(Acids, Bases and salts)

9th book

Unit – 14 – Acids, Bases and salts

Introduction

- We know that the physical world around us is made of large number of chemicals. Soil, air, water, all the life forms and the materials that they use are all consist of chemicals. Out of such chemicals, acids, bases and salts are mostly used in everyday life. Let it be a fruit juice or a detergent or a medicine, they play a key role in our day-to-day activities. Our body metabolism is carried out by means of hydrochloric acid secreted in our stomach. An acid is a the compound which is capable of forming hydrogen ions (H^+) in aqueous solution whereas a base is a compound that forms hydroxyl ions (OH^-) in solution. When an acid and a base react with each other, a neutral product is formed which is called salt. In this lesson let us discuss about them in detail.

Acids

- Look at the pictures of some of the materials used in our daily life, given below:

- All these edible items taste similar i.e. sour. What causes them to taste sour? A certain type of chemical compounds present in them gives sour taste. These are called acids. The word 'acid' is derived from the Latin name "acidus"

- which means sour taste. Substances with sour taste are called acids.

Source	Acid Present
Apple	Malic acid
Lemon	Citric acid
Grape	Tartaric acid
Tomato	Oxalic acid
Vinegar	Acetic acid
Curd	Lactic acid
Orange	Ascorbic acid
Tea	Tannic acid
Stomach juice	Hydrochloric acid
Ant, Bee	Formic acid

- In 1884, a Swedish chemist Svante Arrhenius proposed a theory on acids and bases. According to Arrhenius theory, an acid is a substance which furnishes H+ ions or H3O+ ions in aqueous solution. They contain one or more replaceable hydrogen atoms. For example, when hydrogen chloride is dissolved in water, it gives H1 and Cl2 ions in water.

$$HCl(_{aq)} \rightarrow H1(_{aq}) + Cl2_{(aq)}$$

- What happens to an acid or a base in water? Do acids produce ions only in aqueous solution? Hydrogen ions in HCl are produced in the presence of water. The separation of H+ ion from HCl molecules cannot occur in the absence of water.

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$

- Hydrogen ions cannot exist alone, but they exist in combined state with water molecules. Thus, hydrogen ions must always be H+ (or) Hydronium (H3O+).

$$H^+ + H_2O \rightarrow H_3O^+$$

All acids essentially contain one or more hydrogens. But all the hydrogen containing substances are not acids. For example, methane

(CH4) and ammonia (NH3) also contain hydrogen. But they do not produce H+ ions in aqueous solution.

- The following table enlists various acids and the ions formed by them in water.

Acid	Molecular Formula	Ions formed		No. of replaceable hydrogen
Acetic Acid	CH- $_3$COOH	H+	CH- $_3$COO$^-$	1
Formic Acid	HCOOH	H+	HCOO$^-$	1
Nitric Acid	HNO_3	H+	NO_3^-	1
Sulphuric Acid	H_2SO_4	2H+	SO_4^{2-}	2
Phosphoric Acid	H_3PO_4	3H+	PO_4^{3-}	3

Classification of Acids

- Acids are classified in different ways as given below:

(a) Based on their sources:

- **Organic Acids**: Acids present in plants and animals (living things) are organic acids. Example: HCOOH, CH_3COOH
- **Inorganic Acids**: Acids prepared from rocks and minerals are inorganic acids or mineral acids. Example: HCl, HNO_3, H2SO$_4$

(**b) Based on their Basicity**

- **Monobasic Acid**: Acid that contain only one replaceable hydrogen atom per molecule is called monobasic acid. It gives one hydrogen ion per molecule of the acid in solution. Example: HCl, HNO_3

For acids, we use the term basicity that refers to the number of replaceable hydrogen atoms present in one molecule of an acid. For example, acetic acid (CH3COOH) has four hydrogen atoms but only one can be replaced. Hence it is monobasic.

- **Dibasic Acid:** An acid which gives two hydrogen ions per molecule of the acid in solution. Example: H_2SO_4, H_2CO_3
- **Tribasic Acid**: An acid which gives three hydrogen ions per molecule of the acid in solution. Example: H3PO4

(c) Based on Ionisation

- Acids get ionised in water (produce H+ ions) completely or partially. Based on the extent of ionisation acids are classified as below.
- **Strong Acids**: These are acids that ionise completely in water. Example: HCl
- **Weak Acids**: These are acids that ionise partially in water. Example: CH_3COOH.

Ionisation is the condition of being dissociated into ions by heat or radiation or chemical reactions or electrical discharge.

(d) Based on Concentration

- **Concentrated Acid:** It has relatively large amount of acid dissolved in a solvent.
- **Dilute Acid:** It has relatively smaller amount of acid dissolved in solvent.

Properties of Acids

a) They have sour taste.
b) Their aqueous solutions conduct electricity since they contain ions.
c) Acids turns blue litmus red.
d) Acids react with active metals to give hydrogen gas.

$Mg + H_2SO_4 \rightarrow MgSO_4 + H_2 \uparrow$
$Zn + 2HCl \rightarrow ZnCl_2 + H_2 \uparrow$

Few metals do not react with acid and liberate hydrogen gas. For example: Ag, Cu.

e) Acids react with metal carbonate and metal hydrogen carbonate to give carbon dioxide.

$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2 \uparrow$
$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2 \uparrow$

f) Acids react with metallic oxides to give salt and water.
$CaO + H2SO4 \rightarrow CaSO4 + H2O$
g) Acids react with bases to give salt and water.
$HCl + NaOH \rightarrow NaCl + H2O$

Uses of Acids

- ❖ Sulphuric acid is called King of Chemicals because it is used in the preparation of many other compounds. It is used in car batteries also.
- ❖ Hydrochloric acid is used as a cleansing agent in toilets.
- ❖ Citric acid is used in the preparation of effervescent salts and as a food preservative.
- ❖ Nitric acid is used in the manufacture of fertilizers, dyes, paints and drugs.
- ❖ Oxalic acid is used to clean iron and manganese deposits from quartz crystals. It is also used as bleach for wood and removing black stains.
- ❖ Carbonic acid is used in aerated drinks.
- ❖ Tartaric acid is a constituent of baking powder.

Role of water in acid solution
Acids show their properties only when dissolved in water. In water, they ionise to form H+ ions which determine the properties of acids. They do not ionise in organic solvents. For example, when HCl is dissolved in water it produces H+ ions and Cl_ ions whereas in organic solvents like ethanol they do not ionise and remain as molecule.

Aquaregia

- **We** know that metals like gold and silver are not reactive with either HCl or HNO3. But the mixture of these two acids can dissolve gold. This mixture is called Aquaregia. It is a mixture of hydrochloric acid and nitric acid prepared optimally in a molar ratio of 3:1. It is a yellow-orange fuming liquid. It is a highly corrosive liquid, able to attack gold and other substances.

Chemical formula	: 3 HCL + HNO_3
Solubility in water	: Miscible in water
Melting point	: - 42°C (- 44°F, 231K)
Boiling point	: 108°C (226°F, 381K)

- The **term** aquaregia is a Latin phrase meaning 'King's Water'. The name reflects the ability of aquaregia to dissolve the noble metals such as gold, platinum and palladium.

Uses of Aquaregia

- **It** is used chiefly to dissolve metals such as gold and platinum.

It is used for cleaning and refining gold.

Bases

- According to Arrhenius theory, bases are substances that ionise in water to form hydroxyl ions (OH–). There are some metal oxides which give salt and water on reaction with acids. These are also called bases. Bases that are soluble in water are called alkalis. A base reacts with an acid to give salt and water only.

Base + Acid → Salt + Water

For example, zinc oxide (ZnO) reacts with HCl to give the salt zinc chloride and water.

$ZnO_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl2_{(aq)} + H2O_{(l)}$

Similarly, sodium hydroxide ionises in water to give hydroxyl ions and thus get dissolved in water. So it is an alkali.

$NaOH_{(aq)} \rightarrow Na^{+}{}_{(aq)} + OH^{-}{}_{(aq)}$

- Bases contain one or more replaceable oxide or hydroxyl ions in solution. Table 14.3 enlists various bases and ions formed by them in water.

All alkalis are bases but not all bases are alkalis. For example: NaOH and KOH are alkalis whereas Al(OH)3 and Zn(OH)2 are bases.

Base	Molecular Formula	Ions formed		No. of replaceable hydroxyl ion
Calcium oxide	CaO	Ca^{2+}	O^{2-}	1
Sodium oxide	Na_2O	$2Na^+$	O^{2-}	1
Potassium hydroxide	KOH	K^+	OH^-	1
Calcium hydroxide	$Ca(OH)_2$	$Ca2^+$	OH^-	2
Aluminium hydroxide	$Al(OH)_3$	Al^{3+}	OH^-	3

Classification of Bases

(a) Based on their Acidity

- Monoacidic Base: It is a base that ionises in water to give one hydroxide ion per molecule. Example: NaOH, KOH

- Diacidic **Base**: It is a base that ionises in water to give two hydroxide ions per molecule. Example: Ca(OH)2. Mg(OH)2

- Triacidic **Base:** It is a base that ionises in water to give three hydroxide ions per molecule. Example: Al(OH)3, Fe(OH)3

(b) Based on concentration

- Concentrated **Alkali**: It is an alkali having a relatively high percentage of alkali in its aqueous solution.

- Dilute **Alkali**: It is an alkali having a relatively low percentage of alkali in its aqueous solution.

(c) Based on Ionisation

- Strong **Bases**: These are bases which ionise completely in aqueous solution.

Example: NaOH, KOH

- Weak **Bases**: These are bases that ionise partially in aqueous solution.

Example: NH4OH, Ca(OH)2

The term acidity is used for base, which means the number of replaceable hydroxyl groups present in one molecule of a base.

Properties of Bases

a) They have bitter taste.

b) Their aqueous solutions have soapy touch.

c) They turn red litmus blue.

d) Their aqueous solutions conduct electricity.

e) Bases react with metals to form salt with the liberation of hydrogen gas.

$$Zn + 2\ NaOH \rightarrow Na_2ZnO_2 + H_2\uparrow$$

- f) Bases react with non-metallic oxides to produce salt and water. Since this is similar to the reaction between a base and an acid, we can conclude that non-metallic oxides are acidic in nature.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

g) Bases react with acids to form salt and water.

$$KOH + HCl \rightarrow KCl + H2O$$

The above reaction between a base and an acid is known as Neutralisation reaction.

h) On heating with ammonium salts, bases give ammonia gas.

$$NaOH + NH_4Cl \rightarrow NaCl + H_2O + NH_3\uparrow$$

Few metals do not react with sodium hydroxide. Example: Cu, Ag, Cr

- In the above activity you can observe that the bulb will start glowing only in the case of acids. But, you will observe that glucose and alcohol solution do not conduct electricity. Glowing of the bulb indicates that there is a flow of electric current through the solution. The electric current is carried through the solution by ions. Repeat the same activity using alkalis such as sodium hydroxide and calcium hydroxide.

Uses of Bases

(i) Sodium hydroxide is used in the manufacture of soap.
(ii) Calcium hydroxide is used in white washing of building.
(iii) Magnesium hydroxide is used as a medicine for stomach disorder.
(iv) Ammonium hydroxide is used to remove grease stains from cloths.

Tests for Acids and Bases

a) Test with a litmus paper:

- An acid turns blue litmus paper into red. A base turns red litmus paper into blue.

b) Test with an indicator Phenolphthalein:

- In acid medium, phenolphthalein is colourless. In basic medium, phenolphthalein is pink in colour.

c) Test with an indicator Methyl orange:

- In acid medium, methyl orange is pink in colour. In basic medium, methyl orange is yellow in colour.

Indicator	Colour in acid	Colour in acid
Litmus	Blue to Red	Red to Blue
Phenolphthalein	Colourless	Pink
Methyl orange	Pink	Yellow

Strenght of Acidic or Basic solutions

pH Scale

- A scale for measuring hydrogen ion concentration in a solution is called pH scale. The 'p' in pH stands for 'potenz' in German meaning power. pH scale is a set of numbers from 0 to 14 which is used to indicate whether a solution is acidic, basic or neutral.

  - ❖ Acids have pH less than 7
  - ❖ Bases have pH greater than 7
  - ❖ A neutral solution has pH equal to 7

Salts

- When you say salt, you may think of the common salt. Sea water contains many salts dissolved in it. Sodium chloride is separated from these salts. There are many other salts used in other fields. Salts are the products of the reaction between acids and bases. Salts produce positive ions and negative ions when dissolved in water.

Types of Salts

- Normal Salts: A normal salt is obtained by complete neutralization of an acid by a base.

$$\mathbf{NaOH + HCl \rightarrow NaCl + H2O}$$

- Acid Salts: It is derived from the partial replacement of hydrogen ions of an acid by a metal. When a calculated amount of a base is added to a polybasic acid, acid salt is obtained.

$$\mathbf{NaOH + H2SO_4 \rightarrow NaHSO_4 + H_2O}$$

- **Basic Salts**: Basic salts are formed by the partial replacement of hydroxide ions of a diacidic or triacidic base with an acid radical.

Pb(OH)2 + HCl → Pb(OH)Cl + H2O

- Double **Salts**: Double salts are formed by the combination of the saturated solution of two simple salts in equimolar ratio followed by crystallization. For example, potash alum is a mixture of potassium sulphate and aluminium sulphate. $KAl(SO_4)_2 \cdot 12H2O$

Properties of Salts

- Salts are mostly solids which melt as well as boil at high temperature.

- Most of the salts are soluble in water. For example, chloride salts of potassium and sodium are soluble in water. But, silver chloride is insoluble in water

- They are odourless, mostly white, cubic crystals or crystalline powder with salty taste.

- Salt is hygroscopic in nature.

Water of Crystallisation

- Many salts are found as crystals with water molecules. These water molecules are known as water of crystallisation. Salts that contain water of crystallisation are called hydrated salts. The number of molecules of water hydrated to a salt is indicated after a dot in its chemical formula. For example, copper sulphate crystal have five molecules of water for each molecule of copper sulphate. It is written as CuSO4.5H2O and named as copper sulphate pentahydrate. This water of crystallisation makes the copper sulphate blue. When it is heated, it loses its water molecules and becomes white.

- Salts that do not contain water of crystallisation are called anhydrous salt. They are generally found as powders. Fill in the blanks in the following table based on the concept of water of crystallisation.

Identification of Salts

(i) Physical examination of the salt.

- The physical examination of the unknown salt involves the study of colour, smell and density. This test is not much reliable.

(ii) Dry heating Test.

- This test is performed by heating a small amount of salt in a dry test tube. After all the water get evaporated, the dissolved salts are sedimented in the container.

(iii) Flame Test.

- Certain salts on reacting with concentrated hydrochloric acid (HCl) form their chlorides. The paste of the mixture with con. HCl is introduced into the flame with the help of platinum wire.

Colour of the flame	Inference
Brick red	Ca^{2+}
Golden Yellow	Na^{2+}
Pink Violet	K^{+}
Green Fleshes	Zn^{2+}

(iv) When HCl is added with a carbonate salt, it gives off CO2 gas with brisk effervescence.

Uses of Salts

- Common Salt (Sodium Chloride - NaCl)

It is used in our daily food and used as a preservative.

Washing Soda (Sodium Carbonate-Na_2CO_3)

i. It is used in softening hard water.
ii. It is used in glass, soap and paper industries.

Baking Soda (Sodium bicarbonate -$NaHCO_3$)

i. It is used in making of baking powder which is a mixture of baking soda and tartaric acid.
ii. It is used in soda-acid fire extinguishers.
iii. Baking powder is used to make cakes and bread, soft and spongy.
iv. It neutralizes excess acid in the stomach and provides relief.

Bleaching powder (Calcium Oxychloride - $CaOCl_2$)

i. It is used as disinfectant.
ii. It is used in textile industry for bleaching cotton and linen.

Plaster of Paris (Calcium Sulphate Hemihydrate - $CaSO_4 .\frac{1}{2} H_2O$)

i. It is used for plastering bones.
ii. It is used for making casts for statues.

Points to Remember
• Acid is a substance which furnishes H^+ ions or H_3O^+ ions when dissolved in water. • Base is a substance which releases OH^- ions when dissolved in water. • Salt is the product of reaction between acids and bases. • Acids and bases neutralize each other to form corresponding salts and water. • Salts have various uses in everyday life. • Acidic and basic solutions in water conduct electricity because they produce hydrogen and hydroxide ions respectively. • When an acid reacts with a metal, hydrogen gas is evolved and a corresponding salt is formed. • Phenolphthalein and Methyl orange are used as indicators to find

out whether the given solution is acid or base.

- Litmus paper is also used to find out whether the given solution is acid or base.
- pH paper is find out the given solution whether acidic or basic in nature.
- Aquaregia is a mixture of hydrochloric acid and nitric acid optimally in a molar ratio of 3:1
- pH Scale is used to find out the power of hydrogen ion concentration in a solution.

10th STD

Unit – 9 SOLUTIONS

INTRODUCTION

- You have learnt about mixtures in your lower classes. Most of the substances that we encounter in our daily life are mixtures of two or more substances. The substances present in a mixture may exist in one or more physical state. For example, when we burn wood, the smoke released is a mixture of solid carbon and gases like CO2, CO, etc.

- In some cases of mixtures, their components can be separated easily whereas in some other cases they cannot be. Consider the two mixtures, one which contains salt and water, and the another which contains sand and water. Water is the one of the components in both the mixtures. In the first case salt disolves in water. In the second case the sand does not disolve in water. Sand in water can be separated by filtration but salt cannot be separated as it dissolves in water to form a homogeneous

mixture. This kind of homogenous mixtures are termed as "**solutions**".

SOLUTIONS IN DAY-TO-DAY LIFE

- One of the naturally existing solutions is sea water. We cannot imagine life on earth without sea water. It is a mixture of many dissolved salts. The another one is air. It is a mixture of gases like nitrogen, oxygen, carbon dioxide and other gases.

- All the life forms on the earth are associated with solutions. Plants take solutions of nutrients for their growth from the soil. Most of the liquids found in human body including blood, lymph and urine are solutions. Day to day human activities like washing, cooking, cleaning and few other activities involve the formation of solutions with water. Similarly, the drinks what we take, like fruit juice, aerated drinks, tea, coffee etc. are also solutions. Therefore, the ability of water to form solutions is responsible for sustenance of life. On the other hand, the same characteristic forms the basic cause of the addition of pollutants to water. However, the ability of water to form solutions influences the survival of man on the earth. In this lesson, let us learn the science of solutions.

COMPONENTS OF SOLUTIONS

- We know that, a **solution is a homogeneous mixture of two or more substances**. In a solution, the component which is present in lesser amount (by weight), is called **solute** and the component, which is present in a larger amount (by weight) is called **solvent**. The solute gets distributed uniformly throughout the solvent and thus forming the mixture homogeneous. So, the solvent acts as a dissolving medium in a solution. The process of uniform distribution of solute into solvent is called **dissolution**. Figure 9.2 shows the schematic representation of solution.

- A solution must at least be consisting of two components (a solute and a solvent). Such solutions which are made of one solute and one solvent (two components) are called **binary solutions**. e.g. On adding copper sulphate crystals to water, it dissolves in water forming a solution of copper sulphate as shown in Figure 9.3. It contains two components i.e. one solute- copper sulphate and one solvent-water. So it is a binary solution. Similarly, a solution may contain more than two components. For example if salt and sugar are added to water, both dissolve in water forming a solution. Here two solutes are dissolved in one solvent. Such kind of solutions which contain three components are called **ternary solutions**.

Types of Solutions

Based on the physical state of the solute and the solvent

- We know that substances normally exist in three physical states (phases) i.e., solid, liquid and gas. In binary solutions, both the solvent and solute may exist in any of these physical states. But the solvent constitutes the major part of the solution. Its physical state is the primary factor which determine the characteristics of the solution. Therefore, there are different types of binary solutions as listed.

Solute	Solvent	Example
Solid solution		
Solid	Solid	Copper dissolved in gold (Alloys)
Liquid	Solid	Mercury with sodium (amalgam)
Liquid solution		
Solid	Liquid	Sodium chloride dissolved in water
Liquid	Liquid	Ethyl alcohol dissolved in water
Gas	Liquid	carbon-di-oxide dissolved in water (Soda water)
Gaseous solution		
Liquid	Gas	Water vapour in air (cloud)
Gas	Gas	Mixture of Helium-Oxygen gases,

Based on the type of solvent

- Most of the substances are soluble in water. That is why, water is called as 'Universal solvent". However some substances do not dissolve in water. Therefore, other solvents such as ethers, benzene, alcohols etc., are used to prepare a solution. On the basis of type of solvent, solutions are classified into two types. They are aqueous solutions and non-aqueous solutions.

a) Aqueous solution:

- The solution in which water acts as a solvent is called aqueous solution. In general, ionic compounds are soluble in water and form aqueous solutions more readily than covalent compounds. E.g. Common salt in water, Sugar in water, Copper sulphate in water etc.

b) Non – Aqueous solution:

- The solution in which any liquid, other than water, acts as a solvent is called non-aqueous solution. Solvent other than water is referred to as non-aqueous solvent. Generally, alcohols, benzene, ethers, carbon disulphide, acetone, etc., are used as non-aqueous solvents. Examples for non-aqueous solutions: Sulphur dissolved in carbon disulphide, Iodine dissolved in carbon tetrachloride.

Based on the amount of solute

- The amount of the solute that can be dissolved in the given amount of solvent is limited under any given conditions. Based on the amount of solute, in the given amount of solvent, solutions are classified into the following types:

(i) Saturated solution
(ii) Unsaturated solution
(iii) Super saturated solution

(i) Saturated solution: A solution in which no more solute can be dissolved in a definite amount of the solvent at a given temperature is called saturated solution. e.g. 36 g of sodium chloride in 100 g of water at 25°C forms saturated solution. Further addition of sodium chloride, leave it undissolved.

(ii) Unsaturated solution: Unsaturated solution is one that contains less solute than that of the saturated solution at a given temperature. e.g. 10 g or 20 g or 30 g of Sodium chloride in 100 g of water at 25°C forms an unsaturated solution.

(iii) Super saturated solution: Supersaturated solution is one that contains more solute than the saturated solution at a given temperature. e.g. 40 g of sodium chloride in 100 g of water at 25°C forms super saturated solution. This state can be achieved by altering any other conditions liken temperature, pressure. Super saturated solutions are unstable, and the solute is reappearing as crystals when the solution is disturbed.

Concentrated and dilute solutions

- It is another kind of classification of unsaturated solutions. It expresses the relative concentration of two solutions with respect to their solutes present in the given amount of the solvent. For example, you are given two cups of tea. When you taste them, you feel that one is sweeter than the other. What do you infer from it? The tea which sweet more contains higher amount of sugar than the other. How can you express your observation? You can say that the tea is stronger. But a chemist would say that it is 'concentrated'.

- When we compare two having same solute and solvent in a solutions, the one which contains higher amount of solute per the given amount of solvent is said to be '**concentrated solution' and the another is said to be 'dilute solution'. They are schematically represented by Figure 9.5.**

- Differentiating solutions as dilute and concentrated is a qualitative representation. It does not imply the quantity of the solute. This difference is observed by means of some physical characteristics such as colour, density, etc.

Solubility

- Usually, there is a limit to the amount of solute that can be dissolved in a given amount of solvent at a given temperature. When this limit is reached, we have a saturated solution and any excess solute that is added, simply resides at the bottom of the solution. The extent of dissolution of a solute in a solvent can be better explained by its solubility. Solubility is measure of how much of a solute can be dissolved in a specified amount of a solvent.

Solubility= $\frac{\boldsymbol{mass\ of\ the\ solve}}{\boldsymbol{mass\ of\ the\ solvent}} \times \mathbf{100}$

Solubility's of some common substances in water at 25°C

Name of the solute	Formula of the solute	Solubility g/100 g water
Calcium carbonate	$CaCO_3(s)$	0.0013
Sodium chloride	$NaCl$ (s)	36
Ammonia	$NH_3(g)$	48
Sodium hydroxide	$NaOH(s)$	80
Glucose	$C_6H_{12}O_6(s)$	91
Sodium bromide	$NaBr(s)$	95
Sodium iodide	$NaI(s)$	184

Factors affecting solubility

- There are three main factors which govern the solubility of a solute. They are:

(i) Nature of the solute and solvent
(ii) Temperature
(iii) Pressure

(i) Nature of the solute and solvent

- The nature of the solute and solvent plays an important role in solubility. Although water dissolves an enormous variety of substances, both ionic and covalent, it does not dissolve everything. The phrase that scientists often use when predicting solubility is "like dissolves

- like." This expression means that dissolving occurs when similarities exist between the solvent and the solute. For example: Common salt is a polar compound and dissolves readily in polar solvent like water.
- Non-polar compounds are soluble in non-polar solvents. For example, Fat dissolved in ether. But non-polar compounds, do not dissolve in polar solvents; polar compounds do not dissolve in non-polar solvents.

(ii) Effect of Temperature

Solubility of Solids in Liquid:

- Generally, solubility of a solid solute in a liquid solvent increases with increase in temperature. For example, a greater amount of sugar will dissolve in warm water than in cold water.
- In endothermic process, solubility increases with increase in temperature.
- In exothermic process, solubility decreases with increase in temperature.

Solubility of Gases in liquid

- Do you know why is it bubbling when water is boiled? Solubility of gases in liquid decrease with increase in temperature. Generally, water contains dissolved oxygen. When water is boiled, the solubility of oxygen in water decreases, so oxygen escapes in the form of bubbles.
- Aquatic animals live more in cold regions because, more amount of dissolved oxygen is present in the water of cold regions. This shows that the solubility of oxygen in water is more at low temperatures.

(iii) Effect of Pressure

- Effect of pressure is observed only in the case of solubility of a gas in a liquid. When the pressure is increased, the solubility of a gas in liquid increases.

- The common examples for solubility of gases in liquids are carbonated beverages, i.e. soft drinks, household cleaners containing aqueous solution of ammonia, formalin-aqueous solution of formaldehyde, etc.

Concentration of a Solution

- So far, we discussed what is a solution? what does it consist of and its types. Most of the chemical reactions take place in solutions form. So it is essential to quantify the solute in solvent to study the reactions.

To quantify the solute in a solution, we can use the term "**concentration**".

Concentration of a solution may be defined as the amount of solute present in a given amount of solution or solvent.

- Quantitatively, concentration of a solution may be expressed in different methods. But here, we shall discuss percentage by mass (% mass) and percentage by volume (% volume).

Mass percentage

- Mass percentage of a solution is defined as the percentage by mass of the solute present in the solution. It is mostly used when solute is solid and solvent is liquid.

Mass percentage = $\frac{\textit{mass of the solute}}{\textit{mass of the solution}} \times \mathbf{100}$

Mass percentage = $\frac{\textit{mass of the solute}}{\textit{mass of the solution} + \textit{mass of the solvent}} \times \mathbf{100}$

For example: 5% sugar solution (by mass) means 5 g of sugar in 95 g of water. Hence it is made 100g of solution.

- Usually, mass percentage is expressed as w/w (weight / weight); mass percentage is independent of temperature.

Volume percentage

- Volume percentage is defined as the percentage by volume of solute (in ml) present in the given volume of the solution.

Volume percentage = $\frac{\textit{volume of the solute}}{\textit{volume of the solution}} \times \mathbf{100}$

Volume percentage = $\frac{\textit{volume of the solute}}{\textit{volume of the solution} + \textit{volume of the solvent}} \times \mathbf{100}$

- For example, 10% by volume of the solution of ethanol in water, means 10 ml of ethanol in 100 ml of solution (or 90 ml of water)

- Usually volume percentage is expressed as v/v (volume / volume). It is used when both the solute and solvent are liquids. Volume percentage decreases with increases in temperature, because of expansion of liquid.

- You can notice that in the commercial products that we come across in our daily life such as a solution of syrups, mouth wash, antiseptic solution, household disinfectants etc., the concentration of the ingredients is expressed as v/v. Similarly, in ointments, antacid, soaps, etc., the concentration of solutions are expressed as w/w.

Hydrated salts and Water of Crystallization

- When ionic substances are dissolved in water to make their saturated aqueous solution, their ions attract water molecules which then attached chemically in certain ratio. This process is called hydration. These ionic substances crystallize out from their saturated aqueous solution with a definite number of molecules of water. The number of water molecules found in the crystalline substance is called **water of crystallization**. Such salts are called hydrated salts.

- On heating these hydrated crystalline salts, they lose their water of crystallization and become amorphous or lose their colour (if they are coloured). Table 9.3 shows some common hydrated salts:

Common Name	IUPAC Name	Molecular Formula
Blue Vitriol	Copper (II) sulphate pentahydrate	$CuSO_4.5H_2O$
Epsom Salt	Magnesium sulphate heptahydrate	$MgSO_4.7H_2O$
Gypsum	Calcium sulphate	$CaSO_4.2H_2O$

	dihydrate	
Green Vitriol	Iron (II) sulphate heptahydrate	$FeSO_4.7H_2O$
White Vitriol	Zinc sulphate heptahydrate	$ZnSO_4.7H_2O$

Copper sulphate pentahydrate CuSO4.5H2O (Blue vitriol)

- The number of water molecules in blue vitriol is five. So its water of crystallization is 5. When blue coloured copper sulphate crystals are gently heated, it loses its five water molecules and becomes colourless anhydrous copper sulphate.

$$\underset{\text{(Copper sulphate pentahydrate)}}{CuSO_4\cdot 5H_2O} \underset{\text{Cooling}}{\overset{\text{Heating}}{\rightleftharpoons}} \underset{\text{(Anhydrous copper sulphate)}}{CuSO_4 + 5H_2O}$$

- If you add few drops of water or allow it to cool, the colourless anhydrous salt again turns back into blue coloured hydrated salt.

Magnesium sulphate heptahydrate MgSO4.7H2O (Epsom salt)

- Its water of crystallization is 7. When magnesium sulphate heptahydrate crystals are gently heated, it loses seven water molecules, and becomes anhydrous magnesium sulphate.

$$\underset{\text{(Magnesium sulphate heptahydrate)}}{MgSO_4\cdot 7H_2O} \underset{\text{Cooling}}{\overset{\text{Heating}}{\rightleftharpoons}} \underset{\text{(Anhydrous Magnesium sulphate)}}{MgSO_4 + 7H_2O}$$

- If you add few drops of water or allow it to cool, the colourless anhydrous salt again turns back into hydrated salt.

Hygroscopy

- Certain substances, when exposed to the atmospheric air at ordinary temperature, absorb moisture without changing their physical state. Such substances are called **hygroscopic substances** and this property is called hygroscopy.

Hygroscopic substances are used as drying agents.

Example:

1. Conc.Sulphuric acid (H_2SO_4).
2. Phosphorus Pentoxide (P_2O_5).
3. Quick lime (CaO).
4. Silica gel (SiO_2).
5. Anhydrous calcium chloride ($CaCl_2$).

Deliquescence

- Certain substances which are so hygroscopic, when exposed to the atmospheric air at ordinary temperatures, absorb enough water and get completely dissolved. Such substances are called **deliquescent substances** and this property is called **deliquescence**.
- Deliquescent substances lose their crystalline shape and ultimately dissolve in the absorbed water forming a saturated solution.

Deliquescence is maximum when:

1)The temperature is low
2)The atmosphere is humid

Examples: Calcium chloride ($CaCl_2$), Caustic soda ($NaOH$), Caustic potash (KOH) and Ferric chloride ($FeCl_3$).

Problems Based on Solubility and Percentage by Mass and Volume

I. Problems based on solubility

- 1) 1.5 g of solute is dissolved in 15 g of water to form a saturated solution at 298K. Find out the solubility of the solute at the temperature.

Hygroscopic substances	Deliquescence substances
When exposed to the atmosphere at ordinary temperature, they absorb moisture and do not dissolve.	When exposed to the atmospheric air at ordinary temperature, they absorb moisture and dissolve.
Hygroscopic substances do not change its physical state on exposure to air.	Deliquescent substances change its physical state on exposure to air.
Hygroscopic substances may be amorphous solids or liquids.	Deliquescent substances are crystalline solids.

Mass of the solute = 1.5 g
Mass of the solvent = 15 g

Solubility of the solute = $\frac{mass\ of\ the\ solute}{mass\ of\ the\ solvent} \times 100$

Solubility of the solute = $\frac{1.5}{15} \times 100$

= 10 g

- 2) Find the mass of potassium chloride would be needed to form a saturated solution in 60 g of water at 303 K? Given that solubility of the KCl is 37/100 g at this temperature.

Mass of potassium chloride in 100 g of water in saturated solution = 37 g

Mass of potassium chloride in 60 g of water in saturated solution $= \frac{37}{100} \times 60 \quad = 22.2g$

- 3) What is the mass of sodium chloride that would be needed to form a saturated solution in 50 g of water at 30°C. Solubility of sodium chloride is 36 g at 30°C?

At 30°C, 36 g of sodium chloride is dissolved in 100 g of water.

∴Mass of sodium chloride that would be need for 100 g of water = 36 g

∴ Mass of sodium chloride dissolved in 50 g of water $=\frac{37\times 60}{100}$ =18g

- 4) The Solubility of sodium nitrate at 50°C and 30°C is 114 g and 96 g respectively. Find the amount of salt that will be thrown out when a saturated solution of sodium nitrate containing 50 g of water is cooled from 50°C to 30°C?

Amount of sodium nitrate dissolved in 100 g of water at 50°C is 114 g

∴ Amount of sodium nitrate dissolving in 50 g of water at 50°C is

$$= \frac{114\times 50}{100} = 57g$$

Similarly amount of sodium nitrate dissolving in 50g of water at 30°C is

$$= \frac{96\times 50}{100} = 48g$$

Amount of sodium nitrate thrown when 50g of water is cooled from 50°C to 30°C is

57-48 = 9 g

II. Problem based on mass percentage

- 1) A solution was prepared by dissolving 25 g of sugar in 100 g of water. Calculate the mass percentage of solute.

Mass of the solute = 25 g
Mass of the solvent = 100 g

Mass Percentage = $\frac{mass\ of\ the\ solute}{mass\ of\ the\ solvent} \times 100$

Mass Percentage = $\frac{mass\ of\ the\ solute}{mass\ of\ the\ solute + mass\ of\ the\ solvent} \times 100$

$= \frac{25}{25+100} \times 100$

$= \frac{25}{125} \times 100 = 20g$

- 2) 16 grams of NaOH is dissolved in 100 grams of water at 25°C to form a saturated solution. Find the mass percentage of solute and solvent.

Mass of the solute (NaOH) = 16 g
Mass of the solvent H2O = 100 g

(i) Mass percentage of the solute

Mass percentage of solute $= \frac{mass\ of\ the\ solute}{mass\ of\ the\ solute + mass\ of\ the\ solvent} \times 100$

$= \frac{16 \times 100}{16+100}$

$= \frac{1600}{116}$

Mass percentage of the solute = 13.79 %

(ii) Mass percentage of solvent = 100 – (Mass percentage of the solute)

= 100 – 13.79
= 86.21%

- 3) Find the amount of urea which is to be dissolved in water to get 500 g of 10% w/w aqueous solution?

Mass Percentage(w/w) = $\frac{\textit{mass of the solute}}{\textit{mass of the solvent}} \times \mathbf{100}$

$$\mathbf{10} = \frac{\textit{mass of the urea}}{500} \times \mathbf{100}$$

Mass of urea = 50g

(iii) **Problem based on Volume – volume percentage.**

- 1) A solution is made from 35 ml of Methanol and 65 ml of water. Calculate the volume percentage.

Volume of the ethanol = 35 ml
Volume of the water = 65 ml

Volume Percentage $= \frac{\textit{volume of the solute}}{\textit{volume of the solution}} \times \mathbf{100}$

Volume Percentage $= \frac{\textit{volume of the solute}}{\textit{volume of the solution} + \textit{volume of the solvent}} \times \mathbf{100}$

Volume percentage = $\frac{35}{35+65} \times \mathbf{100}$

Volume percentage = $\frac{35}{100} \times \mathbf{100}$

= 35%

- 2) Calculate the volume of ethanol in 200 ml solution of 20% v/v aqueous solution of ethanol.

Volume of aqueous solution = 200 ml
Volume percentage = 20%

Volume Percentage $= \frac{\textit{volume of the solute}}{\textit{volume of the solution}} \times 100$

20 $= \frac{\textit{volume of the ethanol}}{200} \times 100$

Volume of ethanol $= \frac{20 \times 200}{100} = 40$ **ml**

10th book
Unit 10 - TYPES OF CHEMICAL REACTIONS

INTRODUCTION

- As you know from your earlier studies, a chemical reaction involves breaking of old chemical bonds and formation of new chemical bonds. This change may happen spontaneously or it may be facilitated by external forces or energy. Chemistry is all about chemical reactions. In your day to day life, you could observe many chemical reactions. A clear understanding of these reactions is essential in order to manipulate them for the sake of human life and environment. So, chemistry mainly focuses on chemical reactions. Let us try to find the answer for the following questions:

  - ❖ You need energy to play, walk, run or to perform various physical activities. Where do you get the energy from?
  - ❖ How do plants grow and get their food?
  - ❖ How does a car move using fuel?
  - ❖ Why does iron rust on its exposure to water or air?

- You get energy from the digestion of the food you eat. Plants grow by absorbing nutrients from the Earth and get their food by photosynthesis. The combustion of a fuel makes the car to move. Oxidation of iron causes rusting. So, all these processes are chemical changes i.e. the materials, which undergo changes are converted into some other new materials. For example, by burning petrol, the hydrocarbons present in it are converted into carbon dioxide and water. In this chapter, let us discuss the nature and types of chemical reactions.

What happens during a chemical reaction?

- In a chemical reaction, the atoms of the reacting molecules or elements are rearranged to form new molecules.
- Old chemical bonds between atoms are broken and new chemical bonds are formed.

- Bond breaking absorbs energy whereas bond formation releases energy

How are chemical reactions represented?

- When methane reacts with oxygen, it forms carbon dioxide and water. How can you represent this reaction? It can be written as a word equation as shown below:

$$\text{Methane} + \text{Oxygen} \rightarrow \text{Carbon dioxide} + \text{Water}$$

- But, this equation does not give the chemical composition of the reactants and products. So, to learn the characteristics of a chemical reaction, it is represented by a chemical equation. In the chemical equation, the chemicals of the reaction are represented by their chemical formulas. The compounds or elements, which undergo reactions (reactants) are shown to the left of an arrow and the compounds formed (products) are shown to the right of the arrow. The arrow indicates the direction of the reaction. Thus, the aforesaid reaction can be written as follows:

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

- But, this is also an incomplete chemical equation. Because, the law of conservation of matter states that matter cannot be created or destroyed. You cannot create new atoms by a chemical reaction. In contrast, they are rearranged in different ways by a chemical reaction to form a new compound. So, in a chemical equation, the number of atoms of the reactants and that of the products must be equal. The number of hydrogen and oxygen atoms in the reactants and the products are not equal in the given equation. On balancing the number of atoms, the following equation can be obtained:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

- Further, the chemical equation provides information on the physical state of the substances and the conditions under which the reaction takes place.

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$$

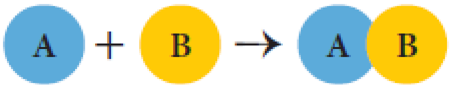
TYPES OF CHEMICAL REACTIONS

Classification based on the nature of rearrangements of atoms

- So far you studied about a chemical reaction and how it can be described as a chemical equation. A large number of chemical reactions are taking place around us every day. Are they taking place in a similar way? No. Each reaction involves different kinds of atoms and hence the way they react also differs. Thus, based on the manner by which the atoms of the reactants are rearranged, chemical reactions are classified as follows.

Combination reactions

- A combination reaction is a reaction in which two or more reactants combine to form a compound. It is otherwise called 'synthesis reaction' or 'composition reaction'. When a reactant 'A' combines with 'B', it forms the product 'AB'. The generalised scheme of a combination reaction is given below:



Example:

- Hydrogen gas combines with chlorine gas to form hydrogen chloride gas.

$$H_{2(g)} + Cl_{2(g)} \rightarrow 2HCl_{(g)}$$

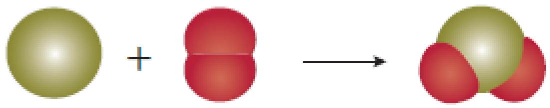
- Depending on the chemical nature of the reactants, there are three classes of combination reactions:

Element + Element → Compound

- In this type of combination reaction, two elements react with one other to form a compound. The reaction may take place between a metal and a non-metal or two non-metals.

Example 1:

- When solid sulphur reacts with oxygen, it produces sulphur dioxide. Here both the reactants are non-metals.



$$S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$$

Example 2:

- Sodium, a silvery-white metal, combines with chlorine, a pale yellow green gas, to form sodium chloride, an edible compound. Here one of the reactants is a metal (sodium) and the other (chlorine) is a non-metal.

$$2Na_{(s)} + Cl_{2(g)} \rightarrow 2NaCl_{(s)}$$

Test Yourself:

- Identify the possible combination reactions between the metals and non-metals given in the following table and write their balanced chemical equations:

Metals	Non-metals
Na, K, Cs, Ca, Mg	F, Cl, Br, I

Compound + Element → Compound

- In this case, a compound reacts with an element to form a new compound. For instance, phosphorous trichloride reacts with chlorine gas and forms phosphorous pentachloride.

$$PCl_{3(l)} + Cl_{2(g)} \rightarrow PCl_{5(s)}$$

Compound + Compound → Compound

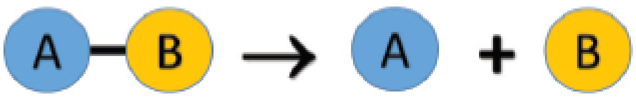
- It is a reaction between two compounds to form a new compound. In the following reaction, silicon dioxide reacts with calcium oxide to form calcium silicate.

$$SiO_{2(s)} + CaO_{(s)} \rightarrow CaSiO_{3(s)}$$

- Most of the combination reactions are exothermic in nature. Because, they involve the formation of new bonds, which releases a huge amount of energy in the form of heat.

Decomposition reactions

- In a decomposition reaction, a single compound splits into two or more simpler substances under suitable conditions. It is the opposite of the combination reaction. The generalised scheme of a decomposition reaction is given below:



- Breaking of bonds is the major phenomenon in a decomposition reaction and hence it requires energy to break the bonds, depending on the nature of the energy used in the decomposition reaction.

There are three main classes of decomposition reactions. They are

- ❖ Thermal Decomposition Reactions
- ❖ Electrolytic Decomposition Reactions
- ❖ Photo Decomposition Reactions

A solution of slaked lime is used for white washing walls. Calcium hydroxide reacts slowly with the carbon dioxide in air to form a thin layer of calcium carbonate on the walls. Calcium carbonate is formed aft er two to three days of white washing and gives a shiny finish to the walls. It is interesting to note that the chemical formula for marble is also $CaCO_3$

$$Ca(OH)_{2(aq)} + CO_{2(g)} \rightarrow CaCO_{3(s)} + H_2O_{(l)}$$

Thermal Decomposition Reactions

- In this type of reaction, the reactant is decomposed by applying heat. For example, on heating mercury (II) oxide is decomposed into mercury metal and oxygen gas. As the molecule is dissociated by the absorption of heat, it is otherwise called 'Thermolysis'. It is a class of compound to element/element decomposition. i.e. a compound (HgO) is decomposed into two elements (Hg and Oxygen).

$$2HgO_{(s)} \xrightarrow{\text{Heat}} 2Hg_{(l)} + O_{2(g)}$$

- Similarly, when calcium carbonate is heated, it breaks down in to calcium oxide and carbon dioxide. It is a type of compound to compound/compound decomposition.

$$CaCO_{3(s)} \xrightarrow{\text{Heat}} CaO_{(s)} + CO_{2(g)}$$

- In thermal decomposition reaction, heat is supplied to break the bonds. Such reactions, in which heat is absorbed, are called 'Endothermic reactions'.

Electrolytic Decomposition Reactions

- In some of the decomposition reactions, electrical energy is used to bring about the reaction. For example, decomposition of sodium chloride occurs on passing electric current through its aqueous solution. Sodium chloride decomposes in to metallic sodium and chlorine gas. This process is termed as 'Electrolysis'.

$$2NaCl_{(aq)} \xrightarrow{\text{Electricity}} 2Na_{(s)} + Cl_{2(g)}$$

- Here, a compound (NaCl) is converted into elements (Na and chlorine). So it is a type of compound to element/element decomposition.

Photo Decomposition Reactions

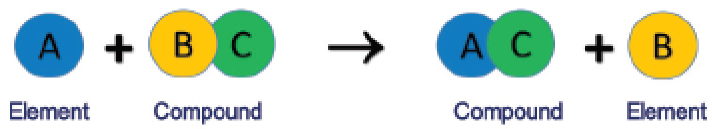
- Light is an another form of energy, which facilitates some of the decomposition reactions. For example, when silver bromide is exposed to light, it breaks down into silver metal and bromine gas. As the decomposition is caused by light, this kind of reaction is also called 'Photolysis'.

$$2AgBr_{(s)} \xrightarrow{Ligh} 2Ag_{(s)} + Br_{2(g)}$$

- The yellow coloured silver bromide turns into grey coloured silver metal. It is also a compound to element/element decomposition.

Single Displacement Reactions

- It is a reaction between an element and a compound. When they react, one of the elements of the compound-reactant is replaced by the element-reactant to form a new compound and an element. The general schematic representation of a single displacement reaction is given as:



- 'A' displaces element 'B' from the compound 'BC' and hence a single displacement reaction occurs. If zinc metal is placed in hydrochloric acid, hydrogen gas is evolved. Here, hydrogen is displaced by zinc metal and zinc chloride is formed.

$$Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$$

$$Fe_{(s)} + CuSO_{4(aq)} \rightarrow FeSO_{4(aq)} + Cu_{(s)}$$

- If an iron nail is placed in an aqueous solution of copper (II) sulphate as shown in Fig. 10.2, the iron displaces copper from its aqueous solution and the so formed copper deposits over the iron nail.

- It is easy to propose so many reactions of this kind with different combinations of reactants. Will they all occur in practice? No. This is most easily demonstrated with halogens. Let us consider the following two reactions:

$$2NaCl_{(aq)} + F_{2(g)} \rightarrow 2NaF_{(aq)} + Cl_{2(g)}$$

$$2NaF_{(aq)} + Cl_{2(g)} \rightarrow 2NaCl_{(aq)} + F_{2(g)}$$

- The first reaction involves the displacement of chlorine from NaCl, by fluorine. In the second reaction, chlorine displaces fluorine from NaF. Out of these two, the second reaction will not occur. Because, fluorine is more active than chlorine and occupies the upper position in the periodic table. So, in displacement reactions, the activity of the elements and their relative position in the periodic table are the key factors to determine the feasibility of the reactions. More active elements readily displace less active elements from their aqueous solution.

The activity series of some elements is given below:

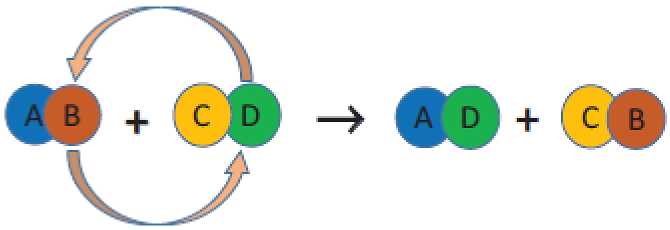
To remember	Activity Series	
Please	Potassium (K)	Most reactive
Send	Sodium (Na)	
Lions	Lithium (Li)	
Cats	Calcium (Ca)	
Monkeys	Magnesuim (Mg)	
And	Aluminium (Al)	
Zebras	Zinc (Zn)	
Into	Iron (Fe)	
Lovely	Lead (Pb)	
Hot	Hydrogen (H) non-metal	
Countries	Copper (Cu)	
Signed	Silver (Ag)	
General	Gold (Au)	
Penguin	Platinum (Pt)	Least reactive

By referring the activity series, try to answer the following questions:

- Which of the metals displaces hydrogen gas from hydrochloric acid? Silver or Zinc. Give the chemical equation of the reaction and Justify your answer

Double Displacement Reactions

- When two compounds react, if their ions are interchanged, then the reaction is called double displacement reaction. The ion of one compound is replaced by the ion of the another compound. Ions of identical charges are only interchanged, i.e., a cation can be replaced by other cations. This reaction is also called 'Metathesis Reaction'. The schematic representation of a double displacement reaction is given below:



- For a double displacement reaction to take place, one of the products must be a precipitate or water. By this way, there are major classes of double displacement reactions. They are:

1. Precipitation Reactions
2. Neutralization Reactions

Precipitation Reactions

- When aqueous solutions of two compounds are mixed, if they react to form an insoluble compound and a soluble compound, then it is called precipitation reaction. Because the insoluble compound, formed as one of the products, is a precipitate and hence the reaction is so called.

Differences between combination and decomposition reactions

COMBINATION REACTIONS	**DECOMPOSITION REACTIONS**
One or more reactants combine to form a single product	A single reactant is decomposed to form one or more products
Energy is released	Energy is absorbed
Elements or compounds may be the reactants	Single compound is the reactant

- When the clear aqueous solutions of potassium iodide and lead (II) nitrate are mixed, a double displacement reaction takes place between them.

$$Pb(NO_3)_{2(aq)} + 2KI_{(aq)} \rightarrow PbI_{2(s)}\downarrow + 2KNO_{3(aq)}$$

Potassium and lead displace or replace one other and form a yellow precipitate of lead.

Neutralization Reactions

- In your lower classes, you have learned the reaction between an acid and a base. It is another type of displacement reaction in which the acid reacts with the base to form a salt and water. It is called 'neutralization reaction' as both acid and base neutralize each other.

Acid + Base → Salt + Water

- Reaction of sodium hydroxide with hydrochloric acid is a typical neutralization reaction. Here, sodium replaces hydrogen from hydrochloric acid forming sodium chloride, a neutral soluble salt.

$$NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

- Similarly, when ammonium hydroxide reacts with nitric acid, it forms ammonium nitrate and water.

$$HNO_{3(aq)} + NH_4OH_{(aq)} \rightarrow NH_4NO_{3(aq)} + H_2O_{(l)}$$

Combustion Reactions

- A combustion reaction is one in which the reactant rapidly combines with oxygen to form one or more oxides and energy (heat). So in combustion reactions, one of the reactants must be oxygen. Combustion reactions are majorly used as heat energy sources in many of our day to day activities. For instance, we use LPG gas for domestic cooking purposes. We get heat and fl ame from LPG gas by its combustion reaction of its constituent gases. LPG is a mixture of hydrocarbon gases like propane, butane, propylene, etc. All these hydrocarbons burn with oxygen to form carbon dioxide and water.

$$C_3H_{8(g)} + 5O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O_{(g)} + \text{Heat}$$

- Since heat is evolved, it is an exothermic reaction. As oxygen is added, it is also an oxidation. So, combustion may be called as an exothermic oxidation. If a flame is formed (as shown in Fig. 10.4), then it is called burning.

1. Digestion of Food
2. Rusting of iron

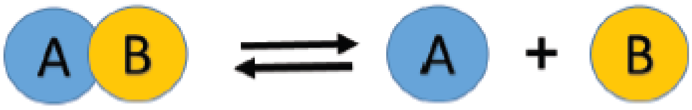
- Many thousands of reactions fall under these five categories and further you will learn in detail about these reactions in your higher classes.

Classification based on the direction of the reaction

- You know that innumerable changes occur every day around us. Are all they permanent? For example, liquid water freezes into ice, but then ice melts into liquid water. In other words, freezing is reversed. So, it is not a permanent change. Moreover, it is a physical change. Physical changes can be reversed easily. Can chemical changes be reversed? Can the products be converted into reactants? Let us consider the burning of a wood. The carbon compounds present in the wood are burnt into carbon dioxide gas and water. Can we get back the wood immediately from carbon dioxide and water? We cannot. So, it is a permanent change. In most of the cases, we cannot. But, some chemical reactions can be reversed. Our mobile phone gets energy from its lithium ion battery by chemical reactions. It is called discharging. On recharging the mobile, these chemical reactions are reversed. Thus, chemical reactions may be reversed under suitable conditions. Hence, they are grouped into two categories such as reversible and irreversible reactions.

Reversible Reactions

- A reversible reaction is a reaction that can be reversed, i.e., the products can be converted back to the reactants. A reversible reaction is represented by a double arrow with their heads in the direction opposite to each other. Thus, a reversible reaction can be represented by the following equation:



Explanation:

- Here, the compound 'AB' undergoes decomposition to form the products 'A' and 'B'. It is the forward reaction. As soon as the products are formed, they combine together to form 'AB'. It is the backward reaction. So, the reaction takes place in both the directions. Do you think then that no products are formed in the aforesaid reaction? If you think so, you are wrong. Because, even though the reaction takes place in both the directions, at the initial stage the rates (speed) of these reactions are not equal. Consider the following decomposition reaction of phosphorous pentachloride into phosphorous trichloride and chlorine.

$$PCl_{5(g)} \rightleftarrows PCl_{3(g)} + Cl_{2(g)}$$

- The forward reaction is the decomposition of PCl_5 and the backward reaction is the combination of PCl_3 and Cl_2. Initially, the forward reaction proceeds faster than the backward reaction. After sometimes, the speed of both the reactions become equal. So, PCl_5 cannot be completely converted into the products as the reaction is reversed. It is a reversible reaction. The actual measurements of the given reaction show that the reaction is at equilibrium, but the amount of PCl_5 is more than that of PCl_3 and Cl_2.

- Thus, more amount of products can be obtained in a reversible reaction by the periodical removal of one of the products or the periodical addition of the reactants.

$$2H2O_{2(aq)} \rightleftarrows 2H_2O_{(l)} + O_{2(g)}$$

Irreversible Reactions

- The reaction that cannot be reversed is called irreversible reaction. The irreversible reactions are unidirectional, i.e., they take place only in the forward direction. Consider the combustion of coal into carbon dioxide and water.

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)} + \text{Heat}$$

- In this reaction, solid coal burns with oxygen and gets converted into carbon dioxide gas and water. As the product is a gas, as soon as it is formed it escapes out of the reaction container. It is extremely hard to decompose a gas into a solid. Th us, the backward reaction is not possible in this case. So, it is an irreversible reaction. Table 10.2 provides the main differences between a reversible and an irreversible reaction:

Differences between reversible and irreversible reactions

REVERSIBLE REACTION	IRREVERSIBLE REACTION
It can be reversed under suitable conditions.	It cannot be reversed.
Both forward and backward reactions take place simultaneously.	It is unidirectional. It proceeds only in forward direction.
It attains equilibrium	Equilibrium is not attained.
The reactants cannot be converted completely into products.	The reactants can be completely converted into products.
It is relatively slow.	It is fast.

RATE OF A CHEMICAL REACTION

- So far we discussed various types of chemical reactions and the nature of the reactants and products. Let us consider the following reactions:

  1. Rusting of iron
  2. Digestion of food

3. Burning of petrol
4. Weathering of rock

- How fast is each reaction? Rank them from the slowest to fastest. How will you determine, which is the fastest and which is the slowest? One of the ways to find out how fast a reaction is as follows: Measure the amount of reactants or products before and after a specific period of time. For example, let us assume that 100 g of a substance 'A' undergoes a reaction and after an hour 50 g of 'A' is left.

$$A \rightarrow \text{Product}$$

- In another instance, 100 g of substance 'C' undergoes a reaction and after an hour, 20 g of 'C' is left.

$$C \rightarrow \text{Product}$$

- Can you say which is the faster reaction? In the first reaction, 50 g of the reactant (A) is converted into products whereas in the second reaction 80 g of the reactant is converted into products in one hour. So, the second reaction is faster. This measurement is called 'the reaction rate'.

- "Rate of a reaction is the change in the amount or concentration of any one of the reactants or products per unit time".

Consider the following reaction

$$A \rightarrow B$$

The rate of this reaction is given by

$$\text{Rate} = -\frac{d[A]}{dt} = +\frac{d[B]}{dt}$$

Where,

[A] – Concentration of A

[B] – Concentration of B

- The negative sign indicates the decrease in the concentration of A with time.

- The postive sign indicates the increase in the concentration of B with time.

Note: '[ ]' represents the concentration, 'd' represents the infinitesimal change in the concentration.

Why is reaction rate important?

- Faster the reaction, more will be the amount of the product in a specified time. So, the rate of a reaction is important for a chemist for designing a process to get a good yield of a product. Rate of reaction is also important for a food processor who hopes to slow down the reactions that cause food to spoil.

Factors influencing the rate of a reaction

- Can the rate of a reaction be changed? The rate of a reaction can be changed. For example, iron gets rusted faster in an acid than in water. Important factors that affect rate of a reaction are

  1. Nature of the reactants
  2. Concentration of the reactants
  3. Temperature
  4. Catalyst
  5. Pressure
  6. Surface area of the reactants

Nature of the reactants

- The reaction of sodium with hydrochloric acid is faster than that with acetic acid. Do you know why? Hydrochloric acid is a stronger acid than acetic acid and thus more reactive. So, the nature of the reactants influence the reaction rate.

$$2Na_{(s)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + H_{2\,(g)} \text{ (fast)}$$

$$2Na_{(s)} + 2CH_3COOH_{(aq)} \rightarrow 2CH_3COONa_{(aq)} + H_{2(g)(}\text{slow)}$$

Concentration of the reactants

- Changing the amount of the reactants also increases the reaction rate. The amount of the substance present in a certain volume of the solution is called ‘concentration’. More the concentration, more particles per volume exist in it and hence faster the reaction. Granulated zinc reacts faster with 2M hydrochloric acid than 1M hydrochloric acid.

Temperature

- Most of the reactions go faster at higher temperature. Because adding heat to the reactants provides energy to break more bonds and thus speed up the reaction. Calcium carbonate reacts slowly with hydrochloric acid at room temperature. When the reaction mixture is heated the reaction rate increases.

Food kept at room temperature spoils faster than that kept in the refrigerator. In the refrigerator, the temperature is lower than the room temperature and hence the reaction rate is less.

Pressure

- If the reactants are gases, increasing their pressure increases the reaction rate. This is because, on increasing the pressure the reacting particles come closer and collide frequently.

Catalyst

- A catalyst is a substance which increases the reaction rate without being consumed in the reaction. In certain reactions, adding a substance as catalyst speeds up the reaction. For example, on heating potassium chlorate, it decomposes into potassium chloride and oxygen gas, but at a slower rate. If manganese dioxide is added, it increases the reaction rate.

Surface area of the reactants

- When solid reactants are involve in a reaction, their powdered form reacts more readily. For example, powdered calcium carbonate reacts more readily with hydrochloric acid than marble chips. Because, powdering of the reactants increases the surface area and more energy is available on collision of the reactant particles. Thus, the reaction rate is increased.

STATE OF EQUILIBRIUM

- In a reversible reaction, both forward and backward reactions take place simultaneously. When the rate of the forward reaction becomes equal to the rate of backward reaction, then no more product is formed. This stage of the reaction is called 'equilibrium state'. After this stage, no net change in the reaction can occur and hence in the amount of the reactants and products. Since this equilibrium is attained in a chemical reaction, it is called 'Chemical Equilibrium'. Chemical Equilibrium: It is state of a reversible chemical reaction in which no change in the amount of the reactants and products takes place. At equilibrium,

Rate of forward reaction = Rate of backward reaction

Explanation:

- Initially the rate of the forward reaction is greater than the rate of the backward reaction. However, during the course of reaction, the concentration of the reactants decreases and the concentration of the products increases. Since the rate of a reaction is directly proportional to the concentration, the rate of the forward reaction decreases with time, whereas the rate of the backward reaction increases.

- At a certain stage, both the rates become equal. From this point onwards, there will be no change in the concentrations of both the reactants and the products with time. This state is called as equilibrium state.

- Let us consider the decomposition of calcium carbonate into lime and carbon dioxide. It is a reversible reaction. The speed of each reaction can be determined by how quickly the reactant disappears. If the reaction is carried out in a closed vessel, it reaches a chemical equilibrium. At this stage,

$$CaCO_{3(s)} \rightleftarrows CaO_{(s)} + CO_{2(g)}$$

- The rate of decomposition of $CaCO_3$ = The rate of combination of CaO and CO_2.

- Not only chemical changes, physical changes also may attain equilibrium. When water kept in a closed vessel evaporates, it forms water vapour. No water vapour escapes out of the container as the process takes place in a closed vessel. So, it builds up the vapour pressure in the container. At one time, the water vapour condenses back into liquid water and when the rate of this condensation becomes equal to that of vapourisation, the process attains equilibrium.

- At this stage, the volume of the liquid and gaseous phases remain constant. Since it is a physical change, the equilibrium attained is called 'Physical Equilibrium'. Physical equilibrium is a state of a physical change at which the volume of all the phases remain unchanged.

$$H2O_{(l)} \underset{\text{Condensation}}{\overset{\text{Evaporation}}{\rightleftarrows}} H_2O\ C_{(g)}$$

Characteristics of equilibrium .

- ❖ In a chemical equilibrium, the rates of the forward and backward reactions are equal.
- ❖ The observable properties such as pressure, concentration, colour, density, viscosity etc., of the system remain unchanged with time.

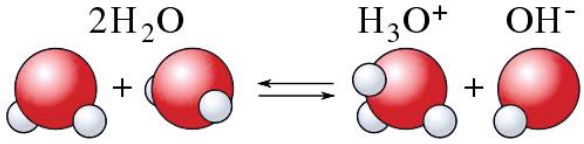
- The chemical equilibrium is a dynamic equilibrium, because both the forward and backward reactions continue to occur even though it appears static externally.
- In physical equilibrium, the volume of all the phases remain constant.

Aerated soft drinks contain dissolved carbon dioxide in a pop bottle (Soda). When the bottle is sealed, the dissolved carbon dioxide (in the form of carbonic acid) and gaseous CO2 are in equilibrium with each other. When you open the bottle, the gaseous CO2 can escape. So, the dissolved CO2 begins to undissolve back to the gas phase trying to replace the gas that was lost, when you opened the bottle. That's why if you leave it open long enough, it will goes 'flat'. All the CO2 will be gone, blown away in the

IONIC PRODUCT OF WATER

- Although pure water is often considered as a non-conductor of electricity, precise measurements show that it conducts electricity to a little extent. This conductivity of water has resulted from the self-ionisation of water. Self-ionisation or auto ionisation is a reaction in which two like molecules react to give ions. In the process of ionisation of water, a proton from one water molecule is transferred to another water molecule leaving behind an OH— ion. The proton gets dissolved in water forming the hydronium ion as shown in the following equation:

$$H2O_{(l)} + H_2O_{(l)} \rightleftarrows H_3O^+_{(aq)} + OH^-_{(aq)}$$



- The hydronium ion formed is a strong acid and the hydroxyl ion is a strong base. So as fast as they are formed, they react again to produce water. Thus, it is a reversible reaction and attains equilibrium very quickly. So, the extent of ionisation is very little and the concentration of the ions produced is also very less. The product of the concentration of the hydronium ion and the hydroxyl ion is called 'ionic product of water'. It is denoted as 'Kw'. It is mathematically expressed as follows:

$$K_w = [H_3O^+] [OH^-]$$

$[H3O^+]$ may be simply written as $[H^+]$. Thus the ionic product of water may also be expressed as

$$K_w = [H^+] [OH^-]$$

Its unit is $mol^2 dm^{-6}$. At 25° C, its value is 1.00×10^{-14}.

pH SCALE

- All the aqueous solutions may contain hydrogen and hydroxyl ions due to self-ionisation of water. In addition to this ionisation, substances dissolved in water also may produce hydrogen ions or hydroxyl ions. The concentration of these ions decides whether the solution is acidic or basic. pH scale is a scale for measuring the hydrogen ion concentration in a solution. The 'p' in pH stands for 'Potenz' in German meaning 'power'. pH notation was devised by the Danish biochemist Sorensen in 1909. pH scale is a set of numbers from 0 to 14 which is used to indicate whether a solution is acidic, basic or neutral.

  - Acids have pH less than 7
  - Bases have pH greater than 7
  - A neutral solution has pH equal to 7

The pH is the negative logarithm of the hydrogen ion concentration

$$pH = -\log_{10}[H^+]$$

Common Acids	**p^H**	**Common bases**	**p^H**
HCL(4%)	0	Blood plasma	7.4
Stomach acid	1	Egg white	8
Lemon juice	2	Sea water	9

Vinegar	3	Baking soda	10
Oranges	3.5	Antacids	10
Soda, Graps	4	Ammonia water	11
Sour milk	4.5	Lime water	12
Fresh Milk	5	Drain cleaner	13
Human saliva	6-8	Caustic soda 4% (NaOH)	14
Pure water	7	Milk of magnesia	10
Tomato juice	4.2	Coffee	5.6

How can we measure the pH of a given solution using pH Paper

- The pH of a solution can be determined by using a universal indicator. It contains a mixture of dyes. It comes in the form of a solution or a pH paper.

- A more common method of measuring pH in a school laboratory is by using the pH paper. A pH paper contains a mixture of indicators. It shows a specific colour at a given pH. A colour guide is provided with the bottle of the indicator or the strips of paper impregnated with it, which are called pH paper strips. The test solution is tested with a drop of the universal indicator, or a drop of the test solution is put on the pH paper. The colour of the solution on the pH paper is compared with the colour chart and the pH value is read from it. The pH values thus obtained are only approximate values.

ROLE OF pH IN EVERYDAY LIFE
Are plants and animals pH sensitive?

- Our body works within the pH range of 7.0 to 7.8. Living organisms can survive only in a narrow range of pH change. Different body fluids have different pH values. For example, pH of blood is ranging from 7.35 to 7.45. Any increase or decrease in this value leads to diseases. The ideal pH for blood is 7.4.

pH in our digestive system

- It is very interesting to note that our stomach produces hydrochloric acid. It helps in the digestion of food without harming the stomach. During indigestion the stomach produces too much acid and this causes pain and irritation. pH of the stomach fluid is approximately 2.0.

pH changes as the cause of tooth decay

- pH of the saliva normally ranges between 6.5 to 7.5. White enamel coating of our teeth is calcium phosphate, the hardest substance in our body. When the pH of the mouth saliva falls below 5.5, the enamel gets weathered. Toothpastes, which are generally basic are used for cleaning the teeth that can neutralise the excess acid and prevent tooth decay.

pH of soil

- In agriculture, the pH of the soil is very important. Citrus fruits require slightly alkaline soil, while rice requires acidic soil and sugarcane requires neutral soil.

pH of rain water

- The pH of rain water is approximately 7, which means that it is neutral and also represents its high purity. If the atmospheric air is polluted with oxide gases of sulphur and nitrogen, they get dissolved in the rain water and make its pH less than 7. Thus, if the pH of rain water is less than 7, then it is called acid rain. When acid rain flows into the rivers it lowers the pH of the river water also.

pH CALCULATION

The pH is the negative logarithm of the hydrogen ion concentration

$$pH = -\log_{10} [H^+]$$

Example:

Calculate the pH of 0.01 M HNO_3?

Solution:

$[H^+] = 0.01$
$pH = -\log_{10} [H^+]$
$pH = -\log_{10} [0.01]$
$pH = -\log_{10} [1 \times 10^{-2}]$
$pH = -(\log_{10}1 - 2 \log_{10}10)$
$pH = 0 + 2 \times \log_{10}10$
$pH = 0 + 2 \times 1 = 2$
$pH = 2$

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pOH:

- The pOH of an aqueous solution is realted to the pH.

The pOH is the negative logarithm of the hydroxyl ion concentration

$$pOH = -\log_{10}[OH^-]$$

Example:

- The hydroxyl ion concentration of a solution is 1×10^{-9}M. What is the pOH of the solution?

Solution

$pOH = -\log_{10} [OH^-]$
$pOH = -\log_{10} [1 \times 10^{-9}]$
$pOH = -(\log_{10} 1.0 + \log10\ 10^{-9})$
$pOH = -(0-9 \log_{10}10)$
$pOH = -(0 - 9)$
$pOH = 9$

Relationship between pH and pOH

- The pH and pOH of a water solution at 25oC are related by the following equation.

pH + pOH = 14

- If either the pH or the pOH of a solution is known, the other value can be calculated.

Example: A solution has a pOH of 11.76. What is the pH of this solution?

$$pH = 14 – pOH$$
$$pH = 14 – 11.76 = 2.24$$

PROBLEMS

Example 1:

Calculate the pH of 0.001 molar solution of HCl.

- **Solution:**

HCl is a strong acid and is completely dissociated in its solutions according to the process:

$$HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$$

From this process it is clear that one mole of HCl would give one mole of H^+ ions. Therefore, the concentration of H+ ions would be equal to that of HCl, i.e., 0.001 molar or 1.0×10^{-3} mol litre^{-1}.

Thus, $[H^+] = 1 \times 10–3$ mol litre^{-1}

$pH = –log10[H^+] = –log1010^{-3} = –(–3 \times log_{10}) = –(3 \times 1) = 3$

Thus, pH = 3

Example 2:

What would be the pH of an aqueous solution of sulphuric acid which is 5×10^{-5} mol litre^{-1} in concentration.

- **Solution:**

Sulphuric acid dissociates in water as:

$$H2SO_{4(aq)} \rightarrow 2\ H^{+}_{(aq)} + SO^{2-}{}_{4(aq)}$$

Each mole of sulphuric acid gives two mole of H^+ ions in the solution. One litre of H_2SO_4 solution contains 5×10^{-5} moles of H_2SO_4 which would give 2 × 5 × 10–5 = 10 × 10–5 or 1.0×10^{-4} moles of H^+ ion in one litre of the solution.

Therefore,

$[H+] = 1.0 \times 10^{-4}$ mol litre^{-1}

$pH = -\log_{10}[H^+] = -\log_{10}10^{-4} = -(-4 \times \log_{10}10) = -(-4 \times 1) = 4$

Example 3:

Calculate the pH of 1 × 10–4 molar solution of NaOH.

- **Solution:**

NaOH is a strong base and dissociates in its solution as:

$$NaOH_{(aq)} \rightarrow Na^{+}_{(aq)} + OH^{-}_{(aq)}$$

One mole of NaOH would give one mole of OH– ions. Therefore,

$$[OH^-] = 1 \times 10^{-4} \text{ mol litre}^{-1}$$

$$pOH = -\log_{10}[OH^-] = -\log_{10} \times [10^{-4}]$$

$= -(-4 \times \log_{10}10) = -(-4) = 4$

Since, pH + pOH = 14

pH = 14 – pOH = 14 – 4= 10

Example 4:

Calculate the pH of a solution in which the concentration of the hydrogen ions is 1.0×10^{-8} mol $litre^{-1}$.

- **Solution:**

Here, although the solution is extremely dilute, the concentration given is not of an acid or a base but that of H^+ ions. Hence, the pH can be calculated from the relation:

pH = –log10[H^+]
given [H^+] = 1.0×10^{-8} mol $litre^{-1}$
pH = $-\log_{10}10^{-8} = -(-8 \times \log_{10}10)$
$= -(-8 \times 1) = 8$

Example 5:

If the pH of a solution is 4.5, what is its pOH?

Solution:

pH + pOH = 14
pOH = 14 – 4.5 = 9.5
pOH = 9.5