both 'liquid state' as well as 'gaseous state'. This is because at its boiling point (of 100°C), the liquid state of water starts changing into its gaseous state (steam).

Q.3. For any substance, why does the temperature remain constant during the change of state ?

Ans. The heat energy supplied to a substance during the change of state (at its melting point or boiling point) is all used up in overcoming (or breaking) the force of attraction between its particles without increasing its kinetic energy. Since the heat (or latent heat) supplied during the change of state does not increase the kinetic energy of the substance, therefore, no rise in temperature takes place. The temperature remains constant.

Q.4. Suggest a method to liquefy atmospheric gases.

Ans. Atmospheric gases can be liquefied by applying pressure and lowering temperature. When enough pressure is applied, the gases are highly compressed into a small volume. The particles of gases get so close together that they start attracting one another sufficiently to form a liquid. When a gas is compressed too much by applying high pressure, a lot of heat is produced. So, while applying pressure to liquefy gases, it is necessary to lower their temperature (or cool them) to take away the heat produced during compression.

NCERT Book, Page 10

Q.1. Why does a desert cooler cool better on a hot dry day ?

Ans. The cooling in a desert room cooler is caused by the evaporation of water. A desert cooler cools better on a hot and dry day because the higher temperature on a hot day increases the rate of evaporation of water, and the dryness of air (low humidity of air) also increases the rate of evaporation of water. And due to increased rate of evaporation of water, a desert room cooler cools better on a hot and dry day.

Q.2. How does the water kept in an earthen pot (*matka*) become cool during summer ?

Ans. The earthen pot (or *matka*) has a large number of extremely small pores in its walls. Some of the water kept in the earthen pot continuously keeps seeping through these pores to the outside of the pot. This water evaporates (changes into vapour) continuously by taking the latent heat of vaporisation from the earthen pot and the remaining water. In this way, the earthen pot and remaining water lose heat and get cooled.

Q.3. Why does our palm feel cold when we put some acetone or petrol or perfume on it ?

Ans. Acetone, petrol and perfume are volatile liquids (which can change into vapours easily). When we put some acetone , petrol or perfume on our palm, the acetone, petrol or perfume evaporate rapidly and our palm feels cold. This is due to the fact that to change from the liquid to the vapour state, acetone, petrol or perfume require latent heat of vaporisation. The acetone, petrol or perfume take this latent heat of vaporisation from our palm. The palm loses heat and feels cold.

Q.4. Why are we able to sip hot tea or milk faster from a saucer than a cup ?

Ans. If the hot tea (or milk) is taken in a cup, then due to the narrow shape of the cup, the surface area of hot tea (or milk) in the cup is comparatively small. Because of small surface area, the evaporation of hot tea (or milk) taken in the cup is slow, cooling caused by evaporation is less, and hence the hot tea (or milk) remains appreciably hot for a much longer time, making it difficult to sip. On the other hand, saucer has a large surface area. Due to the large surface area of hot tea (or milk) taken in the saucer, the evaporation of hot tea (or milk) from the saucer is faster. The faster evaporation cools the hot tea (or milk) much more quickly making it convenient to sip (or drink).

Q.5. What type of clothes should we wear in summer ?

Ans. We should wear cotton clothes in hot summer days to keep us cool and comfortable. This is due to the following reason : During hot summer days, we perspire more (give out more sweat through the pores of the skin). Sweat (*pasina*) is mainly water. The cotton clothes are good absorber of sweat. So, cotton clothes absorb the sweat produced on our skin quickly and expose it to the atmosphere for evaporation. The evaporation of sweat from cotton clothes takes the latent heat of vaporisation from our skin. In this way, our skin loses heat and makes us feel cool and comfortable.

NCERT Book, Page 12

Q.1. Convert the following temperatures to the celsius scale :
(*a*) 293 K (*b*) 470 K

Ans. (*a*)
$$\text{Temp. on Kelvin scale} = \text{Temp. on Celsius scale} + 273$$
$$293 = \text{Temp. on Celsius scale} + 273$$
$$\text{So, Temp. on Celsius scale} = 293 - 273$$
$$= 20°\text{C}.$$

(*b*)
$$\text{Temp. on Kelvin scale} = \text{Temp. on Celsius scale} + 273$$
$$470 = \text{Temp. on Celsius scale} + 273$$
$$\text{So, Temp. on Celsius scale} = 470 - 273$$
$$= 197°\text{C}.$$

Q.2. Convert the following temperatures to the Kelvin scale :
(*a*) 25°C (*b*) 373°C

Ans. (*a*) See Sample Problem 1 on page 23 of this book.
(*b*) Temp. on Kelvin scale = Temp. on Celsius scale + 273
= 373 + 273
= 646 K

Q.3. Give reasons for the following observations :
(*a*) Naphthalene balls disappear with time without leaving any solid.
(*b*) We can get the smell of perfume sitting several metres away.

Ans. (*a*) Naphthalene is a volatile solid organic compound which can undergo sublimation (change from solid state directly into vapour state). The solid naphthalene balls keep subliming slowly (keep changing into vapours slowly). And after a certain time, the naphthalene balls sublime completely forming naphthalene vapours (which go into air), and hence they disappear without leaving any solid residue.
(*b*) We can get the smell of perfume sitting several metres away due to the diffusion of perfume vapours into air. This can be explained as follows : Perfume is a volatile liquid. When liquid perfume is applied by a person, it quickly changes into vapours (or gas). The perfume vapours move very rapidly in all directions in air, mix up with air particles and spread in the air by diffusion. When this air containing perfume vapours reaches several metres away, we can smell the perfume.

Q.4. Arrange the following substances in increasing order of forces of attraction between the particles – water, sugar, oxygen.

Ans. The forces of attraction between the particles in a solid are the strongest, in liquids are less strong whereas in gases are the weakest. Now, out of water, sugar and oxygen :
(*i*) oxygen is a gas, so it has the weakest forces of attraction between its particles.
(*ii*) water is a liquid, so it has stronger forces of attraction between its particles (than oxygen).
(*iii*) sugar is a solid, so it has the strongest forces of attraction between its particles.
Thus, the increasing order of forces of attraction between the particles of water, sugar and oxygen will be :
oxygen < water < sugar

Q.5. What is the physical state of water at :
(*a*) 25°C ? (*b*) 0°C ? (*c*) 100°C ?

Ans. (*a*) The physical state of water at 25°C is liquid.
(*b*) 0°C is the melting point of ice (which is a solid) as well as the freezing point of water (which is a liquid). So, the physical state of water at 0°C can be either a solid (as ice) or liquid.
(*c*) 100°C is the boiling point of water (which is a liquid) as well as the condensation temperature of steam (which is a gas). So, the physical state of water at 100°C can be either a liquid or a gas (steam).

Q.6. Give two reasons to justify :
(*a*) water at room temperature is a liquid.
(*b*) an iron almirah is a solid at room temperature.

Ans. (*a*) The two general properties of liquids are that liquids have 'a fixed volume' but 'no fixed shape'. Now, water is a liquid at room temperature because :
(*i*) water has a fixed volume (which does not change on changing its container).
(*ii*) water has no fixed shape (it takes the shape of the container in which it is kept).
(*b*) The two general properties of solids are that solids have 'a fixed shape' and 'a fixed volume'. An almirah is a solid at room temperature because :
(*i*) an almirah has a fixed shape (which cannot be changed by pressing it with hands).
(*ii*) an almirah has a fixed volume (which depends on the dimensions according to which it is made).

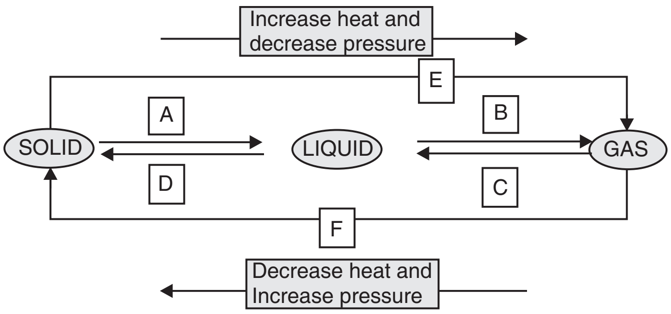
Q.7. Why is ice at 273 K more effective in cooling than water at the same temperature ?

Ans. First of all please note that the temperature of 273 K is equal to 0°C and it is the melting point of ice (to form water) at the same temperature. Another point to be noted is that the latent heat of melting of ice (or fusion of ice) is 3.34×10^5 joules per kilogram. Now, ice at 273 K (or 0°C) is more effective in cooling a substance than water at the same temperature of 273 K (or 0°C) because for melting, each kilogram of ice takes 3.34×10^5 joules of its latent heat from that substance and hence cools the substance more effectively. On the other hand, water at the same temperature of 273 K (or 0°C) cannot take away any such latent heat from the substance and hence does not cool it more effectively.

Q.8. What produces more severe burns – boiling water or steam ?

Ans. When water changes into steam at its boiling point, it absorbs latent heat of vaporisation (which is 22.5×10^5 joules per kilogram). This means that steam at 100°C contains much more heat (in the form of latent heat) than boiling water at the same temperature of 100°C. So, when steam falls on our skin and condenses to form water, it gives out 22.5×10^5 joules per kilogram of more heat than boiling water at the same temperature. Since steam gives out much more heat than boiling water, it causes more severe burns.

Q.9. Name A, B, C, D, E and F in the following diagram showing changes in state :



Ans. (*i*) In process A, a solid is changing into a liquid, so A is melting (or fusion).

(*ii*) In process B, a liquid is changing into a gas, so B is vaporisation (or boiling).

(*iii*) In process C, a gas is changing into a liquid, so C is condensation.

(*iv*) In process D, a liquid is changing into a solid, so D is freezing.

(*v*) In process E, a solid is directly changing into a gas, so E is sublimation.

(*vi*) In process F, a gas is changing directly into a solid, so F is also sublimation.

Chapter : IS MATTER AROUND US PURE

NCERT Book, Page 15

Q.1. What is meant by a pure substance ?

Ans. A pure substance is one which is made up of only one kind of particles. These particles may be atoms or molecules. For example, sulphur is made up of only one kind of particles (called sulphur atoms), therefore, sulphur is a pure substance. Similarly, water is made up of only one kind of particles (called water molecules), therefore, water is also a pure substance. In fact, all the elements and compounds are pure substances because they contain only one kind of particles. A pure substance is homogeneous throughout its mass. A pure substance cannot be separated into other kinds of matter by any physical process. A pure substance has a fixed composition as well as a fixed melting point and boiling point.

Q.2. List the points of differences between homogeneous and heterogeneous mixtures.

Ans. The main points of difference between homogeneous mixtures and heterogeneous mixtures are as follows :

Homogeneous mixtures	*Heterogeneous mixtures*
(*i*) A homogeneous mixture has a uniform composition throughout its mass	(*i*) A heterogeneous mixture does not have a uniform composition throughout its mass.
(*ii*) A homogeneous mixture has no visible boundaries of separation between the various constituents	(*ii*) A heterogeneous mixture has visible boundaries of separation between the various constituents.
(*iii*) The constituents of a homogeneous mixture cannot be seen easily.	(*iii*) The constituents of a heterogeneous mixture can usually be seen easily.

NCERT Book, Page 18

Q.1. Differentiate between homogeneous and heterogeneous mixtures with examples.

Ans. (*a*) Those mixtures in which the substances are completely mixed together and are indistinguishable from one another, are called homogeneous mixtures. A homogeneous mixture has a uniform composition throughout its mass. It has no visible boundaries of separation between the various constituents. A mixture of sugar in water (called sugar solution) is a homogeneous mixture because all the parts of sugar solution have the same sugar-water composition and appear to be equally sweet. There is no visible boundary of separation between sugar and water particles in a sugar solution. A mixture of two (or more) miscible liquids is also a homogeneous mixture. For example, a mixture of alcohol and water is a homogeneous mixture. All the homogeneous mixtures are called solutions.

(*b*) Those mixtures in which the substances remain separate and one substance is spread throughout the other substance as small particles, droplets or bubbles, are called heterogeneous mixtures. A heterogeneous mixture does not have a uniform composition throughout its mass. It has visible boundaries of separation between the various constituents. The mixture of sugar and sand is a heterogeneous mixture because different parts of this mixture will have different sugar-sand compositions. Some parts of this mixture will have more of sugar particles whereas other parts will have more of sand particles. There is a visible boundary of separation between sugar and sand particles. The suspensions of solids in liquids are also heterogeneous mixtures. For example, a suspension of chalk in water is a heterogeneous mixture. A mixture containing two (or more) immiscible liquids is also a heterogeneous mixture. For example, a mixture of petrol and water is a heterogeneous mixture.

Q.2. How are sol, solution and suspension different from each other ?

Ans. Sol is a colloid in which tiny solid particles are dispersed in a liquid medium. So, in this question, the term 'sol' has been used to represent a colloid (or colloidal solution). The main points of difference between solutions, sols (or colloids) and suspensions are given on the next page.

Solution (or True solution)	*Sol (or Colloid)*	*Suspension*
(*i*) A solution is a homogeneous mixture	(*i*) A sol (or colloid) appears to be homogeneous but actually it is heterogeneous	(*i*) A suspension is a heterogeneous mixture
(*ii*) The size of solute particles in a solution is extremely small. It is less than 1 nm in diameter.	(*ii*) The size of solute particles in a sol (or colloid) is bigger than that of true solutions but smaller than that in a suspension. It is between 1 nm and 100 nm in diameter.	(*ii*) The size of solute particles in a suspension is quite large. It is larger than 100 nm in diameter.
(*iii*) The particles of a solution cannot be seen even with a microscope	(*iii*) The particles of most of the sols (or colloids) cannot be seen even with a microscope. The particles of some of the sols (or colloids) can, however, be seen through a high power microscope	(*iii*) The particles of a suspension can be seen easily.
(*iv*) The particles of a solution pass through a filter paper. So, a solution cannot be separated by filtration	(*iv*) The particles of a sol (or colloid) can pass through a filter paper, so a sol (or colloid) cannot be separated by filtration	(*iv*) The particles of a suspension do not pass through a filter paper, so a suspension can be separated by filtration.
(*v*) The solutions are very stable. The particles of solute present in a solution do not separate out on keeping	(*v*) The sols (or colloids) are quite stable. The particles of a sol (or colloid) usually do not separate out on keeping	(*v*) The suspensions are unstable. The particles of a suspension settle down after some time.
(*vi*) A true solution does not scatter light (because its particles are very, very small)	(*vi*) A sol (or colloid) scatters a beam of light passing through it (because its particles are fairly large).	(*vi*) A suspension scatters a beam of light passing through it (because its particles are quite large).

Q.3. To make a saturated solution, 36 g of sodium chloride is dissolved in 100 g of water at 293 K. Find its concentration at this temperature.

Ans. Concentration of solution $= \dfrac{\text{Mass of solute}}{\text{Mass of solution}} \times 100$

Here, Mass of solute (sodium chloride) = 36 g

And, Mass of solvent (water) = 100 g

So, Mass of solution = Mass of solute + Mass of solvent

$= 36 + 100$

$= 136$ g

Now, putting these values of 'mass of solute' and 'mass of solution' in the above formula, we get :

Concentration of solution $= \dfrac{36}{136} \times 100$

$= \dfrac{3600}{136}$

= 26.47 per cent (by mass)

NCERT Book, Page 24

Q.1. How will you separate a mixture containing kerosene and petrol (difference in their boiling points is more than 25°C), which are miscible with each other ?

Ans. If the difference in the boiling points of two miscible liquids is 25°C (or more), their mixture can be separated by the process of simple distillation. In this case, the difference in the boiling points of two miscible liquids, kerosene and petrol, is 25°C, therefore, a mixture containing kerosene and petrol can be separated by the process of simple distillation. This can be done as follows : The mixture of kerosene and petrol is taken in a distillation flask fitted with a thermometer and a water condenser. On heating the distillation flask with a burner, the petrol having lower boiling point distils over first and collected in a suitable container. Kerosene having higher boiling point distils over later and collected in another container (**Caution** : Petrol is highly inflammable. It catches fire easily).

Q.2. Name the technique to separate :
(*i*) butter from curd.
(*ii*) salt from sea-water.
(*iii*) camphor from salt.

Ans. (*i*) Centrifugation
(*ii*) Evaporation
(*iii*) Sublimation

Q.3. What type of mixtures are separated by the technique of crystallisation ?

Ans. The mixtures containing solids in which the impurities may be either 'less soluble' in the solvent or 'more soluble' in the solvent than the solids, are separated by the technique of crystallisation. For example, the impurities present in impure copper sulphate, common salt and alum, etc., can be separated by the technique of crystallisation to obtain the respective pure substances.

NCERT Book, Page 24

Q.1. Classify the following as chemical or physical changes :
(*i*) cutting of trees
(*ii*) melting of butter in a pan
(*iii*) rusting of almirahs
(*iv*) boiling of water to form steam
(*v*) passing of electric current through water and the water breaking down into hydrogen and oxygen gases
(*vi*) dissolving common salt in water
(*vii*) making a fruit salad with raw fruits, and
(*viii*) burning of paper and wood

Ans.

Chemical changes	*Physical changes*
(*i*) cutting of trees	(*ii*) melting of butter in a pan
(*iii*) rusting of almirahs	(*iv*) boiling of water to form steam
(*v*) passing of electric current through water and water breaking down into hydrogen and oxygen gases	(*vi*) dissolving common salt in water
	(*vii*) making a fruit salad with raw fruits
(*viii*) burning of paper and wood	

Q.2. Try segregating the things around you as pure substances or mixtures.

Ans. Some of the things around us are : Tap water, Milk, Napthalene balls, Sodium chloride, Air, Gold ornaments, Ice-cream, Steel, Distilled water, Diamond, Steam, Kerosene oil, Alum, Salt solution, Brass, Alcohol, Vinegar, Graphite, Wood and Baking soda. We can segregate (or separate) these things as pure substances or mixtures as shown below :

Pure substances	*Mixtures*
Naphthalene balls	Tap water
Sodium chloride	Milk
Distilled water	Air
Diamond	Gold ornaments
Steam	Ice-cream
Alum	Steel
Alcohol	Kerosene oil
Graphite	Salt solution
Baking soda	Brass
	Vinegar
	Wood

NCERT Book, Pages 28, 29 and 30

Q.1. Which separation technique will you apply for the separation of the following ?

(*a*) Sodium chloride from its solution in water
(*b*) Ammonium chloride from a mixture containing sodium chloride and ammonium chloride
(*c*) Small pieces of metal in the engine oil of a car.
(*d*) Different pigments from an extract of flower petals.
(*e*) Butter from curd.
(*f*) Oil from water.
(*g*) Tea leaves from tea.
(*h*) Iron pins from sand.
(*i*) Wheat grains from husk.
(*j*) Fine mud particles suspended in water.

Ans. (*a*) Evaporation (*b*) Sublimation (*c*) Filtration (*d*) Chromatography
(*e*) Centrifugation (*f*) Separating funnel (*g*) Filtration
(*h*) Magnetic separation (by using a magnet) (*i*) Winnowing (*j*) Loading (by using alum)

Q.2. Write the steps you would use for making tea. Use the words solution, solvent, solute, dissolve, soluble, insoluble, filtrate and residue.

Ans. Take a few cups of water in a pan and heat it on a gas burner. To the hot water, add some tea leaves and boil. The water acts as a solvent and extracts soluble substances from tea leaves giving a dark brown mixture. Then add sugar and milk. Sugar is a solute which dissolves in hot water to form a solution. After boiling for some more time, the mixture is filtered through a tea-strainer. The prepared tea passes through the fine holes of the tea-strainer and collects as a filtrate in the cup placed below. The used tea-leaves, being insoluble, collect as a residue in the tea-strainer.

Q.3. Pragya tested the the solubility of four different substances at different temperatures and collected the data as given below (results are given in the following table as grams of substance dissolved in 100 grams of water to form a saturated solution).

Substance dissolved	Solubility				
	283 K	293 K	313 K	333 K	353 K
1. Potassium nitrate	21	32	62	106	167
2. Sodium chloride	36	36	36	37	37
3. Potassium chloride	35	35	40	46	54
4. Ammonium chloride	24	37	41	55	66

(*a*) What mass of potassium nitrate would be needed to produce a saturated solution of potassium nitrate in 50 grams of water at 313 K ?

(*b*) Pragya makes a saturated solution of potassium chloride in water at 353 K and leaves the solution to cool at room temperature. What would she observe as the solution cools ? Explain.

(*c*) Find the solubility of each salt at 293 K. Which salt has the highest solubility at this temperature ?

(*d*) What is the effect of change in temperature on the solubility of a salt ?

Ans. (*a*) The solubility of potassium nitrate at 313 K is 62 grams (see the given table). This means that 62 grams of potassium nitrate is needed to make a saturated solution of potassium nitrate in 100 grams of water at 313 K. So, to make a saturated solution in 50 grams of water we will need half of 62 grams of potassium nitrate, which is $\frac{62}{2} = 31$ grams of potassium nitrate.

(*b*) When a saturated solution of potassium chloride at 353 K is left to cool, then solid potassium chloride (or crystals of potassium chloride) will gradually separate out from the solution (because the solubility decreases on cooling).

(*c*) The solubility of various salts at 293 K is : Potassium nitrate 32 g ; Sodium chloride 36 g ; Potassium chloride 35 g ; and Ammonium chloride 37 g. Ammonium chloride has the highest solubility (of 37 g) at this temperature of 293 K.

(*d*) The given data shows that the solubility of a salt increases on increasing the temperature.

Q.4. Explain the following giving examples :

(*a*) saturated solution **(*b*) pure substance**
(*c*) colloid **(*d*) suspension**

Ans. (*a*) **Saturated solution.** A solution in which no more solute can be dissolved at that temperature, is called a saturated solution. For example, if in an aqueous salt solution, no more salt can be dissolved at that temperature, then that salt solution will be a saturated solution. Thus, a saturated solution contains the maximum amount of solute which can be dissolved in it at that temperature. For example, a maximum of 36 grams of sodium chloride (common salt) can be dissolved in 100 grams of water at 20°C, so a saturated solution of sodium chloride at 20°C contains 36 grams of sodium chloride dissolved in 100 grams of water.

(*b*) **Pure substance.** See Q. No. 1 on page 225 of this book.

(*c*) **Colloid.** A colloid is a kind of solution in which the size of solute particles is intermediate between those in true solutions and those in suspensions. The size of solute particles in a colloid is bigger than that of a true solution but smaller than those of a suspension. Though colloids appear to be homogeneous to us but actually they are found to be heterogeneous when observed through a high power microscope. So, a colloid is not a true solution. Some of the examples of colloids (or colloidal solutions) are : Soap solution, Starch solution, Milk, Ink, Blood, Jelly and Solutions of synthetic detergents. Colloids are also known as colloidal solutions.

(*d*) **Suspension.** A suspension is a heterogeneous mixture in which the small particles of a solid are spread throughout a liquid without dissolving in it. Some common examples of suspensions are : Chalk-water mixture, Muddy water, Milk of Magnesia, Sand particles suspended in water, and Flour in water. Chalk-water mixture is a suspension of fine chalk particles in water; muddy water is a suspension of soil particles in water; and milk of Magnesia is a suspension of magnesium hydroxide in water. Please note that solid particles and water remain separate in a suspension. The particles do not dissolve in water.

Q.5. Classify each of the following as a homogeneous or heterogeneous mixture :
soda water, wood, air, soil, vinegar, filtered tea

Ans.

Homogeneous mixtures	*Heterogeneous mixtures*
soda water	wood
air	soil
vinegar	
filtered tea	

Q.6. How would you confirm that a colourless liquid given to you is pure water ?

Ans. Pure water has a fixed boiling point of 100°C under standard atmospheric pressure. This fact can be used to confirm that a colourless liquid given to us is water as follows : We take the colourless liquid in a distillation flask fitted with a thermometer. Let us heat the flask with a gas burner till the liquid starts boiling. If all the colourless liquid distils over (or boils off) at the same temperature of 100°C, without leaving behind any residue in the distillation flask, it will be pure water.

Q.7. Which of the following materials fall in the category of a "pure substance" ?
(*a*) Ice (*b*) Milk (*c*) Iron (*d*) Hydrochloric acid
(*e*) Calcium oxide (*f*) Mercury (*g*) Brick (*h*) Wood (*i*) Air

Ans. Pure substances are : Ice, Iron, Calcium oxide and Mercury.
(**Note.** Hydrochloric acid is a mixture of hydrogen chloride gas and water, so it is not a pure substance).

Q.8. Identify the solutions among the following mixtures :
(*a*) Soil (*b*) Sea-water (*c*) Air (*d* Coal (*e*) Soda water

Ans. Sea-water, Air and Soda-water.

Q.9. Which of the following will show " Tyndall effect" ?
(*a*) Salt solution (*b*) Milk (*c*) Copper sulphate solution (*d*) Starch solution

Ans. Milk and Starch solution (Because they are colloids).

Q.10. Classify the following into elements, compounds and mixtures :
(*a*) Sodium (*b*) Soil (*c*) Sugar solution (*d*) Silver (*e*) Calcium carbonate
(*f*) Tin (*g*) Silicon (*h*) Coal (*i*) Air (*j*) Soap
(*k*) Methane (*l*) Carbon dioxide (*m*) Blood

Ans. See Sample Problem 3 on page 55 of this book.

Q.11. Which of the following are chemical changes ?
(*a*) Growth of a plant (*b*) Rusting of iron (*c*) Mixing of iron filings and sand (*d*) Cooking of food
(*e*) Digestion of food (*f*) Freezing of water (*g*) Burning of a candle

Ans. Chemical changes : Growth of a plant ; Rusting of iron ; Cooking of food ; Digestion of food ; and Burning of a candle.

Chapter : ATOMS AND MOLECULES

NCERT Book, Pages 32 and 33

Q.1. In a reaction, 5.3 g of sodium carbonate reacted with 6 g of ethanoic acid. The products were 2.2 g of carbon dioxide, 0.9 g of water and 8.2 g of sodium ethanoate. Show that these observations are in agreement with the law of conservation of mass.

Ans. See Sample Problem 1 on page 112 of this book.

Q.2. Hydrogen and oxygen combine in the ratio of 1 : 8 by mass to form water. What mass of oxygen gas would be required to react completely with 3 g of hydrogen gas ?

Ans. See Sample Problem 2 on page 114 of this book.

Q.3. Which postulate of Dalton's atomic theory is the result of the law of conservation of mass ?

Ans. The postulate of Dalton's atomic theory which says that "Atoms can neither be created nor destroyed in chemical reactions" is the result of the law of conservation of mass.

Q.4. Which postulate of Dalton's atomic theory can explain the law of definite proportions ?

Ans. The postulate of Dalton's atomic theory which says that "The number and kind of atoms in a given compound is fixed" can explain the law of definite proportions.

NCERT Book, Page 35

Q.1. Define the atomic mass unit.

Ans. Atomic mass unit is equal to $\frac{1}{12}$ (one-twelfth) the mass of a carbon-12 atom.

Q.2. Why is it not possible to see an atom with naked eyes ?

Ans. It is not possible to see an atom with naked eyes because an atom is a very, very small particle. The radius of an atom is of the order of 10^{-10} metre (which is extremely small).

NCERT Book, Page 39

Q.1. Write down the formulae of :

(*i*) sodium oxide **(*ii*) aluminium chloride**

(*iii*) sodium sulphide **(*iv*) magnesium hydroxide**

Ans. (*i*) Formula of sodium oxide (made of sodium Na and oxygen O) :

Symbols :	Na	O	Na	O				
					$Na_2 O_1$	or	Na_2O	
Valencies :	1+	2–	1+	2–				
(or charges)			Cross-over valencies				Formula	

Thus, the formula of sodium oxide is Na_2O

(*ii*) Formula of aluminium chloride (made of aluminium Al and chlorine Cl) :

Symbols :	Al	Cl	Al	Cl				
					Al_1Cl_3	or	$AlCl_3$	
Valencies :	3+	1–	3+	1–				
(or Charges)			Cross-over-valencies				Formula	

Thus, the formula of aluminium chloride is $AlCl_3$.

(*iii*) Formula of sodium sulphide (made of sodium Na and sulphur S) :

Symbols :	Na	S	Na	S				
					Na_2S_1	or	Na_2S	
Valencies :	1+	2–	1+	2–				
(or Charges)			Cross-over valencies				Formula	

Thus, the formula of sodium sulphide is Na_2S.

(*iv*) Formula of magnesium hydroxide (made of magnesium Mg and hydroxide OH) :

Symbols :	Mg	OH	Mg	OH	$Mg_1(OH)_2$ or $Mg(OH)_2$	
Valencies : (or Charges)	2+	1–	2+	1–		
			Cross-over valencies		Formula	

Thus, the formula of magnesium hydroxide is $Mg(OH)_2$.

Q.2. Write down the names of compounds represented by the following formulae :

(*i*) $Al_2(SO_4)_3$ (*ii*) $CaCl_2$ (*iii*) K_2SO_4 (*iv*) KNO_3 (*v*) $CaCO_3$

Ans. (*i*) Aluminium sulphate (*ii*) Calcium chloride
(*iii*) Potassium sulphate (*iv*) Potassium nitrate (*v*) Calcium carbonate

Q.3. What is meant by the term chemical formula ?

Ans. The chemical formula of a compound represents the composition of a molecule of the compound in terms of the symbols of the elements present in it. For example , the chemical formula of water H_2O tells us that one molecule of water is made up of 2 hydrogen atoms and 1 oxygen atom chemically combined together.

Q.4. How many atoms are present in a :

(*i*) H_2S molecule, and

(*ii*) PO_4^{3-} ion ?

Ans. (*i*) Three atoms are present in a H_2S molecule.
(*ii*) Five atoms are present in a PO_4^{3-} ion.

NCERT Book, Page 40

Q.1. Calculate the molecular masses of H_2, O_2, Cl_2, CO_2, CH_4, C_2H_6, C_2H_4, NH_3, CH_3OH.

(Atomic masses : H = 1 ; O = 16 ; Cl = 35.5 ; C = 12 ; N = 14)

Ans. (*i*) Molecular mass of H_2 = Mass of 2H atoms
= 2 × 1
= 2 u

(*ii*) Molecular mass of O_2 = Mass of 2 'O' atoms
= 2 × 16
= 32 u

(*iii*) Molecular mass of Cl_2 = Mass of 2Cl atoms
= 2 × 35.5
= 71 u

(*iv*) Molecular mass of CO_2 = Mass of C atom + Mass of 2 'O' atoms
= 12 + 2 × 16
= 12 + 32
= 44 u

(*v*) Molecular mass of CH_4 = Mass of C atom + Mass of 4H atoms
= 12 + 4 × 1
= 12 + 4
= 16 u

(*vi*) Molecular mass of C_2H_6 = Mass of 2C atoms + Mass of 6H atoms
= 2 × 12 + 6 × 1
= 24 + 6
= 30 u

(*vii*) Molecular mass of C_2H_4 = Mass of 2C atoms + Mass of 4H atoms
= 2 × 12 + 4 × 1
= 24 + 4
= 28 u

(*viii*) Molecular mass of NH_3 = Mass of N atom + Mass of 3H atoms
$= 14 + 3 \times 1$
$= 14 + 3$
$= 17$ u

(*ix*) Molecular mass of CH_3OH = Mass of C + Mass of 4H + Mass of O
$= 12 + 4 \times 1 + 16$
$= 12 + 4 + 16$
$= 32$ u

Q.2. Calculate the formula unit masses of ZnO, Na_2O, K_2CO_3.
(Given : Atomic masses of Zn = 65 u ; Na = 23 u ; K = 39 u ; C = 12 u and O = 16 u)

Ans. (*i*) Formula mass of ZnO = Mass of Zn atom + Mass of O atom
$= 65 + 16$
$= 81$ u

(*ii*) Formula mass of Na_2O = Mass of 2Na atoms + Mass of O
$= 2 \times 23 + 16$
$= 46 + 16$
$= 62$ u

(*iii*) Formula mass of K_2CO_3 (See Sample Problem on page 138 of this book).

NCERT Book, Page 42

Q.1. If one mole of carbon atoms weighs 12 grams, what is the mass (in grams) of 1 atom of carbon ?

Ans. See Sample Problem 6 on page 161 of this book.

Q.2. Which has more number of atoms, 100 grams of sodium or 100 grams of iron ?
(Given : Atomic masses of Na = 23 u, Fe = 56 u)

Ans. See Sample Problem 7 on page 161 of this book.

NCERT Book, Pages 43 and 44

Q.1. A 0.24 g sample of compound of oxygen and boron was found by analysis to contain 0.096 g of boron and 0.144 g of oxygen. Calculate the percentage composition of the compound by weight.

Ans. See Sample Problem 4 on page 115 of this book.

Q.2. When 3.0 g of carbon is burnt in 8.00 g of oxygen, 11.00 g of carbon dioxide is produced. What mass of carbon dioxide will be formed when 3.00 g of carbon is burnt in 50.00 g of oxygen ? Which law of chemical combination will govern your answer ?

Ans. See Sample Problem 3 on page 115 of this book.

Q.3. What are polyatomic ions ? Give examples.

Ans. Those ions which are formed from groups of joined atoms are called polyatomic ions. For example, ammonium ion, NH_4^+, is a polyatomic ion which is made up of two types of atoms, nitrogen (N) and hydrogen (H) joined together. Similarly, carbonate ion CO_3^{2-}, sulphate ion SO_4^{2-}, nitrate ion NO_3^- and hydroxide ion OH^-, are all polyatomic ions.

Q.4. Write the chemical formulae of the following :
(*a*) Magnesium chloride (*b*) Calcium oxide (*c*) Copper nitrate
(*d*) Aluminium chloride (*e*) Calcium carbonate

Ans. (*a*) Formula of magnesium chloride (made of magnesium Mg and chlorine Cl) :

Symbols :	Mg	Cl	Mg	Cl	Mg_1Cl_2 or $MgCl_2$
Valencies : (or Charges)	2+	1–	2+	1–	
			Cross-over valencies		Formula

Thus, the formula of magnesium chloride is $MgCl_2$.

(*b*) Formula of calcium oxide (made of calcium Ca and oxygen O) :

Symbols :	Ca	O	Ca $\quad$ O		
				Ca_2O_2 or	CaO
Valencies :	2+	2–	2+ $\quad$ 2–		
(or Charges)			Cross-over valencies		Formula

Thus, the formula of calcium oxide is CaO.

(*c*) Formula of copper nitrate (made of copper Cu and nitrate NO_3) :

Symbols :	Cu	NO_3	Cu $\quad$ NO_3		
				$Cu_1(NO_3)_2$ or	$Cu(NO_3)_2$
Valencies :	2+	1–	2+ $\quad$ 1–		
(or Charges)			Cross-over valencies		Formula

Thus, the formula of copper nitrate is $Cu(NO_3)_2$.

(*d*) Formula of aluminium chloride [see Q.No. 1 (*ii*) on page 230 of this book].

(*e*) Formula of calcium carbonate (made of calcium Ca and carbonate CO_3) :

Symbols :	Ca	CO_3	Ca $\quad$ CO_3		
				$Ca_2(CO_3)_2$ or	$CaCO_3$
Valencies :	2+	2–	2+ $\quad$ 2–		
(or Charges)			Cross-over valencies		Formula

Thus, the formula of calcium carbonate is $CaCO_3$.

Q.5. Give the names of the elements present in the following compounds :

(*a*) Quick lime $\qquad$ **(*b*) Hydrogen bromide**

(*c*) Baking soda $\qquad$ **(*d*) Potassium sulphate**

Ans. (*a*) Quick lime is calcium oxide, CaO. The elements present in quick lime are : Calcium (Ca) and Oxygen (O).

(*b*) Hydrogen bromide is HBr. The elements present in hydrogen bromide are : Hydrogen (H) and Bromine (Br).

(*c*) Baking soda is sodium hydrogencarbonate, $NaHCO_3$. The elements present in baking soda are : Sodium (Na), Hydrogen (H), Carbon (C) and Oxygen (O).

(*d*) Potassium sulphate is K_2SO_4. The elements present in potassium sulphate are : Potassium (K), Sulphur (S) and Oxygen (O).

Q.6. Calculate the molar masses of the following substances :

(*a*) Ethyne, C_2H_2 $\qquad$ **(*b*) Sulphur molecule, S_8** $\qquad$ **(*c*) Phosphorus molecule, P_4**

(*d*) Hydrochloric acid, HCl $\qquad$ **(*e*) Nitric acid, HNO_3**

Ans. See Sample Problem on page 155 of this book.

Q.7. What is the mass of :

(*a*) 1 mole of nitrogen atoms ?

(*b*) 4 moles of aluminium atoms ?

(*c*) 10 moles of sodium sulphite (Na_2SO_3) ?

(Atomic masses : N = 14 u, Al = 27 u, Na = 23 u, S = 32 u and O = 16 u)

Ans. (*a*) Mass of 1 mole of nitrogen atoms (N) = Atomic mass of nitrogen expressed in grams

= 14 g

(*b*) Mass of 4 moles of aluminium atoms (See Sample Problem 2 on page 160 of this book).

(*c*) Mass of 1 mole of sodium sulphite = Molecular mass of sodium sulphite (Na_2SO_3) in grams

= Mass of 2Na + Mass of S + Mass of 3 'O'

$= 2 \times 23 + 32 + 3 \times 16$

$= 46 + 32 + 48$

= 126 g

So, Mass of 10 moles of sodium sulphite $= 126 \times 10$ g

= 1260 g

Q.8. Convert into moles :
(*a*) 12 g of oxygen gas
(*b*) 20 g of water
(*c*) 22 g of carbon dioxide
(Atomic masses : O = 16 u, H = 1 u and C = 12 u)

Ans. (*a*) Oxygen gas consists of O_2 molecules. So, molecular mass of oxygen gas (O_2) = 16 × 2 = 32 u

Now, 1 mole of oxygen gas = Molecular mass of oxygen in grams
= 32 g

If 32 g of oxygen gas = 1 mole

Then 12 g of oxygen gas $= \frac{1}{32} \times 12$ mole
= 0.375 mole

(*b*) Water consists of H_2O molecules. So, molecular mass of water (H_2O) = 1 × 2 + 16 = 18 u.

Now, 1 mole of water = Molecular mass of water in grams
= 18 g

If 18 g of water = 1 mole

Then 20 g of water $= \frac{1}{18} \times 20$ mole
= 1.11 moles

(*c*) Carbon dioxide consists of CO_2 molecules. So, molecular mass of carbon dioxide (CO_2) = 12 + 16 × 2 = 12 + 32 = 44 u.

Now, 1 mole of carbon dioxide = Molecular mass of carbon dioxide in grams
= 44 g

If 44 g of carbon dioxide = 1 mole

Then, 22 g of carbon dioxide $= \frac{1}{44} \times 22$ mole
$= \frac{1}{2}$ mole
= 0.5 mole

Q.9. What is the mass of :
(*a*) 0.2 mole of oxygen atoms ?
(*b*) 0.5 mole of water molecules ?

Ans. (*a*) The atomic mass of oxygen (O) is 16 u. So, the mass of 1 mole of oxygen atoms will be 16 grams.

Now, 1 mole of oxygen atoms = 16 g
So, 0.2 mole of oxygen atoms = 16 × 0.2 g
= 3.2 g

(*b*) The molecular mass of water (H_2O) is 18 u, so the mass of 1 mole of water molecules is 18 grams.

Now, 1 mole of water molecules = 18 g
so, 0.5 mole of water molecules = 18 × 0.5 g
= 9 g

Q.10. Calculate the number of molecules of sulphur (S_8) present in 16 g of solid sulphur (Atomic mass of S = 32)

Ans. The molecular formula of sulphur is given to be S_8 (it contains 8 atoms of sulphur). So, the molecular mass of sulphur molecule is 32 × 8 = 256 u. This means that 1 mole of sulphur molecules is equal to 256 grams.

Now, 256 g of sulphur = 1 mole of sulphur molecules

So, 16 g of sulphur $= \frac{1}{256} \times 16$ mole of sulphur molecules
= 0.0625 mole of sulphur molecules

Also, 1 mole of sulphur molecules = 6.023×10^{23} molecules
So, 0.0625 mole of sulphur molecules = $6.023 \times 10^{23} \times 0.0625$ molecules
= 3.76×10^{22} molecules

Q.11. Calculate the number of aluminium ions present in 0.051 g of aluminium oxide.
(Hint. The mass of an ion is the same as that of an atom of the same element. Atomic mass of Al = 27 u)

Ans. See Sample Problem 14 on page 171 of this book.

Chapter : STRUCTURE OF THE ATOM

NCERT Book, Page 47

Q.1. What are canal rays ?

Ans. Canal rays (or anode rays) are streams of positively charged particles which move towards the negative electrode (cathode) in a discharge tube when high voltage electricity is passed through a gas at very low pressure taken in the discharge tube.

Q.2. If an atom contains one electron and one proton, will it carry any charge or not ?

Ans. No, the atom will not carry any electric charge. This is because the electron has 1 unit negative charge whereas a proton has an equal and opposite 1 unit positive charge due to which the net charge on the atom is zero.

NCERT Book, Page 49

Q.1. On the basis of Thomson's model of an atom, explain how the atom is neutral as a whole.

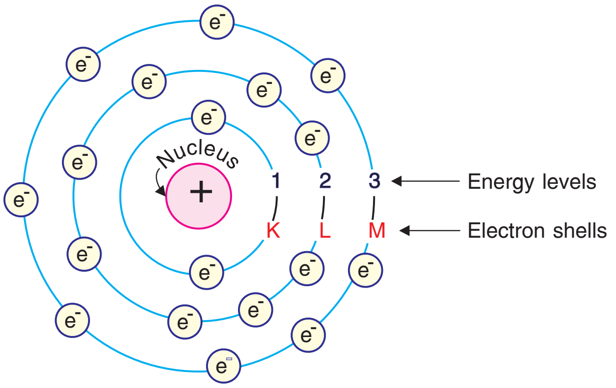
Ans. According to Thomson's model, an atom consists of a sphere (or ball) of positive charge with negatively charged electrons embedded in it (like the seeds in a watermelon). The total negative charge of electrons is equal to the total positive charge of the sphere. These equal and opposite charges balance each other due to which an atom becomes electrically neutral as a whole.

Q.2. On the basis of Rutherford's model of an atom, which sub-atomic particle is present in the nucleus of an atom ?

Ans. Rutherford's model says that an atom has positively charged nucleus. So, the sub-atomic particle present in the nucleus of an atom is proton (which carries positive charge).

Q.3. Draw a sketch of Bohr's model of an atom with three shells.

Ans. A sketch of Bohr's model of an atom with three electron shells is shown below :



In this Bohr's model of the atom, the positively charged nucleus is at the centre and negatively charged electrons revolve round the nucleus in 'fixed' energy levels (n = 1, 2, 3) or electron shells (K, L, M).

Q.4. What do you think would be the observation if the α-particle scattering experiment is carried out using a foil of a metal other than gold ?

Ans. (*i*) If the foil of a heavy metal like platinum (having a very heavy nucleus) is used, then the observations in the α-particle scattering experiment would be the same as that in the gold foil experiment.

(*ii*) If, however, the foil of a light metal like lithium (having a very light nucleus) is used, then the fast moving heavy α-particles may even push the light nucleus aside and may not be deflected back.

NCERT Book, Page 49

Q.1. Name the three sub-atomic particles of an atom.

Ans. Electron, proton and neutron.

Q.2. Helium atom has an atomic mass of 4 u and two protons in its nucleus. How many neutrons does it have ?

Ans. See Sample Problem 3 on page 187 of this book.

NCERT Book, Page 50

Q.1. Write the distribution of electrons in carbon and sodium atoms.

Ans. (*i*) The atomic number of carbon is 6. This means that a normal atom of carbon has 6 electrons. Out of these 6 electrons, 2 electrons will occupy the first electron shell which is K shell and the remaining 4 electrons will occupy the second electron shell which is L shell. So, the electron distribution in a carbon atom will be :

$$\begin{matrix} K & L \\ 2, & 4 \end{matrix}$$

(*ii*) The atomic number of sodium is 11, so a normal atom of sodium has 11 electrons in it. Out of these 11 electrons, the first 2 electrons will go to K shell, the next 8 electrons will go to L shell and the remaining 1 electron will go to M shell. So, the electron distribution in a sodium atom will be :

$$\begin{matrix} K & L & M \\ 2, & 8, & 1 \end{matrix}$$

Q.2. If K and L shells of an atom are full, then what would be the total number of electrons in the atom ?

Ans. See Sample Problem 6 on page 190 of this book.

NCERT Book, Page 52

Q.1. How will you find the valency of chlorine, sulphur and magnesium ?

Ans. (*i*) **Valency of chlorine**. The atomic number of chlorine is 17. The chlorine atom has 17 electrons, so its electron configuration is $\begin{matrix} K & L & M \\ 2, & 8, & 7 \end{matrix}$. A chlorine atom has 7 electrons in its valence shell (M shell). A chlorine atom can accept 1 more electron to achieve the inert gas electron arrangement (of 8 valence electrons), so the valency of chlorine is 1.

(*ii*) **Valency of sulphur.** The atomic number of sulphur is 16. The sulphur atom has 16 electrons, so its electron distribution is $\begin{matrix} K & L & M \\ 2, & 8, & 6 \end{matrix}$. A sulphur atom has 6 electrons in its valence shell (M shell). A sulphur atom can accept 2 more electrons to achieve the inert gas electron arrangement (of eight valence electrons), so the valency of sulphur is 2.

(*iii*) **Valency of magnesium**. The atomic number of magnesium is 12. The magnesium atom has 12 electrons, so its electron configuration is $\begin{matrix} K & L & M \\ 2, & 8, & 2 \end{matrix}$. A magnesium atom has 2 electrons in its outermost shell (M shell). A magnesium atom can lose its 2 outermost electrons to achieve the inert gas electron configuration (of 8 valence electrons), so the valency of magnesium is 2.

NCERT Book, Page 52

Q.1. If the number of electrons in an atom is 8 and the number of protons is also 8, then (*i*) what is the atomic number of the atom ? and (*ii*) what is the charge on the atom ?

Ans. See Sample Problem 2 on page 186 of this book.

Q.2. With the help of Table given below, find out the mass numbers of oxygen and sulphur atoms :

Name of element	Symbol	Atomic number	Number of protons	Number of neutrons	Number of electrons
Oxygen	O	8	8	8	8
Sulphur	S	16	16	16	16

Ans. (*i*) Mass number of oxygen = No. of protons + No. of neutrons

= 8 + 8

= 16

(*ii*) Mass number of sulphur = No. of protons + No. of neutrons
= 16 + 16
= 32

NCERT Book, Page 53

Q.1. For the symbols H, D and T, tabulate three sub-atomic particles found in each of them.

Ans. H, D and T are the three isotopes of hydrogen having the same atomic number 1 but different mass numbers of 1, 2 and 3 respectively. The symbol H stands for ordinary Hydrogen (of mass number 1), the symbol D stands for Deuterium (which is heavy hydrogen of mass number 2) and symbol T stands for Tritium (which is very heavy hydrogen of mass number 3). The three sub-atomic particles, electrons, protons and neutrons, in the three isotopes of hydrogen are given in the following table :

Isotope	*Symbol*	*Mass number*	*Number of electrons*	*Number of protons*	*Number of neutrons*
Hydrogen	H	1	1	1	0
Deuterium	D	2	1	1	1
Tritium	T	3	1	1	2

Q.2. Write the electronic configuration of any one pair of isotopes and isobars.

Ans. See Sample Problem 2 on page 210 of this book.

NCERT Book, Pages 54, 55 and 56

Q.1 Compare the properties of electrons, protons and neutrons.

Ans. See Table on page 179 of this book.

Q.2 What are the limitations of J.J. Thomson's model of the atom ?

Ans. (*i*) J.J. Thomson's model of the atom could not explain the results of alpha particle scattering experiment carried out by Rutherford. That is, J.J. Thomson's model of the atom could not explain why most of the positively charged alpha particles pass straight through the gold foil, a few alpha particles are deflected through small and large angles, whereas a very few alpha particles completely rebound on hitting the gold foil and turn back on their path.

(*ii*) J.J. Thomson's model of the atom was just based on imagination, it did not have any experimental evidence in its support (like the Rutherford's model of the atom).

Q.3. What are the limitations of Rutherford's model of the atom ?

Ans. The major limitation of Rutherford's model of the atom is that it does not explain the stability of the atom. This will become clear from the following discussion. In Rutherford's model of the atom, the negatively charged electrons are revolving around the positively charged nucleus in circular paths. Since the direction of motion of electrons moving in circular paths changes continuously, therefore, the motion of electrons moving around the nucleus is accelerated. Now, according to the electromagnetic theory of physics, the charged electrons undergoing accelerated motion around the nucleus will lose their energy continuously by radiation. The speed of electrons will, therefore, go on decreasing, they will be attracted more strongly by the oppositely charged nucleus, they will come more and more close to the nucleus and ultimately fall into the nucleus by taking a spiral path. This should make the atoms very unstable due to which the atoms should collapse quickly. This, however, does not happen. The electrons do not fall into the nucleus, atoms are very stable and do not collapse on their own. The Rutherfords' model, however, does not explain this stability of an atom.

Q.4. Describe Bohr's model of the atom.

Ans. See page 183 of this book.

Q.5. Compare all the proposed models of an atom given in this chapter.

Ans. A comparison between the models of an atom proposed by J.J. Thomson, Rutherford and Bohr is given below :

Thomson's model of an atom	*Rutherford's model of an atom*	*Bohr's model of an atom*
(*i*) An atom consists of sphere (or ball) of positive charge with negatively charged electrons embedded in it (like the seeds in a watermelon). (*ii*) The total positive charge on the sphere is equal to the total negative charge on the electrons due to which an atom is electrically neutral. It has no overall positive or negative electric charge. ***Limitation.*** Thomson's model of an atom could not explain the results of alpha particle scattering experiment carried out by Rutherford.	(*i*) An atom consists of a very small positively charged nucleus (containing all the protons and neutrons) at its centre with negatively charged electrons revolving around it in circular paths with high speeds. (*ii*) The electrostatic attraction between the positively charged nucleus and the negatively charged electrons holds the atom together. (*iii*) The number of positive protons is equal to the number of negative electrons due to which an atom is electrically neutral. (*iv*) Almost the entire mass of an atom is concentrated in the nucleus. (*v*) Most of the atom is empty space. ***Limitation.*** Rutherford's model of an atom could not explain the stability of the atom because the accelerated circular motion of revolving electrons should make them lose energy by radiation, fall into the nucleus and make the atom to collapse quickly (which does not happen at all).	(*i*) An atom is made up of three particles : electrons, protons and neutrons. Electrons have negative charge, protons have positive charge whereas neutrons have no charge, they are neutral. (*ii*) Due to the presence of equal number of negative electrons and positive protons the atom on the whole is electrically neutral. (*iii*) The protons and neutrons are located in a small nucleus at the centre of the atom. Due to the presence of protons, nucleus is positively charged. (*iv*) The electrons revolve rapidly around the nucleus in fixed circular paths called energy levels or shells (denoted either by the numbers 1, 2, 3, 4, 5 and 6 or by the letters K, L, M, N, O and P) counted from the centre outwards. (*v*) Each energy level (or shell) is associated with a fixed amount of energy (the energy increasing from the centre outwards). (*vi*) There is no change in the energy of electrons as long as they keep revolving in the same energy level. ***Advantage.*** Bohr's model of an atom explains the stability of atoms by saying that there is no loss in the energy of revolving electrons of the atom as long as they keep on revolving in the same energy level due to which the atoms remain stable.

Q.6. Summarise the rules for writing of distribution of electrons in various shells for the first eighteen elements.

Ans. The various rules for writing of distribution of electrons in various shells of an atom are as follows :

(*i*) The maximum number of electrons which can be accommodated in any energy level of the atom of an element is given by $2n^2$ (where n is the number of that energy level). By using this relation we will find that :

(*a*) the maximum number of electrons which can be accommodated in 1st energy level ($n = 1$) or K shell is $2 \times (1)^2 = 2 \times 1 = 2$

(*b*) the maximum number of electrons which can be accommodated in 2nd energy level ($n = 2$) or L shell is $2 \times (2)^2 = 2 \times 4 = 8$.

(*c*) the maximum number of electrons which can be accommodated in 3rd energy level ($n = 3$) or M shell is $2 \times (3)^2 = 2 \times 9 = 18$

(*d*) the maximum number of electrons which can be accommodated in 4th energy level ($n = 4$) or N shell is $2 \times (4)^2 = 2 \times 16 = 32$.

(*ii*) The outermost shell of an atom cannot accommodate more than 8 electrons, even if it has the capacity to accommodate more electrons (If, however, the outermost shell of an atom is the first shell or K shell, then it cannot accommodate more than 2 electrons).

(*iii*) The electrons in an atom do not occupy a new shell unless all the inner shells are completely filled with electrons. This means that first all the electrons fill K shell, then L shell, then M shell, then N shell, and so on.

Q.7. Define valency by taking the examples of silicon and oxygen.

Ans. The valency of an element is defined as the number of electrons lost, gained or shared by one atom of the element to achieve the nearest inert gas electron configuration (of having 8 electrons in the outermost shell (or 2 electrons if the outermost shell is K shell).

(*i*) **Valency of silicon.** The atomic number of silicon is 14, so it has 14 electrons in its atom. The electronic configuration of silicon atom will be $\begin{matrix} K & L & M \\ 2, & 8, & 4 \end{matrix}$. Thus, the silicon atom has 4 electrons in its outermost shell (which is M shell). Now, a silicon atom can neither lose 4 electrons nor gain 4 electrons to achieve the octet (8 electrons in the outermost shell) due to energy considerations. So, a silicon atom will share its 4 electrons with the 4 electrons of atoms of other elements to achieve the 8-electron inert gas electron configuration. Since one silicon atom shares 4 electrons to achieve inert gas electron arrangement, therefore, the valency of silicon is 4.

(*ii*) **Valency of oxygen.** The atomic number of oxygen is 8, so it has 8 electrons in its atom. The electronic configuration of oxygen atom will be $\begin{matrix} K & L \\ 2, & 6 \end{matrix}$. Thus, the oxygen atom has 6 electrons in its outermost shell (which is L shell). Now, an oxygen atom having 6 outermost electrons can gain 2 electrons from some other atom to achieve inert gas electron configuration of $6 + 2 = 8$ outermost electrons. Since one atom of oxygen can gain 2 electrons to achieve the inert gas electron configuration, therefore, the valency of oxygen is 2.

Q.8. Explain with examples (*i*) Atomic number (*ii*) Mass number (*iii*) Isotopes, and (*iv*) Isobars. Give any two uses of isotopes.

Ans. (*i*) **Atomic number.** The number of protons in one atom of an element is known as atomic number of that element. For example, one atom of sodium element has 11 protons in it, so the atomic number of sodium is 11. Similarly, one atom of carbon element has 6 protons in it, so the atomic number of carbon is 6.

(*ii*) **Mass number.** The total number of protons and neutrons present in one atom of an element is known as its mass number. For example, one atom of sodium element contains 11 protons and 12 neutrons, so the mass number of sodium is $11 + 12 = 23$. Similarly, a normal carbon atom has 6 protons and 6 neutrons, so the mass number of carbon is $6 + 6 = 12$.

(*iii*) **Isotopes.** Isotopes are atoms of the same element having the same atomic number but different mass numbers. The isotopes of an element have the same atomic number because they contain the same number of protons (and electrons). The isotopes of an element have different mass numbers because they contain different number of neutrons. Here is an example of isotopes. All the chlorine atoms contain 17 protons, so the atomic number of all the chlorine atoms is 17. Now, some chlorine atoms have 18 neutrons whereas other chlorine atoms contain 20 neutrons. Chlorine atoms can, therefore, have mass numbers of 17 + 18 = 35 or 17 + 20 = 37. Thus, chlorine has two isotopes of mass numbers 35 and 37 respectively. The two isotopes of chlorine can be written as ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$.

(*iv*) **Isobars.** Isobars are the atoms of different elements having different atomic numbers but the same mass number. Isobars have different number of protons in their nuclei but the total number of nucleons (protons + neutrons) in them is the same. An example of isobars is argon, ${}^{40}_{18}Ar$, and calcium, ${}^{40}_{20}Ca$. This is because argon and calcium are atoms of different elements having different atomic numbers of 18 and 20 respectively but they have the same mass number of 40.

Uses of Isotopes. (*i*) Radioactive isotopes (such as Uranium–235) are used as a fuel in nuclear reactors of nuclear power plants for generating electricity (*ii*) Radioactive isotopes (such as Cobalt–60) are used in the treatment of cancer.

Q.9. Na^+ has completely filled K and L shells. Explain.

Ans. See Sample Problem 5 on page 190 of this book.

Q.10. If bromine is available in the form of, say, two isotopes ${}^{79}_{35}Br$ (49.7%) and ${}^{81}_{35}Br$ (50.3%), calculate the average atomic mass of bromine atom.

Ans. See Sample Problem 3 on page 206 of this book.

Q.11. The average atomic mass of a sample of an element X is 16.2 u. What are the percentages of isotopes ${}^{16}_{8}X$ and ${}^{18}_{8}X$ in the sample.

Ans. See Sample Problem 4 on page 207 of this book.

Q.12. If Z = 3, what would be the valency of the element ? Also name the element.

Ans. See Sample Problem 3 on page 202 of this book.

Q.13. Composition of the nuclei of two atomic species X and Y is given as under :

	X	Y
Protons =	6	6
Neutrons =	6	8

Give the mass numbers of X and Y. What is the relation between the two species ?

Ans. See Sample Problem 2 on page 206.

Q.14. For the following statements, write T for true and F for false :

(*a*) J.J. Thomson proposed that the nucleus of an atom contains only nucleons.

(*b*) A neutron is formed by an electron and a proton combining together. Therefore, it is neutral.

(*c*) The mass of an electron is about $\frac{1}{2000}$ times that of a proton.

(*d*) A radioactive isotope of iodine is used for making tincture iodine, which is used as a medicine.

Ans. (*a*) F (*b*) F (*c*) T (*d*) F

Q.15. Rutherford's alpha-particle scattering experiment was responsible for the discovery of :

(*a*) Atomic nucleus (*b*) Electron (*c*) Proton (*d*) Neutron

Ans. (*a*) Atomic nucleus

Q.16. Isotopes of an element have :

(*a*) the same physical properties (*b*) different chemical properties

(*c*) different number of neutrons (*d*) different atomic numbers

Ans. (*c*) different number of neutrons.

Q.17. Number of valence electrons in Cl^- ion are :

(*a*) 16 (*b*) 8 (*c*) 17 (*d*) 18

Ans. (*b*) 8 (For details, see Sample Problem 4 on page 202 of this book).

Q.18. Which of the following is a correct electronic configuration of sodium ?

(*a*) 2, 8 (*b*) 8, 2, 1 (*c*) 2, 1, 8 (*d*) 2, 8,1

Ans. (*d*) 2, 8, 1

Q.19. Complete the following table :

Atomic number	Mass number	Number of neutrons	Number of protons	Number of electrons	Name of the atomic species
9	—	10	—	—	—
16	32	—	—	—	Sulphur
—	24	—	12	—	—
—	2	—	1	—	—
—	1	0	1	0	—

Ans. **(*a*) First row :**

(*i*) Since the atomic number is given to be 9, therefore, the number of protons is 9 and the number of electrons is also 9.

(*ii*) Mass number is equal to the number of protons plus the number of neutrons, that is, mass number = 9 + 10 = 19.

(*iii*) The atomic species having atomic number 9 is fluorine.

(*b*) Second row :

(*i*) Since the atomic number is given to be 16, therefore, the number of protons is 16 and the number of electrons is also 16.

(*ii*) Number of neutrons is equal to mass number minus the number of protons, that is, number of neutrons = 32 – 16 = 16

(*c*) Third row :

(*i*) Since the number of protons is given to be 12, so the atomic number is 12 and the number of electrons is also 12.

(*ii*) Number of neutrons is equal to mass number minus the number of protons, that is, number of neutrons = 24 – 12 = 12.

(*iii*) The atomic species of atomic number 12 is magnesium.

(*d*) Fourth row :

(*i*) Since the number of protons is given to be 1, so the atomic number is 1 and the number of electrons is also 1.

(*ii*) Number of neutrons is equal to mass number minus the number of protons, that is, number of neutrons = 2 – 1 = 1.

(*iii*) The atomic species of atomic number 1 and mass number 2 is heavy hydrogen or deuterium.

(*e*) Fifth row

(*i*) Since the number of protons is 1, so the atomic number is also 1.

(*ii*) The atomic species of atomic number 1 and mass number 1 is ordinary hydrogen or protium.

We can now write the completed Table as follows :

Atomic number	*Mass number*	*Number of neutrons*	*Number of protons*	*Number of electrons*	*Name of the atomic species*
9	19	10	9	9	Fluorine
16	32	16	16	16	Sulphur
12	24	12	12	12	Magnesium
1	2	1	1	1	Deuterium
1	1	0	1	0	Protium (Hydrogen)

Value Based Questions
(with Answers)
FIRST TERM

Q.1. Imran and Rohan are best friends. They study in different schools in Srinagar in Kashmir. Imran has just entered class IX whereas Rohan is a student of class X. This year, winter is very severe in Kashmir. So, Imran and Rohan were discussing the central heating systems which could be used to heat their homes during severe cold in this winter season. Imran said that they can use boiling hot water in hot water radiators for the central heating of their homes in winter. Rohan, however, did not agree with Imran. Rohan said that theoretically they should use hot steam in steam radiators for the central heating of their homes. Rohan then explained the theoretical reason for recommending the use of steam in central heating system. Rohan said that he, however, does not know the practical implications of his recommendation.

(*a*) What is the temperature of boiling water under normal conditions ?

(*b*) What is the temperature of steam formed from boiling water under normal conditions ?

(*c*) Out of boiling water and steam, which causes more severe burns on the skin and why ?

(*d*) State whether boiling water or steam is better for use in radiators for central heating in homes during extreme winter. Give reason for your choice.

(*e*) In which of the above two cases (boiling water or steam), a change of state will take place during use in radiators ? What will be this change in state ? What special name is given to this change of state ?

(*f*) What values are displayed by Rohan in this episode ?

Ans. (*a*) The temperature of boiling water under normal conditions is 100°C.

(*b*) The temperature of steam (formed from boiling water) under normal conditions is also 100°C.

(*c*) Steam (at 100°C) causes more severe burns than boiling water (at the same temperature of 100°C) because steam contains more heat in the form of latent heat of vaporisation (than boiling water). So, when steam falls on our skin and condenses to form water, it gives 22.5×10^5 joules per kilogram more heat than boiling water at the same temperature. Since steam gives out more heat than boiling water, therefore, it causes more severe burns.

(*d*) Theoretically, steam is better for central heating purposes than boiling water. This is because steam contains more heat (in the form of latent heat) than boiling water.

(*e*) A change of state will take place in the case of steam. When steam gets cooled, it changes into water. So, a change in state from gas (or vapour) to liquid takes place. The special name of this change of state from steam to water is condensation.

(*f*) The various values displayed by Rohan in this episode are (*i*) Knowledge of latent heat of steam (*ii*) Application of knowledge to solve everyday problems, and (*iii*) Desire to protect his family from severe cold in winter.

Q.2. Ajay and Rakesh live in Rajgarh town of Churu district of Rajasthan. As usual, the summer in this area of Rajasthan in extremely hot. Ajay's sister is getting engaged in the month of May. Ajay's family and relatives were waiting for the guests to arrive for the engagement ceremony. They had brought a slab of ice and put it in a tub of water for cooling the warm bottles of soft drinks. Since the guests were late, Ajay's local relatives consumed all the cold bottles of soft drinks. Just when they had finished drinking all the cold soft drink bottles, the guests (including would-be bridegroom) arrived. Ajay and Rakesh were in a fix because they had only warm bottles of soft drinks left with them. Ajay suggested that they should put the warm soft drink bottles in the ice cold water which they already had in the tub but Rakesh did not agree with him. Rakesh quickly brought a big slab of ice from the nearby shop and crushed it well. He then put the warm soft drink bottles in an empty tub and surrounded them well with crushed ice. These warm soft drink bottles got cooled in a short time and were served to the guests. All the guests enjoyed cold soft drinks on a very hot day and felt refreshed.

(*a*) What is the temperature of water formed from freshly melted ice ?

(*b*) What is the temperature of melting ice ?

(*c*) A person holds some ice-cold water in his left hand palm and a piece of ice in his right hand palm. Which of the two will appear to be more cold and why ?

(*d*) Explain why, the warm soft drink bottles could be cooled more quickly by placing them in a tub of crushed ice than in a tub of ice cold water.

(*e*) Can you suggest another way in which the warm soft drinks can be cooled even more quickly by using ice (than by keeping the bottles in crushed ice) ?

(*f*) What type of change of state takes place when ice is used for cooling purposes ? What is the special name of this change of state ?

(*g*) What values are displayed by Rakesh in this episode ?

Ans. (*a*) The temperature of water formed from the freshly melted ice is 0°C.

(*b*) The temperature of melting ice is also 0°C.

(*c*) The piece of ice held in the right hand palm will appear to be more cold to the person. This is because when the piece of ice held on the right hand palm starts melting, it takes the latent heat (required for melting) from the right hand palm of the person. The right hand palm loses more heat to the melting ice and hence the person feels it to be more cold. The ice cold water held in the left hand palm, however, cannot take away any latent heat (because no change in state is involved).

(*d*) The warm soft drink bottles can be cooled more quickly by placing in crushed ice because, when the ice melts, it will take the latent heat required for melting from the soft drink bottles and the liquid contained in them. And by losing this heat, the warm soft drink bottles will get cooled more quickly. But ice cold water cannot take away any latent heat of melting from warm soft drink bottles.

(*e*) The warm soft drinks can be cooled even more quickly by opening the bottles, pouring the soft drinks in jugs and placing pieces of ice in them.

(*f*) When ice is used for cooling purposes, it melts to form water. So, the change of state is from solid to liquid. The special name of this change of state is fusion (of ice).

(*g*) The values displayed by Rakesh in this episode are (*i*) Knowledge of latent heat of fusion of ice (*ii*) Application of knowledge in solving everyday problems, and (*iii*) Desire to prevent embarrassment to his friend's family.

Q.3. Roshni is a student of class IX in a school in Delhi. One day Roshni's mother, Mrs. Deepa, was complaining that the woollen and silk clothes which she had stored in closed steel trunks had been partially eaten up and damaged by some tiny insects. Mrs. Deepa had to spend a lot of money to get these damaged clothes repaired. When Roshni heard her mother complaining, she asked her to place some small, white balls of a particular material inside the folds of the woollen and silk clothes before storing them again in trunks, and closing the lids of trunks properly. Mrs. Deepa did the same. When Mrs. Deepa opened the trunks again after about six months to take out a silk saree for a marriage function, she found that the stored clothes had remained safe, they had not been damaged this time. At the same time, she noticed that the small white balls placed inside the folds of clothes had become much smaller in size. Mrs. Deepa asked Roshni why the white balls had become much smaller in size on keeping. Roshni explained everything to her mother. Roshni also told her mother that one day all the white balls placed for protecting stored woollen and silk clothes would disappear completely without leaving behind any residue and then new balls will have to be placed for further protection of stored clothes.

(*a*) What is the usual name of the tiny insects which eat up and damage stored woollen and silk clothes in Roshni's home ?

(*b*) What is the material of small white balls placed in stored woollen and silk clothes by Mrs. Deepa ?

(*c*) How do the small white balls placed inside the folds of stored clothes work to prevent damage to stored clothes ?

(*d*) Why do small white balls kept within the folds of stored woollen and silk clothes become smaller and smaller with time and ultimately disappear completely one day ? What is the special name of the process which makes the white balls become smaller or disappear completely without leaving behind any residue ?

(*e*) Name one other material whose balls can also be used for the protection of stored woollen and silk clothes ?

(*f*) What values are displayed by Roshni in this episode ?

Ans. (*a*) Moths (or Clothes moths).

(*b*) Naphthalene.

(*c*) Naphthalene is an insecticide. The solid naphthalene balls give off toxic vapours (or poisonous vapours) slowly. These toxic naphthalene vapours get trapped within the layers of stored clothes and kill the moths that damage the clothes.

(*d*) Naphthalene is a solid organic compound which undergoes sublimation and gets converted into vapours (or gas) directly. So, when naphthalene balls are placed in stored clothes, they take heat from the surroundings and sublime (vaporise) slowly. Due to gradual sublimation (conversion into vapours) of naphthalene balls, their size goes on decreasing. And when these naphthalene balls sublime completely, they just disappear. So, the special name of this process is 'sublimation'.

(*e*) Camphor.

(*f*) The various values displayed by Roshni in this episode are (*i*) Knowledge that naphthalene is an insecticide and undergoes sublimation (*ii*) Application of knowledge in solving everyday problems, and (*iii*) Desire to help her mother (by preventing damage to stored clothes).

Q.4. Vibha is a student of 9th standard. Vibha's family has an LPG connection in the kitchen. When Vibha's mother, Mrs. Chopra, was preparing breakfast for the family, the cooking gas cylinder got empty. Mrs. Chopra keeps a spare gas cylinder. So, she removed the empty gas cylinder and connected the filled gas cylinder to the cooking gas stove. Mrs. Chopra then lighted the gas stove and started preparing breakfast again. Just then Vibha came running into the kitchen and told her mother that she could smell the leaking cooking gas from the new LPG cylinder even from a distance. Vibha closed the gas supply from the leaking cylinder by turning off the regulator knob quickly. She also asked her mother not to use this leaking gas cylinder till the leakage is set right. She also opened the window of kitchen to let the leaked LPG go out. Vibha then called up their LPG distributor on telephone and complained about the leaking gas cylinder. The gas mechanic of the distributor came to Vibha's house within half an hour. When he checked the gas cylinder, he found that the rubber washer of the cylinder had a cut in it through which the gas was leaking. The gas mechanic changed the defective rubber washer and then checked for the leakage again. There was no gas leakage now. When Mrs. Chopra wanted to pay money to the gas mechanic, Vibha told her that this gas leakage rectification service is provided free of charge by the LPG distributor. Mrs. Chopra was happy that Vibha had saved their lives as well as money.

(*a*) (*i*) What substance is added to the LPG cylinder by the filling company to help in detecting gas leakage from the cylinder ?

(*ii*) Which property of the above substance is made use of in detecting the leaking gas from LPG cylinder ?

(*b*) Name the physical process which helps in bringing leaking LPG containing the above substance to us even from a distance.

(*c*) Define the above physical process.

(*d*) How is the leaking cooking gas from LPG cylinder detected ?

(*e*) What would have happened if Mrs. Chopra had continued to use the leaking gas cylinder ?

(*f*) What values are displayed by Vibha in this episode ?

Ans. (*a*) (*i*) Ethyl mercaptan.

(*ii*) Strong smell of ethyl mercaptan.

(*b*) Diffusion (in gases).

(*c*) The spreading out and mixing of a gas with another gas due to the motion of their particles is called diffusion in gases.

(*d*) The leaking cooking gas containing the strong smelling substance ethyl mercaptan spreads and mixes with the surrounding air by the process of diffusion. When the air containing ethyl mercaptan reaches our nose, we can smell it and come to know of the gas leakage.

(*e*) LPG is a highly inflammable gas (which catches fire very easily). If Mrs. Chopra had continued to use the leaking LPG cylinder, then a lot of LPG would have collected in the kitchen after some time. This collected LPG could ignite on coming in contact with gas stove flame causing a big fire in the kitchen. Even the LPG cylinder could catch fire and burst causing a big explosion. This could lead to the loss of life and property.

(*f*) The various values displayed by Vibha in this episode are (*i*) Good smelling power (so as to smell leaking cooking gas even from a distance) (*ii*) Knowledge of the risks of using a leaking LPG cylinder (*iii*) Responsible citizen (in calling LPG distributor to rectify gas leakage), and (*iv*) Desire to protect her family and property (from any LPG related accident).

Q.5. Some of the students of Gyan Bharti School have formed a 'School Band'. Anhad is a student of class IX who is the drummer in this Band. The School Band is set to perform on the annual day function being celebrated next week. All the members of School Band wanted to create some special effect on the stage during their Band's performance but they did not know what to do. Anhad thought over the problem for a while and came out with an idea which was liked by all others. The idea was to create 'fog effect' on the stage during the performance of their Band. On the evening of annual day function, when Anhad's Band was to perform on stage, he asked one of his classmates (who was not performing on stage) to lift a certain white solid brick with hand-gloves on, and put it in a bucket of warm water kept on one side of the stage (hidden from view). As soon as this was done, there was a dense white fog on the stage and all the performers appeared to float in it. This fog created a magical environment on stage. Everyone congratulated Anhad for this wonderful feat.

(*a*) What is fog ?

(*b*) What was the white solid used to create artificial fog effect on the stage ?

(*c*) What is the special property of the above white solid which is used to create fog effect ?

(*d*) What is the purpose of putting the white solid in warm water ?

(*e*) How does this white solid produce the fog effect on stage ?

(*f*) What values are displayed by Anhad in this episode ?

Ans. (*a*) Fog is a thick cloud of tiny water droplets suspended in air which reduces the visibility. The objects engulfed in fog are difficult to see clearly.

(*b*) The white solid used to create artificial fog effect on the stage was 'dry ice' (which is solid carbon dioxide or frozen carbon dioxide). Dry ice is an extremely cold substance.

(*c*) The special property of dry ice is 'sublimation'. When warmed, solid dry ice changes directly into carbon dioxide gas.

(*d*) The purpose of putting dry ice in warm water is to supply heat for the sublimation of dry ice to form extremely cold carbon dioxide gas (for producing dramatic fog effect on stage).

(*e*) When dry ice is put into a bucket of warm water, then warm water supplies heat to it. By absorbing this heat, dry ice (or solid carbon dioxide) sublimes to form extremely cold carbon dioxide gas. This cold carbon dioxide gas mixes with air on stage and cools it. When air gets cooled, then the water vapour present in air condenses to form fog. This thick fog looks like moving smoke and creates a special effect on stage.

(*f*) The various values displayed by Anhad in this episode are (*i*) Awareness of the formation of fog (*ii*) Knowledge of sublimation of dry ice (solid carbon dioxide) (*iii*) Ability to apply knowledge in everyday situations, and (*iv*) Helping nature (in creating special effect on stage).

Q.6. Abhinav is a student of class IX. One day all the students were performing experiments in the science laboratory. Just then, the chemistry teacher, Mrs. Prasad, came to the laboratory. She had three beakers in her hands labelled A, B and C. All the beakers contained colourless liquids which looked exactly the same. Mrs. Prasad turned to the students and said that one of the beakers contained a pure substance whereas the other two beakers contained solutions of the same solute in the same solvent but different concentrations. She also told the students that the weight of liquids in the three beakers A, B and C were 110 g, 120 g and 100 g respectively. Mrs. Prasad wanted one of the students to find out experimentally which beaker contained a pure substance and which two beakers contained solutions. She also wanted them to show experimentally two properties which could tell why the solutions are considered mixtures, even though they are homogeneous substances. Mrs. Prasad allowed them to use any required apparatus from the laboratory for this purpose. Abhinav offered to perform the experiments to distinguish between the pure substance and solutions and also to show experimentally why solutions are considered mixtures.

(*a*) What did Abhinav do to find out which of the given liquids is a pure substance and which liquids are solutions ? What were the observations made by Abhinav ?

(*b*) What did Abhinav conclude from the above observations ?

(*c*) Which property of the pure substance is exhibited by this experiment ?

(*d*) Which properties of a solution are exhibited in this experiment ?

(*e*) What values are displayed by Abhinav in this episode ?

Ans. (*a*) Abhinav took the three liquids A, B and C in three different china dishes and evaporated them by heating. Abhinav observed that :

(*i*) The liquid in beaker A evaporated leaving behind a white 'solid' residue.

(*ii*) The liquid in beaker B evaporated leaving behind much more quantity of white solid residue.

(*iii*) The liquid in beaker C evaporated completely, without leaving behind any residue.

(*b*) Abhinav concluded that :

(*i*) Liquids A and B are solutions or mixtures (because they leave behind residue on evaporation).

(*ii*) Liquid C is a pure substance (because it evaporates completely, without leaving behind any residue).

(*c*) The property of a pure substance exhibited by this experiment is that a pure substance cannot be separated into its constituents by physical methods (here evaporation).

(*d*) The properties of a solution exhibited in this experiment are that :

(*i*) a solution can be separated into its components by physical methods (here evaporation).

(*ii*) a solution has a variable composition (here the two solutions contain different amounts of dissolved solids).

(*e*) The values displayed by Abhinav in this episode are (*i*) Knowledge of pure substances and solutions (*ii*) Application of knowledge in solving problems, and (*iii*) Boldness (to accept challenge).

Q.7. All the students of class 9 were performing experiments to study the types of solutions in the science laboratory. Vikalp took some water in a beaker and heated it slowly with the help of a burner. He started adding potassium nitrate to the hot water with a spoon and stirred it with a glass rod continuously, so that potassium nitrate goes on dissolving in water. Vikalp took the temperature of water up to 40°C, and then keeping the temperature constant, went on adding more and more of potassium nitrate to water, till no more potassium nitrate dissolved in it and some potassium nitrate is also left undissolved at the bottom of the beaker. The contents of the beaker are now filtered through a filter paper arranged in a funnel. A clear solution is obtained in the form of a filtrate.

(*a*) Depending upon the amount of solute present, the solutions can be classified into two groups. Name these two groups of solutions.

(*b*) What type of potassium nitrate solution has been prepared by Vikalp at 40°C ? Define the type of solution prepared by Vikalp.

(*c*) What will happen if the potassium nitrate solution prepared by Vikalp at 40°C is heated further (say to 60°C) ? Give reason for your answer.

(*d*) What will happen if the potassium nitrate solution prepared by Vikalp at 40°C is allowed to cool (say to 20°C) ? Give reason for your answer.

(*e*) Which term/phrase can be used to convey that a maximum of 106 grams of potassium nitrate can be dissolved in 100 grams of water at a temperature of 60°C ?

(*f*) What values are displayed by Vikalp in this episode ?

Ans. (*a*) (*i*) Saturated solutions, and (*ii*) Unsaturated solutions.

(*b*) (*i*) Vikalp has prepared a saturated solution of potassium nitrate at 40°C.

(*ii*) A solution in which no more solute (here potassium nitrate) can be dissolved at that temperature, is called a saturated solution.

(*c*) If the saturated solution of potassium nitrate at 40°C is heated further to a higher temperature, then it will become an unsaturated solution (and more of potassium nitrate can then be dissolved in it). This is because the solubility of potassium nitrate in water increases on heating (or raising the temperature).

(*d*) If the saturated solution of potassium nitrate at 40°C is allowed to cool, then some of the dissolved potassium nitrate from the solution will separate out as a solid and settle down at the bottom of the beaker. This is because the solubility of potassium nitrate in water decreases on cooling (or lowering the temperature).

(*e*) The solubility of potassium nitrate in water is 106 g at 60°C.

(*f*) The values displayed by Vikalp in this episode are (*i*) Awareness of saturated and unsaturated solutions (*ii*) Knowledge of effect of heating and cooling on saturated solutions, and (*iii*) Application of knowledge in solving problems.

Q.8. Raghvan is a student of class 9 in a Chennai school. His teacher, Mr. Murthy, had just finished a lecture on various types of changes which take place even in the same substance under different experimental conditions. Mr. Murthy gave a beaker full of a common liquid to Raghvan. A drop of this liquid can turn anhydrous copper sulphate blue. Mr. Murthy then asked Raghvan to perform two different experiments

starting with the given liquid which lead to the formation of gas/gases under different experimental conditions. He also asked Raghvan to classify these changes under 'different types' of changes. Raghvan first arranged a distillation apparatus. He took some of the given liquid in the distillation flask and started heating it with a burner. After some time, a gas started forming and going into the condenser. The condenser cooled the gas and re-converted it into the original liquid. Raghvan then arranged an apparatus to pass electric current into the given liquid. He took the given liquid in the appropriate apparatus, acidified it by adding a little of sulphuric acid, and then passed electric current from a battery for a considerable time. He collected two gases in the two water-filled test-tubes inverted over the two electrodes of the apparatus. When he mixed these two gases and ignited this mixture very, very carefully (with the help of his teacher), he heard a little explosion and saw the drops of original liquid being formed. Raghvan explained both the experiments and the conclusions obtained to his teacher. Mr. Murthy was very happy.

(*a*) What do you think was the liquid given to Raghvan by Mr. Murthy ?

(*b*) Which gas is formed when heat energy is applied to the liquid in the distillation flask ? What type of change occurs in this case ?

(*c*) Which two gases are formed when electric energy is applied to the acidified liquid in the appropriate apparatus ? What type of change occurs in this case ?

(*d*) How does the above change (which occurs on passing electric current through acidified liquid) differ from the change which takes place when a piece of paper is burnt ?

(*e*) What values are displayed by Raghvan in this episode ?

Ans. (*a*) The liquid which turns anhydrous copper sulphate blue is water. So, the liquid given to Raghvan by Mr. Murthy was water.

(*b*) When heat energy is applied to water in the distillation flask, then water boils to form 'steam' as gas. The change which occurs in converting water into steam is a physical change.

(*c*) When electric energy is applied to acidified water in the appropriate apparatus, then two gases, hydrogen and oxygen, are formed. The change which occurs in converting water into hydrogen and oxygen is a chemical change.

(*d*) The chemical changes are permanent changes which usually cannot be reversed. But the chemical change of decomposing water into hydrogen and oxygen gases by passing electricity is an exception because it can be fairly easily reversed (by burning hydrogen in oxygen to form water again). On the other hand, the burning of paper to form carbon dioxide, water vapour, smoke and ash is a chemical change which cannot be reversed at all.

(*e*) The values displayed by Raghvan in this episode are (*i*) Knowledge of physical changes and chemical changes (*ii*) Application of knowledge in solving problems, and (*iii*) Boldness (to accept challenge)

Q.9. Rohit and Arun are two friends both of whom study in class IX in different schools. Earlier Rohit's mother used to purchase ordinary common salt for cooking food. But since the time Rohit had studied the benefits of using iodised common salt, he had made his mother purchase and use only iodised salt for cooking food. One day, while working in the kitchen, Rohit's mother mixed some ammonium chloride in iodised salt container by mistake. Rohit and Arun had recently studied the various methods for the separation of mixtures in the class. They started discussing the components and the method of separation of the mixture made by Rohit's mother unknowingly. Arun said that the mixture obtained by mixing ammonium chloride with iodised salt actually contains ammonium chloride, iodine and salt in it, so they had to use more than one method to separate this mixture into its components. Rohit, however, did not agree with Arun. He explained his point of view to Arun.

(*a*) What are the benefits of using iodised salt ?

(*b*) What can you say about Arun's statement that the mixture obtained by mixing ammonium chloride and iodised salt contains ammonium chloride, iodine and salt ?

(*c*) Name and define the process which can be used for the separation of mixture containing ammonium chloride and iodised salt.

(*d*) Describe briefly, how a mixture of ammonium chloride and iodised salt can be separated.

(*e*) What values are displayed by Rohit in this episode ?

Ans. (*a*) The benefits of using iodised salt are as follows :

(*i*) Iodised salt provides iodine to the thyroid gland for making thyroxine hormone which regulates metabolism, growth and development of the body. It also prevents 'goitre' disease.

(*ii*) Iodised salt provides iodine which improves the functions of brain such as memory, concentration and the ability to learn.

(*b*) Arun's statement is not correct. This is because iodised salt does not contain free iodine element (I_2). Iodised salt usually contains iodine in the form of its salt, potassium iodide (KI). Moreover, iodised salt contains minute quantity of potassium iodide (which is only about 0.01 per cent of salt).

(*c*) The mixture of ammonium chloride and iodised salt can be separated by the process of sublimation. The changing of a solid directly into vapours on heating, and of vapours into solid on cooling is called sublimation.

(*d*) The mixture of ammonium chloride and iodised salt is heated in a china dish covered with an inverted funnel having a loose cotton plug at the top end. Ammonium chloride sublimes on heating and collects as a sublimate on the cold, inner walls of the inverted funnel. Iodised salt does not sublime, so it is left behind in the china dish.

(*e*) The values displayed by Rohit in this episode are (*i*) Awareness of the composition of iodised salt (that it is mostly common salt with minute quantity of potassium iodide but no free iodine) (*ii*) Knowledge that ammonium chloride sublimes but common salt and potassium iodide present in iodised salt do not sublime (*iii*) Application of knowledge in solving everyday problems, and (*iv*) Concern for the health of his family (in enforcing use of iodised salt).

Q.10. Bhavna is a student of class IX in a city school. She has a five year old younger brother Bunty who is very naughty. Bhavna's mother, Mrs. Malik, had purchased a big bottle of nail polish remover from the market about six months back. She had used less than half of this bottle so far. One day Mrs. Malik left this bottle on the dining table by mistake and went out of the house for some work. In her absence, Bunty opened the half empty bottle of nail polish remover and filled it by adding water in it. When Mrs. Malik came back, she was very angry with Bunty and scolded him for spoiling her expensive bottle of nail polish remover. Mrs. Malik was about to throw away this bottle containing nail polish remover mixed with water when her daughter Bhavna came back from school. She told her problem to Bhavna. Bhavna thought over this problem for a while and said that there was no need to throw away the mixture of nail polish remover and water She told her mother that she could recover pure nail polish remover from this mixture. Next day, Bhavna took the bottle containing this mixture to her school laboratory. With the permission of her teacher, Bhavna set up an apparatus which included a particular type of flask fitted with a tall column. She put the mixture of nail polish remover and water in the flask and heated it gradually. On heating, nail polish remover was turned into vapour, which were cooled by a water condenser to obtain pure nail polish remover. Water was left behind in the flask. Mrs. Malik was very happy to get back her nail polish remover.

(*a*) What is nail polish remover ?

(*b*) State whether nail polish remover and water are miscible liquids or immiscible liquids.

(*c*) Name the process used by Bhavna for the complete separation of mixture of nail polish remover and water. Also define this process.

(*d*) On what factors does the separation of nail polish remover and water mixture by the above process depend ?

(*e*) Name the tall column used in the flask during the separation of a mixture of nail polish remover and water.

(*f*) What values are displayed by Bhavna in this episode ?

Ans. (*a*) Nail polish remover is an organic liquid called 'acetone'. It is a very good solvent.

(*b*) Nail polish remover (acetone) and water are completely miscible liquids.

(*c*) (*i*) The complete separation of a mixture of nail polish remover (acetone) and water was done by Bhavna by using the process of fractional distillation.

(*ii*) Fractional distillation is the process of separating two (or more) miscible liquids by distillation (by using a fractionating column), the distillate being collected in fractions boiling at different temperatures.

(*d*) The separation of nail polish remover (acetone) and water depends on the difference in their boiling points. (The boiling point of acetone is 56°C whereas that of water is 100°C).

(*e*) Fractionating column.

(*f*) The various values displayed by Bhavna in this episode are (*i*) Knowledge of separation of a mixture of two miscible liquids (*ii*) Application of knowledge in solving real-life problems, and (*iii*) Desire to help her mother (by preventing wastage of expensive nail polish remover).

Q.11. Bunny is a ten year old boy. His mother, Mrs. Bhatia, is having high fever today. Bunny is to go for playing a cricket match with his friends in the afternoon but his white cricket dress is very dirty. He does not know how to operate the washing machine. So, Bunny decided to wash his dirty clothes himself with hands without disturbing his mother. After washing his clothes with detergent powder, he squeezed them well to remove the maximum water out of these clothes. Bunny then kept the washed and squeezed clothes as such in the bathroom itself for drying. He checked the wet clothes periodically. Bunny found that the wet washed clothes had not dried even after keeping for four hours in the bathroom. Just then Bunny's elder sister Anushka, who is a student of class IX, returned from school. Bunny shared his problem with her. Anushka found that Bunny had kept the washed clothes after squeezing out water as such without even spreading them. Anushka took these wet, washed clothes to the roof of their house where there was still bright sunshine. Even wind was blowing faster on the roof top. Anushka spread the wet clothes properly on the clothes line fixed on the roof of their house. Bunny was glad to find that the wet clothes had now dried in less than two hours.

(*a*) Which process is involved in the drying of wet clothes ? Define this process.

(*b*) Apart from drying clothes, state another important use of the above process.

(*c*) Why did Anushka spread the wet clothes properly on the clothes line ?

(*d*) Why did Anushka put the wet clothes in sunshine ?

(*e*) How did blowing of wind help in the quick drying of wet clothes ?

(*f*) What values are displayed by Anushka in this episode ?

Ans. (*a*) (*i*) The wet clothes dry due to the evaporation of water present in them. So, the process involved in the drying of wet clothes is 'evaporation'.

(*ii*) The process of a liquid changing into vapour (or gas) even below its boiling point is called evaporation.

(*b*) The process of evaporation is used to obtain common salt from sea-water.

(*c*) The rate of evaporation increases on increasing the surface area of the liquid (here water). Anushka spread the washed wet clothes (containing water) properly on the clothes line to increase their surface area for the rapid evaporation of water present in them (which leads to quicker drying).

(*d*) The rate of evaporation increases on increasing the temperature of liquid (here water). Anushka put the washed wet clothes in sunshine to raise their temperature for the rapid evaporation of water from them (which leads to quicker drying).

(*e*) The rate of evaporation of a liquid (here water) increases with increasing wind speed. The blowing wind carries away the particles of water vapour from near the wet clothes decreasing the amount of water vapour in their surroundings. This increases the rate of evaporation of water from wet clothes (which leads to quicker drying).

(*f*) The various values displayed by Anushka in this episode are (*i*) Awareness of the process of evaporation (*ii*) Knowledge of the factors affecting evaporation (like surface area, temperature and wind speed), (*iii*) Application of knowledge in solving day to day problems, and (*iv*) Helping nature.

Q.12. Pawan is a student of class IX. The students of his class have recently studied the topic on the separation of various types of mixtures. One day, when the students were performing experiments in the science laboratory, their chemistry teacher Mr. Jain came to the laboratory with a packet in his hand. Mr. Jain told Pawan that the packet contained a mixture of aluminium powder, sulphur powder and nickel powder. He asked Pawan to separate all the three constituents of this mixture. Mr. Jain allowed the use of any other equipment/device/chemical, etc., required for this purpose from the laboratory. Pawan thought over the methods to be used for separating the given mixture for a while and then started working on the separation of mixture. He succeeded in separating all the constituents of the mixture, one by one. Mr. Jain appreciated his effort.

(*a*) Which property of sulphur powder could be used by Pawan to separate it from aluminium powder and nickel powder ?

(*b*) Describe briefly, how Pawan separated sulphur powder from the mixture of aluminium powder, sulphur powder and nickel powder.

(*c*) Which property of nickel powder could be used by Pawan to separate it from aluminium powder ?

(*d*) Describe briefly, how Pawan separated nickel powder from aluminium powder.

(*e*) What values are displayed by Pawan in this episode ?

Ans. (*a*) Sulphur is soluble in an organic liquid 'carbon disulphide' (whereas aluminium powder and nickel powder are not soluble in carbon disulphide). So, the property of solubility of sulphur powder in carbon disulphide is used to separate it from aluminium powder and nickel powder.

(*b*) The mixture of aluminium powder, sulphur powder and nickel powder is taken in a test-tube and shaken with some carbon disulphide. Sulphur powder present in the mixture dissolves in carbon disulphide. On filtering, aluminium powder and nickel powder remain behind on the filter paper as residue and sulphur dissolved in carbon disulphide is obtained as a filtrate. On evaporating the filtrate, carbon disulphide is eliminated and sulphur powder is left behind.

(*c*) Nickel is a magnetic material which is attracted by a magnet (whereas aluminium is a non-magnetic material which is not attracted by a magnet). So, the magnetic property of nickel is used to separate nickel powder from aluminium powder.

(*d*) The mixture containing aluminium powder and nickel powder is taken in a watch glass. A horse-shoe type magnet is moved in the mixture of aluminium powder and nickel powder repeatedly. The nickel powder is attracted by the magnet, it clings to the poles of the magnet and gets separated. Aluminium powder is not attracted by the magnet. So, aluminium powder remains behind.

(*e*) The various values displayed by Pawan in this episode are (*i*) Knowledge of the solubility of sulphur in carbon disulphide; magnetic nature of nickel and non-magnetic nature of aluminium, and (*ii*) Application of knowledge in solving real-life problems.

SECOND TERM

Q.13. One day Vaibhav was performing experiments in the science laboratory based on the laws of chemical combination. Just then his chemistry teacher, Mr. Rajeev, came into the laboratory. Mr. Rajeev told Vaibhav that in an experiment conducted by a class IX student when 10.6 g of sodium carbonate was reacted with 12.0 g of ethanoic acid in a closed flask, then 16.4 g of sodium ethanoate, 4.4 g of carbon dioxide and an unknown mass of substance Y were produced. Mr. Rajeev asked Vaibhav to make use of this information and answer the following questions :

(*a*) Write a word equation for the reaction which takes place on reacting sodium carbonate and ethanoic acid.

(*b*) What is the substance Y which is produced in this reaction ?

(*c*) What mass of substance Y is produced in this reaction ?

(*d*) Which law of chemical combination has been made use of in calculating the mass of substance Y ? State this law.

(*e*) What values are displayed by Vaibhav in this episode ?

Ans. (*a*) When sodium carbonate and ethanoic acid react together, then sodium ethanoate, carbon dioxide and water are produced. A word equation for this reaction can be written as :

$$\text{Sodium carbonate} + \text{Ethanoic acid} \longrightarrow \underset{\text{ethanoate}}{\text{Sodium}} + \underset{\text{dioxide}}{\text{Carbon}} + \underset{\text{(Y)}}{\text{Water}}$$

(*b*) The substance Y produced in this reaction is 'water'.

(*c*) We will now calculate the mass of substance Y or mass of water produced in the given reaction. In this reaction, sodium carbonate and ethanoic acid are reactants whereas sodium ethanoate, carbon dioxide and water are products.

Here, $\quad \text{Mass of reactants} = \underset{\text{carbonate}}{\text{Mass of sodium}} + \underset{\text{acid}}{\text{Mass of ethanoic}}$

$$= 10.6 \text{ g} + 12.0 \text{ g}$$
$$= 22.6 \text{ g} \qquad \text{... (1)}$$

Now, suppose the mass of substance Y is x.

So, $\quad \text{Mass of products} = \underset{\text{ethanoate}}{\text{Mass of sodium}} + \underset{\text{dioxide}}{\text{Mass of carbon}} + \underset{\text{water}}{\text{Mass of}}$

$$= 16.4 \text{ g} + 4.4 \text{ g} + x \text{ g}$$
$$= 20.8 \text{ g} + x \text{ g} \qquad \text{... (2)}$$

Now, according to the law of conservation of mass :

$$\text{Mass of products} = \text{Mass of reactants}$$

So, $20.8 + x = 22.6$

And $x = 22.6 - 20.8$

$= 1.8$ g

Thus, the mass of substance Y or mass of water produced is 1.8 grams.

(*d*) (*i*) The law of conservation of mass in chemical reactions has been made use of in calculating the mass of substance Y or water.

(*ii*) The law of conservation of mass states that in a chemical reaction, the total mass of products is equal to the total mass of reactants. There is no change in mass during a chemical reaction.

(*e*) The values displayed by Vaibhav in this episode are (*i*) Knowledge of the law of conservation of mass in chemical reactions, and (*ii*) Ability to use this knowledge in solving problems.

Q.14. Ravi was performing some experiments related to the laws of chemical combination in the science laboratory under the guidance of his chemistry teacher Mr. John. Ravi found that when he burned 1 gram of hydrogen gas in 8 grams of oxygen gas in a closed vessel, he obtained 9 grams of water. He repeated this experiment many times but obtained the same results every time.

(*a*) Write a balanced chemical equation for the reaction between hydrogen and oxygen to form water. Also write the names of all the substances involved below their formulae in the equation.

(*b*) What are the reactants and products in the above reaction ?

(*c*) Which law of chemical combination is illustrated by the fact that when Ravi burned 1 g of hydrogen in 8 g of oxygen, he obtained 9 g of water ?

(*d*) What mass of water will be obtained if 1 g of hydrogen is burned in 10 g of oxygen ? Which law of chemical combination will govern your answer ?

(*e*) What values are displayed by Ravi in this episode ?

Ans. (*a*) The balanced chemical equation for the reaction between hydrogen and oxygen to form water can be written as :

$$\underset{\text{Hydrogen}}{2H_2} + \underset{\text{Oxygen}}{O_2} \longrightarrow \underset{\text{Water}}{2H_2O}$$

(*b*) (*i*) The reactants in this reaction are : Hydrogen and Oxygen

(*ii*) The product in this reaction is : Water

(*c*) Here, Mass of reactants = Mass of hydrogen + Mass of oxygen

= 1 g + 8 g

= 9 g

And, Mass of product = Mass of water

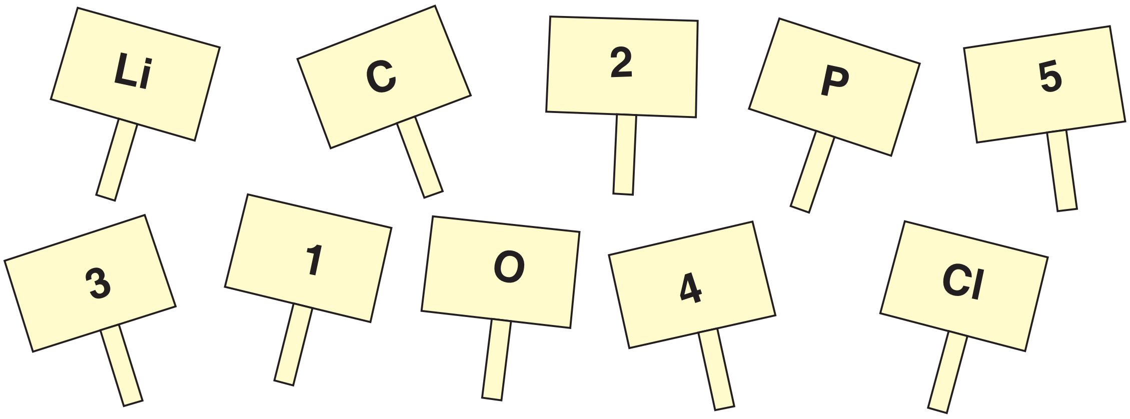
= 9 g

Now, since the mass of product (9 g) is equal to the mass of reactants (9 g), therefore, the given experimental data illustrates the 'law of conservation of mass' in chemical reactions.

(*d*) Our answer will be governed by the law of constant proportions. It has been given in this question that when 1 g of hydrogen is burned in 8 g of oxygen, then 9 g of water is always obtained. Now, since hydrogen and oxygen combine in the fixed proportion of 1 : 8 by mass to produce 9 g of water, therefore, the same mass of water (9 g water) will be obtained even if we burn 1 g of hydrogen in 10 g of oxygen. The extra oxygen (10 – 8 = 2 g oxygen) will remain unreacted in this case.

(*e*) The various values displayed by Ravi in this episode are (*i*) Knowledge of the law of conservation of mass and law of constant proportions in chemical reactions, and (*ii*) Application of knowledge in solving problems.

Q.15. The students of class IX have made placards showing the symbols of some elements and valencies of these elements. These placards somehow got mixed up as shown below :



On the basis of these placards the chemistry teacher, Mrs. Shanti, asked a student Vikas to answer the following questions :

(*a*) Choose the symbol of an element from among the placards which exhibits valencies of 3 and 5. What is the name of this element ? Is it a metal or a non-metal ?

(*b*) Choose the symbol of an element from the given placards which shows a valency of 2. What is the name of this element ? Is it a metal or a non-metal ?

(*c*) Work out the formula of the compound formed between the element of valency 3 and element of valency 2. Also name this compound.

(*d*) Work out the formula of the compound formed between the element exhibiting the valency of 5 with the element having valency 2. Also name this compound.

(*e*) What values are displayed by Vikas in this episode ?

Ans. (*a*) The symbol of element which exhibits the valencies of 3 and 5 is P. The name of this element is phosphorus. It is a non-metal.

(*b*) The symbol of element which exhibits a valency of 2 is O. The name of this element is oxygen. It is also a non-metal.

(*c*) The formula of compound formed between phosphorus element exhibiting a valency of 3 and oxygen element of valency 2 can be worked out as follows :

Symbols : P O P O

P_2O_3

Valencies : 3 2 3 2

Thus, the formula of compound formed between phosphorus element of valency 3 and oxygen element of valency 2 is P_2O_3. The name of this compound is phosphorus trioxide.

(*d*) The formula of compound formed between phosphorus element exhibiting a valency of 5 and oxygen element of valency 2 can be worked out as follows :

Symbols : P O P O

P_2O_5

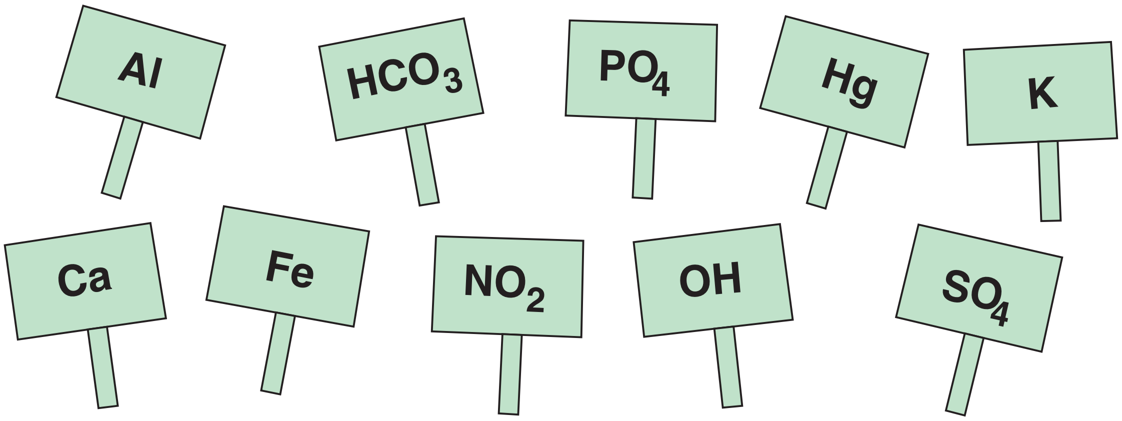
Valencies : 5 2 5 2

Thus, the formula of compound formed between phosphorus element of valency 5 and oxygen element of valency 2 is P_2O_5. The name of this compound is phosphorus pentoxide.

(*e*) The values displayed by Vikas in this episode are (*i*) Knowledge of the symbols of elements and their valencies, and (*ii*) Ability to apply knowledge in solving problems.

Q.16. Pratap is a student of class IX in a city school. He has recently studied the writing of formulae of ionic compounds in the class. Pratap has made some placards for a science quiz showing the symbols of some elements and some ions but forgot to write the electric charges on the ions. Moreover, the placards made

by Pratap got mixed up as shown below :



Based on these placards, the chemistry teacher, Mr. Suri, asked Pratap to answer the following questions :

(*a*) Choose the symbol of the element from among the placards which can form divalent and trivalent cations. Name this element. Also write the symbols of these cations alongwith their charges.

(*b*) Choose the symbol of a divalent anion from among the given placards. What is the name of this anion. Also write the symbol of this anion alongwith its charge.

(*c*) Work out the formula of the ionic compound formed between the divalent cation and divalent anion described above. Also name the compound formed.

(*d*) Work out the formula of the ionic compound formed between the trivalent cation and divalent anion described above. Also name the compound formed.

(*e*) What values are displayed by Pratap in this episode ?

Ans. (*a*) The positively charged ions are called cations. The symbol of element which can form divalent cations. (valency 2+ ions) and trivalent cations (valency 3+ ions) is Fe. The name of the this element is iron. The symbols of two cations formed by iron element are Fe^{2+} [ferrous ion or iron(II) ion] and Fe^{3+} ion [ferric ion or iron(III) ion].

(*b*) The negatively charged ions are called anions. The symbol of the divalent anion (valency 2– ion) is SO_4. The name of this anion is sulphate ion. The symbol of sulphate ion alongwith its charge is SO_4^{2-}.

(*c*) The divalent cation (or valency 2+ ion) is Fe^{2+} and the divalent anion (valency 2– ion) is SO_4^{2-}. The formula of compound formed from these ions can be worked out as follows :

Symbols :	Fe	SO_4	Fe	SO_4		
					$Fe_2(SO_4)_2$ or	$FeSO_4$
Valencies : (or Charges)	2+	2–	2+	2–		

Thus, the formula of compound formed is $FeSO_4$. It is ferrous sulphate or iron(II) sulphate.

(*d*) The trivalent cation (or valency 3+ ion) is Fe^{3+} and the divalent anion (or valency 2– ion) is SO_4^{2-}. The formula of compound formed from these ions can be worked out as follows :

Symbols :	Fe	SO_4	Fe	SO_4	
					$Fe_2(SO_4)_3$
Valencies : (or Charges)	3+	2–	3+	2–	

Thus, the formula of compound formed is $Fe_2(SO_4)_3$. It is ferric sulphate or iron(III) sulphate.

(*e*) The values displayed by Pratap in this episode are (*i*) Knowledge of cations (positive ions) and anions (negative ions), and their valencies, and (*ii*) Ability to use this knowledge in solving problems.

Q.17. Vikram is a student of class IX in a village school. He lives on the outskirts of the village in a farmhouse. There is an underground oil pipeline going to an Oil Refinery in the area which passes near his farmhouse. One day Vikram found that a lot of workers had started digging the whole underground pipeline at some distance from his house. When he enquired about it, he was told that a leakage in oil pipeline (due to some crack, etc.) is suspected in this area, so digging has to be done in a considerable area to find the

place of leakage and set it right. Vikram asked the workers to stop digging all around. He said that he can pinpoint the place of leakage in the oil pipeline made of metal by using a certain procedure. Vikram then explained how the solution of a particular substance can be introduced in the pipeline carrying oil and the place of leakage of this substance can be detected by using a special instrument. The place of leakage of this substance will tell the place of crack in the pipeline from where the oil leaks.

(*a*) What type of substance is used to detect the leakage (or crack) in the underground oil pipeline ?

(*b*) Which special instrument is used to detect the leakage of the above substance from the oil pipeline ?

(*c*) Describe briefly, how the leakage in underground oil pipeline is detected by using the above particular substance and the special instrument.

(*d*) Which property/properties of the above mentioned particular substance introduced in the oil pipeline helps its detection above the ground ?

(*e*) What is the advantage of using this substance in detecting the leakage in underground oil pipeline ?

(*f*) What values are displayed by Vikram in this episode ?

Ans. (*a*) A radioactive substance is used to detect leakage (or crack) in the underground oil pipeline.

(*b*) A Geiger counter is used to detect the radiations emitted by the leaking radioactive substance put in the oil pipeline.

(*c*) A small quantity of the solution of a radioactive susbstance is introduced in the underground oil pipeline in which the place of leakage is to be detected. This radioactive substance will leak out alongwith oil at the place where there is a crack in the metal pipeline. A Geiger counter is moved over the surface of ground all along the buried oil pipeline. The area above the ground where a high intensity of radioactive radiations is detected by Geiger counter will pinpoint the place of leakage in pipeline. The underground pipeline can then be dug up at this place and crack in the pipeline can be repaired.

(*d*) The radioactive substance emits high energy radiations having high penetrating power. Due to their high penetrating power, radioactive radiations can pass through the layers of soil over the underground oil pipeline and hence can be detected by Geiger counter above the ground.

(*e*) The advantage of using a radioactive substance is that the place of leakage (or crack) in the underground oil pipeline can be pinpointed without digging up the whole pipeline. This saves a lot of labour, time and money.

(*f*) The values displayed by Vikram in this episode are (*i*) Knowledge of the properties of radioactive substances (*ii*) Application of knowledge in solving everyday problems, and (*iii*) Helping nature.

Q.18. Ramnik is a student of class 9. One day he was studying a chapter of chemistry in the class alongwith other students. The teacher, Mr. Bhagi, told the students that the scientists James Chadwick, J.J. Thomson and E. Goldstein had discovered three subatomic particles P, Q and R, respectively. He gave the characteristics of all these particles, their locations and arrangements in the atom. Mr. Bhagi also described the contributions of scientists Ernest Rutherford and Neils Bohr in this regard. After completing the discussion on this chapter, Mr. Bhagi asked Ramnik to answer the following questions :

(*a*) What is the name of particle P ? What is the nature of charge on it ? State its location in the atom.

(*b*) What is the name of particle Q ? What is the nature of charge on it ? State its location in the atom.

(*c*) What is the name of particle R ? What is the nature of charge on it ? State its location in the atom.

(*d*) (*i*) Which of the particles P, Q and R is not present in an ordinary hydrogen atom ?

(*ii*) Which of the particles P, Q and R is not present in an alpha particle ?

(*e*) What is the total number of P and R particles present in one atom of an element known as ?

(*f*) The number of particles Q in one neutral atom of an element is nineteen. How are these particles arranged in various energy levels in the atom ?

(*g*) What values are displayed by Ramnik in this episode ?

Ans. (*a*) James Chadwick discovered the subatomic particle called 'neutron'. So, the particle P is neutron. Neutron has no charge, it is electrically neutral. Neutron is located inside the nucleus of an atom.

(*b*) J.J. Thomson discovered the subatomic particle called 'electron'. So, the particle Q is electron. Electron has negative charge. The relative charge of an electron is, –1 (minus one). Electron is located outside the nucleus in an atom.

(*c*) E. Goldstein discovered the subatomic particle called 'proton'. So, the particle R is proton. Proton has positive charge. The relative charge of a proton is +1 (plus one). Proton occurs inside the nucleus of an atom.

(*d*) (*i*) Particle P (neutron) is not present in an ordinary hydrogen atom.

(*ii*) Particle Q (electron) is not present in an alpha particle.

(*e*) The total number of particles P (neutrons) and R (protons) in one atom of an element is called its mass number.

(*f*) The number of particles Q (or electrons) in one neutral atom of the element is 19. These 19 electrons can be arranged in four energy levels or shells as K L M N
2, 8, 8, 1

(*g*) The various values displayed by Ramnik in this episode are (*i*) Knowledge of the structure of atom, and (*ii*) Ability to use this knowledge in solving problems.

Q.19. Naveen is a student of class IX in a city school. His uncle Ram Dev who lives in a village is not keeping good health. He has a tumour in his body. Ram Dev has come to city alongwith his son Ramesh for treatment. Naveen accompanied them to the most famous hospital for medical check-up and treatment. When Ram Dev told the person at the reception desk that he had a tumour, he was asked to go to the oncology department of the hospital. The special doctor (called oncologist) examined the tumour of Ram Dev carefully. He then removed some tissue from the tumour and sent it for 'biopsy', so as to find whether the tumour was malignant or not. The result of biopsy showed that the tumour was malignant. The doctor told Ram Dev that he had come to the hospital at the right time due to which his disease had been detected at an early stage and can be cured successfully. The doctor then recommended radiotherapy for Ram Dev. Naveen had come to know of the term radiotherapy while studying the uses of radioactive isotopes in his class. So, as soon as doctor talked of radiotherapy, Naveen could make out what disease his uncle was suffering from. He also shared his knowledge of this disease with his uncle and his son.

(*a*) What do you think is the disease Ram Dev is suffering from ? Define this disease.

(*b*) What are (*i*) tumour (*ii*) oncology (*iii*) oncologist, and (*iv*) biopsy ?

(*c*) What is meant by saying that the tumour is malignant ?

(*d*) What is radiotherapy ? Explain its working briefly.

(*e*) Which radioactive isotope is usually used in the treatment of this disease by radiotherapy ? How does it work ?

(*f*) What values are displayed by Naveen in this episode ?

Ans. (*a*) (*i*) Ram Dev is suffering from the disease called 'cancer'.

(*ii*) Cancer is a disease caused by an uncontrolled division of abnormal cells in a part of the body.

(*b*) (*i*) Tumour is a swelling of a part of the body caused by an abnormal growth of tissue. A tumour does not necessarily mean a cancer.

(*ii*) Oncology is the branch of medicine which studies and treats tumours and cancer.

(*iii*) An oncologist is a doctor who specialises in treating people with cancer.

(*iv*) Biopsy is the examination of tissue removed from any part of the body of a patient to know the presence, cause or extent of a disease (such as cancer).

(*c*) By saying that the tumour is malignant, it means that the tumour is cancerous. If a tumour is not cancerous, it is said to be benign.

(*d*) Radiotherapy is the treatment of cancer disease by using high energy radiations such as X-rays, gamma rays and electron beams, etc. In radiotherapy, the high energy radiations destroy the cancer cells in the affected area of the body and stop them from growing and multiplying.

(*e*) Cobalt-60 radioactive isotope is used in the treatment of cancer by radiotherapy. Cobalt-60 radioisotope emits high energy gamma rays. When the high energy gamma radiations are directed very carefully at the cancerous tumour in the human body, the cancerous cells get burnt.

(*f*) The various values displayed by Naveen in this episode are (*i*) Awareness of cancer disease (*ii*) Knowledge of the treatment of cancer by radiotherapy (by using radioactive isotopes), and (*iii*) Helping nature.

Q.20. Akshay and Saurabh are the students of class IX. They have recently studied the chapter on structure of atom in the class. Both Akshay and Saurabh were performing some activities in the science laboratory. Akshay took a plastic comb and rubbed it in his dry hair. When he brought this plastic comb (rubbed in dry hair) near tiny pieces of paper, the comb attracted the pieces of paper towards it. Meanwhile, Saurabh took a glass rod and rubbed it with a piece of silk cloth. When he brought this glass rod (rubbed with silk cloth) near the tiny pieces of paper, the glass rod also attracted the pieces of paper towards it (just like the plastic comb). Akshay and Saurabh had studied an instrument called electroscope in class VIII.

So, they decided to make use of a positively charged electroscope having diverged leaves (or opened up leaves) in their activity. Akshay took the plastic comb (rubbed in dry hair) and touched the metal top of positively charged electroscope with it. This made the diverged leaves of electroscope to fold up. Saurabh then took the glass rod (rubbed with silk cloth) and touched the metal top of another positively charged electroscope with it. This made the diverged leaves of the electroscope to diverge (or open up) even more. Akshay did not understand the various conclusions which could be drawn from all these observations. Saurabh explained him everything very clearly.

(*a*) What conclusion can be drawn from the observation that a plastic comb rubbed in dry hair and a glass rod rubbed with silk cloth, both attract tiny pieces of paper ?

(*b*) What do the above observations tell us about the atoms present in plastic comb and glass rod ?

(*c*) (*i*) What conclusion do you get from the observation that when a plastic comb rubbed in dry hair is touched with the metal top of a positively charged electroscope, then its diverged leaves fold up ?

(*ii*) What conclusion do you get from the observation that when a glass rod rubbed with silk cloth is touched with the metal top of a positively charged electroscope, then its leaves diverge even more ?

(*d*) What are the two types of electric charges present in atoms as shown by the above observations ? Name the subatomic particles which carry these charges.

(*e*) (*i*) Which electric charges are gained by a plastic comb on rubbing in dry hair ?

(*ii*) Which electric charges are lost by a glass rod on rubbing with silk cloth ?

(*f*) What values are displayed by Saurabh in this episode ?

Ans. (*a*) It is a known fact that an electrically charged object can attract an uncharged object. So, both a plastic comb rubbed in dry hair and a glass rod rubbed with silk cloth are electrically charged (having electric charges on them) due to which they attract the uncharged pieces of paper.

(*b*) These observations tell us that some charged particles are present in the atoms of plastic comb as well as glass rod.

(*c*) (*i*) This observation shows that the charge on plastic comb is opposite to that of positively charged electroscope. In other words, the plastic comb rubbed in dry hair carries negative electric charge.

(*ii*) This observation shows that the charge on glass rod is of the same type as that of positively charged electroscope. In other words, the glass rod rubbed with silk cloth carries positive electric charge.

(*d*) The atoms contain negative electric charges as well as positive electric charges. The subatomic particles having negative charge are electrons whereas the subatomic particles having positive charge are protons. (A neutral atom contains an equal number of electrons and protons).

(*e*) (*i*) The plastic comb gains negative charges (electrons) from dry hair on rubbing.

(*ii*) The glass rod loses negative charges (electrons) to silk cloth on rubbing.

(*f*) The various values displayed by Saurabh are (*i*) Awareness that atoms contain two types of electric charges : negative (electrons), and positive (protons), and (*ii*) Knowledge that only loosely held negative charges (electrons) can be transferred from atoms of one substance to another by friction during rubbing (the strongly held positive charges or protons cannot be transferred by friction during rubbing).