UNIT 02

MATTER

Student Learning Outcomes (SLOs)

After completing this lesson, the student will be able to:

- Define matter as a substance having mass and occupying space.
- State the distinguishing macroscopic properties of commonly observed states of solids, liquids, and gases in particular density, compressibility and fluidity.
- Identify that state is a distinct form of matter (examples could include familiarity with plasma, intermediate states and exotic states e.g. BEC or liquid crystals).
- Explain the allotropic forms of solids (some examples may include diamond, graphite, and fullerenes).
- Explain the differences between elements, compounds, and mixtures.
- Identify solutions, colloids and suspensions as mixtures and give an example of each.
- Explain the effect of temperature on solubility and formation of unsaturated and saturated solutions

INTRODUCTION

The study of chemistry revolves around the study of matter which is all around us; not only is the entire world made up of matter but so are we, so are the objects that we use. From this we can derive the definition of matter:

Anything that has mass and occupies space is called matter. This makes air, water, rocks, and even people are examples of matter. Different types of matter can be described by their mass. Matter is itself composed of the atom. The atom is the building block of all matter and it is the various combinations of these atoms that make up all the matter that we see around us. You may ask yourself how the book you are reading and the water you are drinking are both matter. They neither look nor feel nothing alike. So how can they both fall into the definition of matter? From there we reach the conclusion that there are states of matter which differ from each other in the way that the atoms that make them up are arranged:

2.1 STATE OF MATTER

There are four states of matter

1. **Gas**
2. **Liquid**
3. **Solid**
4. **Plasma**

Each state is a distinct form of matter.

1. States of matter are the different forms in which matter can exist. These are solids, liquids, gases, and plasmas. These states are determined by the arrangement and movement of particles and the strength of intermolecular and atomic forces.
2. Energy can change matter into different states. For example, solids become liquids or gases when heated. At very high temperatures or when subjected to a strong electric field, the gas transforms into plasma. Under normal conditions, most substances remain in one distinct state: solid, liquid, or gas. Temperatures and energy levels on the Earth are not sufficient to ionize atoms and create plasma.
3. When heated, some crystalline solids turn into cloudy liquids. This cloudy state is called liquid crystal. Liquid crystal states have many properties of liquids and some properties of solids. This form exists within a certain temperature range. When heated further, the state of the liquid crystal changes to a transparent liquid.
4. Furthermore, there are other states such as Bose-Einstien Condensates(BEC) which is defined as the state of matter in which separate atoms cooled to temperatures very close to absolute zero. BEC is observable under extreme conditions of cold temperature. Superfliud and superconductors are the two main materials which contain BEC.

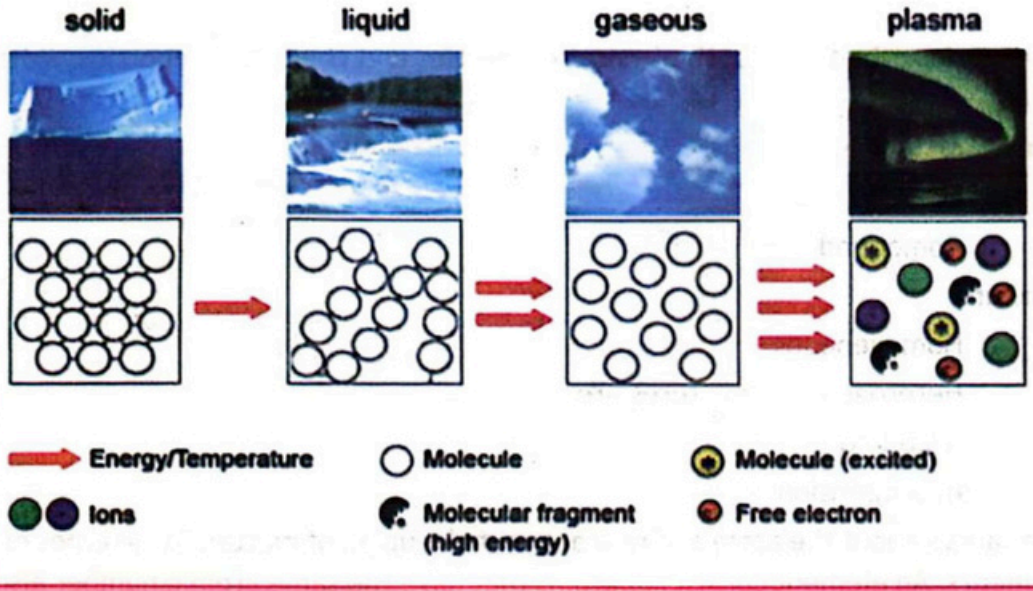


Figure 2.1: State of MAtter

Macroscopic properties can be visualized by the naked eye and we can measure them easily. Some common examples of macroscopic properties of matter include density, fluidity, compressibility.

Table 2.1: Properties of different states of matter

State of matter	Gas	Liquid	Solid
Density	Low density at normal condition due large spaces between molecules	High density at normal condition	High density at normal condition
Compressibility	Very compressible because of large empty spaces	moderately compressible	not compressible
Fluidity	Can flow	Can flow	Can not flow

Have you ever boiled water on a stove? What do you observe when the water heats up? Bubbles form and the water turns into the gas. This tells us a very important fact about the states of matter. Though the states of matter are distinct and are easily distinguishable from the other, through physical techniques we can convert one state of matter into the other. Physical techniques are techniques where we manipulate the physical aspects of matter such as the temperature or pressure. However, the chemical composition of matter stays the same.

2.2 ELEMENTS, COMPOUNDS AND MIXTURES

Matter can be described with both physical properties and chemical properties. Matter can be classified as

1 **Pure substance**
   a) Element
   b) Compound

2 **Mixture**
   a) Homogeneous
   b) Heterogeneous mixtures are
      i) Colloid
      ii) Suspension

Earlier, we talked about the atom and how atoms make up all of matter. Same types of atoms are called *elements*. An element consists of atoms that have the same atomic number also known as the proton number. This is the simplest form of matter which cannot be broken down through chemical means. While a physical change alters the physical properties of a substance, a chemical change forms a new substance completely.

***Element*:** The simplest form of matter made up the same type of atoms.

So we have learnt that matter is made up of atoms and the atoms that have the same proton number are called elements. The combination of these different elements makes up the diversity of objects we see around us. When two or more elements chemically combine, meaning undergo a chemical reaction to form a new substance, this is called a compound. As this is a completely new substance, it is completely different from the elements that were used to make it.

Compound: A substance formed when two or more different atoms chemically combine.

Mixtures are the physical combinations of substances. A mixture does not contain the same types of particles. If you were to examine the chemical composition of the particles in a mixture, the particles would be chemically different from each other. Tea is an example of a mixture. Tea is made up of milk, water, tea leaves and sugar all of which have different chemical compositions.

Mixture: It is a substance formed when two or more substances physically combine.

2.3 ALLOTROPES

The property of an element to exist in different physical forms is called allotropy. These different forms in the same physical state are called allotropes. Atoms of the same element arranged in different manners in the same physical state in allotropes. They are different structural forms of the same element. For example,

Diamond, graphite and buckyballs are three important allotropes of carbon.

Graphite:

Graphite is composed of flat two dimensional layers of hexagonally arranged carbon atoms. In a layer, each C-atom is covalently bonded to three other Carbon atoms. Weak intermolecular bonds exist between each layer which allows the layers to slide over one another without breaking the

bonds. This arrangement makes graphite soft and slippery, making it ideal to be used as a lubricant. Graphite is a good conductor of electricity.

Diamond:

Diamond is the hardest and the purest crystalline allotrope of carbon. In its structure, each C-atom is covalently bonded to four other carbon atoms forming a rigid network of tetrahedral shape. This tetrahedral, three-dimensional arrangement makes it the hardest substance with a very high melting point. Since all the Carbon atoms are bonded with other carbon atoms, no free electrons are present resulting in the structure being non-conductive. Diamond is non-conductor of electricity.

Buckyballs (C-60):

Buckyballs, also known as fullerenes, have a football like fused hollow ring structure made up of twenty hexagons and twelve pentagons. Each of its 60 carbon atoms are bonded to 3 carbon atoms.

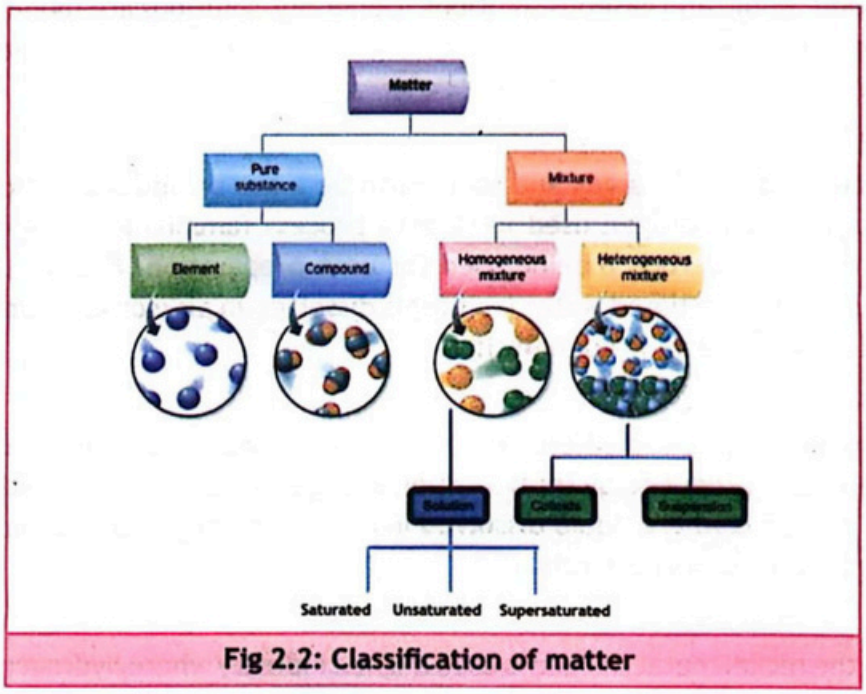


Fig 2.2: Classification of matter

2.4 Solution

A solution is a homogeneous mixture of two or more substances in which one substance is dissolved in the other. Homogeneous means that no particles or parts of different substances can be seen. When one substance dissolves, the solution looks exactly the same. **A substance that is dissolved is called a solute and a substance in which it is dissolved is called a solvent.** In solution, the particles are microscopic, less than 1 nm in diameter. A solution is a very stable mixture and the solute does not separate from the solvent itself.

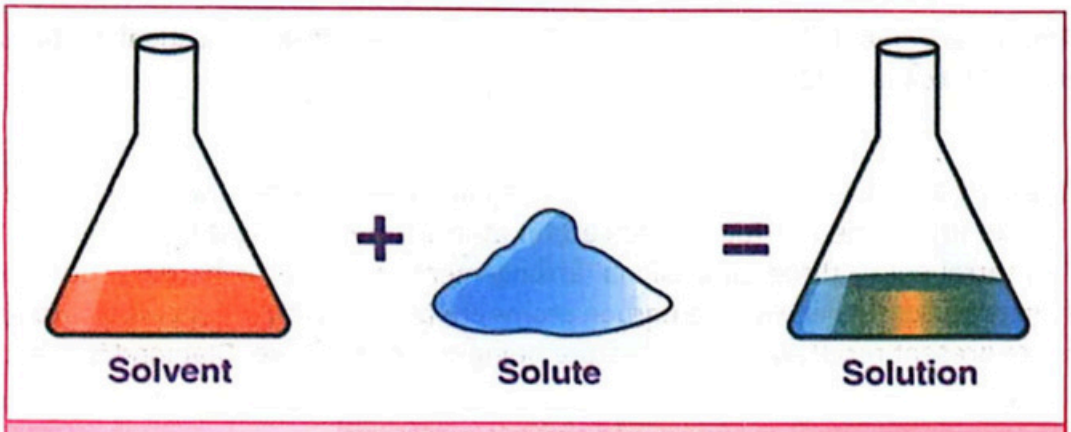


Fig 2.3: Formation of Solution

In salt solution, salt is the solute and water is solvent. More than one solute may be present in a solution. For example, in soft drinks, water is a solvent while other substances like sugar, salts and CO_2 are solutes. Consider the example of air where Nitrogen gas is solvent and oxygen, carbon dioxide and trace gases are solute. On the basis of physical states of solvent and solute can be categorized as solid, liquid and gaseous solutions. Generally, solutions are found in three physical states depending upon the physical state of the solvent, e.g. air is a gaseous, sea water is a liquid solution and alloy is a solid solution in real life.

Gaseous Solutions

In Gaseous Solutions solvent is a gas and solute can be a gas or liquid or solid. For example a mixture of nitrogen and hydrogen used in Haber's process (ammonia formation) and other is mixture of ammonia and carbon dioxide used for urea preparation. Fog, clouds and mist are examples of solutions where liquid water (solute) is dissolved in air (solvent). Smoke is a solution of carbon particle in gaseous air in our daily life.

Liquid Solutions

Carbonated drinks are solutions where solvent is liquid water and solute is gaseous carbon dioxide. Rectified spirit produced by fermentation of sugar cane, Vinegar (acetic acid in water), are examples of solutions where liquid dissolved in liquid. Brine and sugar syrup are solutions of solid salt and sugar in water respectively.

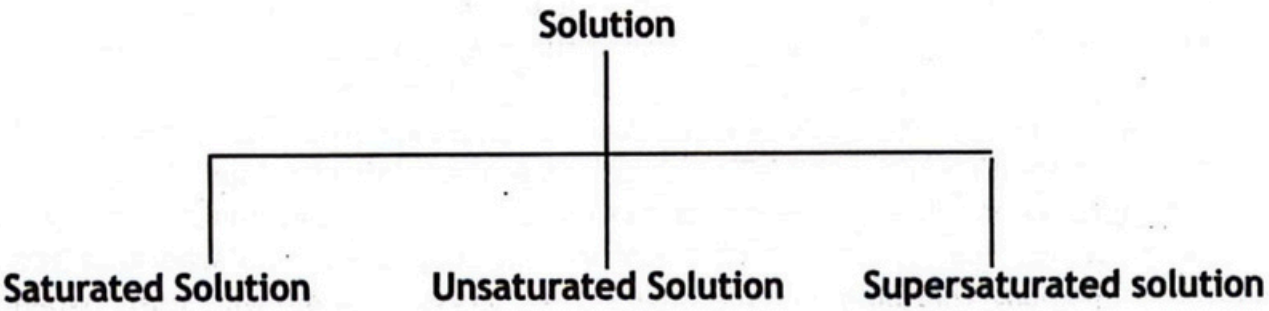
Solid Solutions

Hydrogen gas on the nickel metal surface is used in ghee industry where hydrogen gas is solute and nickel catalyst is solvent. Solution of any metal (solid) in liquid mercury is called amalgam. Alloy industry is very common these days. Alloys are formed by mixing different metal (Brass, Bronze, steel).

2.4.1 Aqueous Solutions

Aqueous solution is formed by dissolving a substance in water. The dissolved substances in an aqueous solution may be solids, gases, or other liquids. In order to be a true solution, a mixture must be stable. For example, sugar in water and table salt in water. Water is called a universal solvent because it dissolves majority of compounds present in earth's crust. Aqueous solutions are mostly used in the laboratories.

Depending on amount of solute solution can be classified as



2.4.2 Saturated Solution

A solution containing maximum amount of solute at a given temperature is called saturated solution.

When a small amount of solute at given temperature is added in a solvent, solute dissolves very easily in the solvent. If the addition of solute is kept on, a stage is reached when solvent cannot dissolve any more solute. At this stage, further added solute remains undissolved and it settles down at the bottom of the container. On the particle level, a saturated solution is the one, in which undissolved solute is in equilibrium with dissolved solute. At this stage, dynamic equilibrium is established. Although dissolution and crystallization continue at a given temperature, but the net amount of dissolved solute remains constant.

2.4.3 Unsaturated Solution

A solution which contains lesser amount of solute than that which is required to saturate it at a given temperature, is called unsaturated solution. Such solutions have the capacity to dissolve more solute to become a saturated solution.

2.4.5 Supersaturated Solution

When saturated solutions are heated, they develop further capacity to dissolve more solute. Such solutions contain greater amount of solute than is required to form a saturated solution and they become more concentrated. The solution that is more concentrated than a saturated solution is known as supersaturated solution. Supersaturated solutions are not stable. Therefore, an easy way to get a supersaturated solution is to prepare a saturated solution at high temperature. It is then cooled to a temperature where excess solute crystallizes out and leaves behind a saturated solution.

Activity 2.1

Take 100g water in a beaker. Add a tea spoon of sugar in it. Stirr it. The sugar will dissolve.Repeat the process and the and added sugar will again dissolve in it. **A solution which can dissolve more of the solute at a given temperature is called an unsaturated solution.**

Go on adding sugar in the above solution till it starts settling down at the bottom of the beaker at a particular temperature. **The solution which cannot dissolve more solute at a particular temperature is called a saturated solution.**

Now heat the solution, stir it, add more sugar and it will dissolve. Go on adding more sugar and stir it. A stage will reach when no more sugar will dissolve and will start settling down at the bottom of the beaker. This solution is called supersaturated solution. A solution that contains more of the solute than is contained in the saturated solution is called supersaturated solution. How to know whether a solution is saturated or supersaturated? A supersaturated solution is not stable in the presence of crystals of solute. If you add a crystal of sodium thiosulphate to its saturated solution, it will simply drop to the bottom, without dissolving. But if you add a crystal of sodium thiosulphate to a supersaturated solution of sodium thiosulphate (see figure 2.4), crystallization will start. When crystallization has finished, you will have a saturated solution in the presence of sodium thiosulphate crystals.

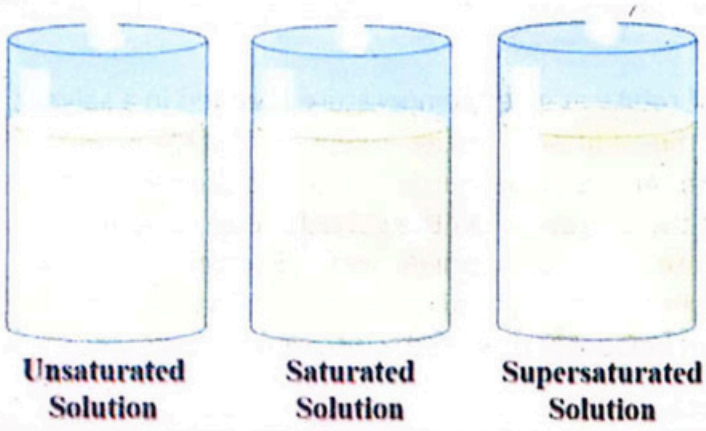


Fig 2.4: Different types of solutions

2.4.6 Concentrated and Dilute Solution

The solutions are classified as dilute or concentrated on the basis of relative amount of solute present in them. Dilute solutions are those which contain relatively small amount of dissolved solute in the solution.

Concentrated solutions are those which contain relatively large amount of dissolved solute in the solution. For example, brine is a concentrated solution of common salt in water. These terms describe the concentration of the solution. Addition of more solvent will dilute the solution and its concentration decreases.

2.4.7 Solubility

Solubility is the maximum amount of solute which dissolves in a specified amount of solvent at a specific temperature. The solubility of a substance depends on the solvent used, as well as temperature and pressure. See Table 2.2.

2.4.8 Effect of Temperature on Solubility

The solubility of solutes depends on temperature. Depending on the nature of solute there is either:

a) **Increase in solubility with temperature e.g., KCl, NH_4Cl**

b) **Decrease in solubility with temperature e.g., Na_2SO_4 $Ca(OH)_2$**

Table 2.2: Solubility of some salts g/100g of solvent at Different Temperatures

(Solute)	Solubility (Amount of solute in 100g of solvent at 20°C	Solubility (Amount of solute in 100g of solvent at 100°C
NaCl	36.5g/100g H_2O	39.2g/100g H_2O
KCl	34.7g/100g H_2O	56g/100g H_2O
NH_4Cl	37.5g/100g H_2O	77g/100g H_2O
$Ca(OH)_2$	0.173g/100g H_2O	0.066g/100g H_2O

Example:

An example of a solute Whose decreases in solubility with increasing temperature is calcium hydroxide, which can be used to treat chemical burns and as an antacid.

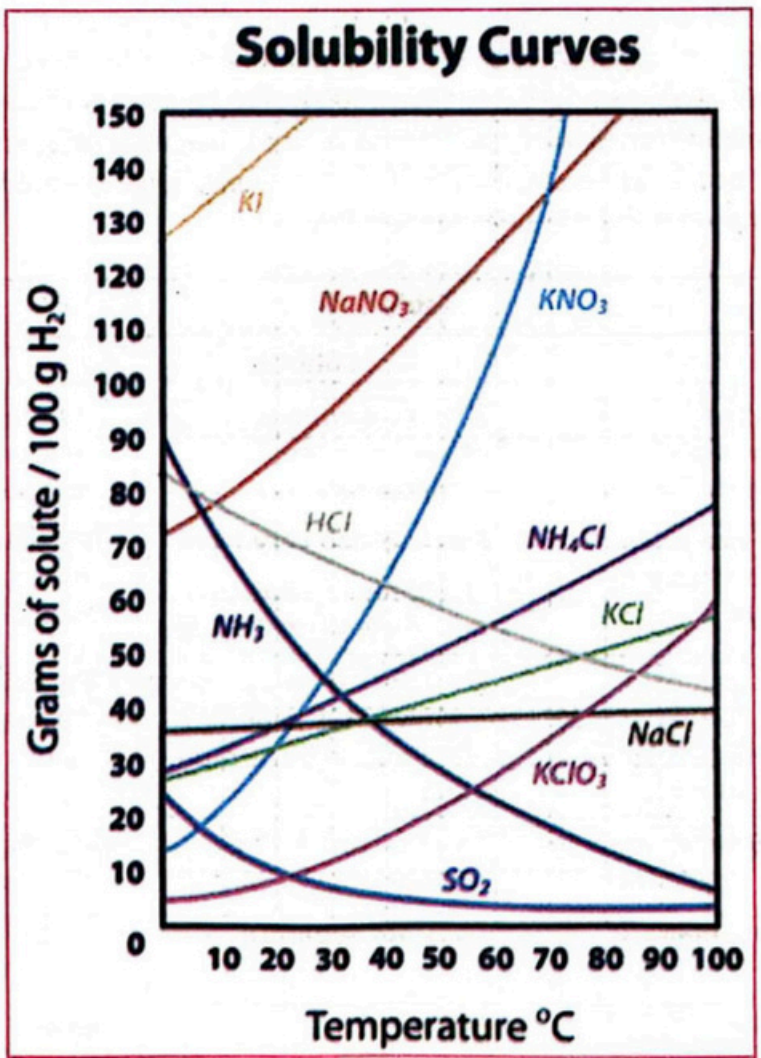


Fig.2.4 Effect of temperature on solubility

2.5 COLLOIDS & SUSPENSIONS

Colloid

These are heterogeneous mixtures in which the solute particles are larger than those present in the true solutions but not large enough to be seen by naked eye. A colloid is a mixture that has particles ranging between 1 and 1000 nanometers in diameter, yet are still able to remain evenly distributed throughout the solution. These are also known as colloidal dispersions because the substances remain dispersed and do not settle to the bottom of the container. The particles in such system dissolve and do not settle down for a long time. But particles of colloids are big enough to scatter the beam of light. It is called Tyndall effect. We can see the path of scattered light beam inside the colloidal solution. Tyndall effect is the main characteristic which distinguishes colloids from solutions. Hence, these solutions are called false solutions or colloidal solutions. Examples are starch, albumin, soap solutions, blood, milk, ink, jelly and toothpaste, etc.

Suspension

A suspension is defined as a heterogeneous mixture in which the solid particles are spread throughout the liquid without dissolving in it. It is mixture of undissolved particles in a given medium. Particles are big enough (greater than 1000nm) to be seen with naked eyes. Examples are chalk in water (milky suspension), paints and milk of magnesia (suspension of magnesium oxide in water). For better understanding of true solutions, false solution and suspension, a comparison of their characteristics is given in table 2.3

Table 2.3

S.No	Solution	Colloids	Suspension
1	A homogeneous mixture of two or more components	A heterogeneous mixture of two or more components	A heterogeneous mixture of two or more components
2	Particle size is less than 1nm. Not visible by naked eye	Particle size vary from 1-10^3 nm. Visible by naked eye by naked eye	Particle size greater than 10^3 nm. Visible by naked eye by naked eye
3	Particles can pass through normal as well as ultra-filter paper	Particles can pass through normal filter paper but not through ultra-filter paper	Particles cannot pass through normal as well as ultra-filter paper
4	Cannot Scatter the light (due to small size)	Can Scatter the light (Tyndal effect)	Can Scatter the light (Tyndal effect)
5	Does not separate	Does not separate	Separate or settles down when stationary
Examples	Sea water	Milk	Muddy water

KEY POINTS

- Anything that has mass and occupies space is called matter.
- Plasma is an electrically charged gas, which is affected by electrical and magnetic fields.
- The property of an element to exist in different physical forms is called allotropy.
- Element: the simplest form of matter made up the same type of atoms
- Compound: A substance formed when two or more different atoms chemically combine.
- A homogeneous mixture of two or more components is called solution.
- Aqueous solution is formed by dissolving a substance in water.
- A solution containing maximum amount of solute at a given temperature is called saturated solution.
- A solution which contains lesser amount of solute than that which is required to saturate it at a given temperature, is called unsaturated solution
- A colloid is a mixture that has particles ranging between 1 and 1000 nanometers in diameter
- A suspension is defined as a heterogeneous mixture in which the solid particles are spread throughout the liquid without dissolving in it
- **References for additional information**
- Matter and its properties: Joseph Midthun, Paul Kobasa
- Cambridge IGSE™ Chemistry 5th Edition
- Cambridge International AS & A Level Chemistry (9701)

REVIEW QUESTIONS

1. Encircle the correct answer.

(i) Anything that has mass and occupies space is called.

(a) Liquid (b) Gas
(c) solid (d) Matter

(ii) Following are states of matter

(a) Gas (b) Liquid
(c) Solid (d) All of these

ii) Macroscopic properties are properties that can be visualized by

(a) the naked eye (b) microscope
(c) electron microscope (d) telescope

(iv) Matter can be described by both its

(a) physical properties and chemical properties.

(b) physical properties (c) chemical properties.

(v) A substance formed when two or more different elements combine chemically.

(a) atom (b) compound

(c) element (d) solution

2. Give short answer.

(i) Can you write the formula of the carbon dioxide gas that we exhale?

(ii) Define the element, Compound, Mixture

(iii) Differentiate between compound and mixture

(iv) Differentiate between concentrated and dilute solution

3. Define the term Allotropes Explain the allotropes of Carbon

4. What is difference between Homogeneous and heterogeneous solution?

5. Differentiate between the colloids, suspension and solution.

6. If there are 18 protons in the Argon atom, then what is the atomic number of Argon?

7. Describe State of matter with example

8. Differentiate between the following.

a. Colloids and Suspensions

b. Elements and Compounds

c. Concentrated and Dilute solutions

9. Examine the concept of solubility.

THINK TANK

10. Why is a solution considered mixture?

11. How will you test weather given solution is a colloid or a solution?

PROJECT

Create a poster that illustrates the various form of matter in the students everyday environment.