APPOLO STUDY CENTRE
CHENNAI

APPOLO STUDY CENTRE

PHYSICS
TEST – 6

10th science	Unit 9	Solutions
	Unit 10	Types Of Chemical Reactions
	Unit 11	Carbon And Its Compounds
11th physics	Unit 1	Nature Of Physical World And Measurement

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 '**concentratedsolution' 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$=\frac{\text{mass of the solve}}{\text{mass of the solvent}} \times 100$

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 containingaqueous 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 $= \frac{\text{mass of the solute}}{\text{mass of the solution}} \times 100$

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

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 $= \frac{\text{volume of the solute}}{\text{volume of the solution}} \times 100$

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

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 dihydrate	$CaSO_4.2H_2O$
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 watermolecules 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 atmosphericair 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 = $\frac{37}{100}\times 60$ =22.2g
60 g of water in saturated solution

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

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 nitratedissolving in 50 g of water at 50°C is

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

Similarly amount of sodium nitratedissolving 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

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

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

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

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

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

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

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

$$= \frac{1600}{116}$$

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?

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

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

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

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

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

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

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

$$= 35\%$$

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%

$$\text{VolumePercentage} = \frac{volume\ of\ the\ solute}{volume\ of\ the\ solution} \times 100$$

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

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

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 notequal 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.

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

Depending on the chemical nature of the reactants, there are threeclassesof 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.

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.

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

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 schemeof 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'.

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

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 ofreactants. 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:

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 isanother 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.

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 flame 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 aregrouped 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.

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

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.

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

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 themain 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 gof 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. Forexample, 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,

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

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.

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

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:

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

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}.

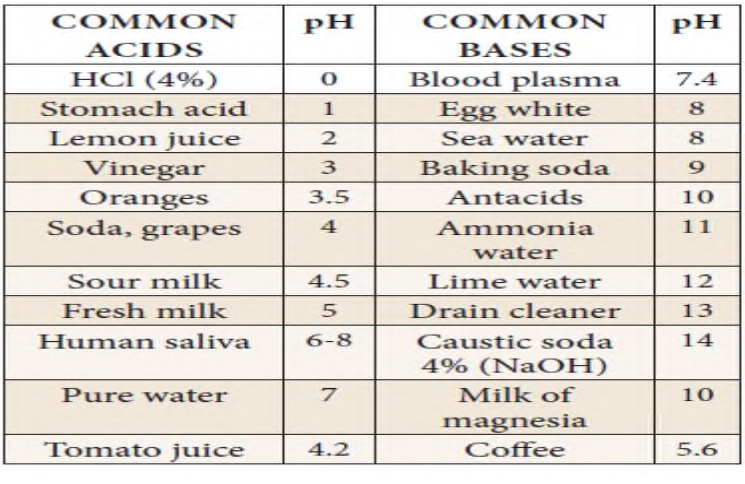
pH SCALE

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	pH	COMMON BASES	pH
HCl (4%)	0	Blood plasma	7.4
Stomach acid	1	Egg white	8
Lemon juice	2	Sea water	8
Vinegar	3	Baking soda	9
Oranges	3.5	Antacids	10
Soda, grapes	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:

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

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,

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

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

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

$$\text{Since, } pH + pOH = 14$$

$$pH = 14 - pOH = 14 - 4 = 10$$

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

= –(–8 × 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

10th book
Unit – 11 CARBON AND ITS COMPOUNDS

INTRODUCTION

You have studied, in your lower classes, that carbon is an inseparable element in human life as we use innumerable number of carbon compounds in our day to day life. Because, the food we eat, medicines we take when ill, clothes we wear; domestic and automobile fuels, paint, cosmetics, automobile parts, etc., that we use contain carbon compounds. The number of carbon compounds found in nature and man-made, is much higher than that of any other element in the periodic table. Infact there are more than 5 million compounds of carbon. The unique nature of carbon, such as catenation, tetravalency and multiple bonding, enables it to combine with itself or other elements like hydrogen, oxygen, nitrogen,sulphur etc., and hence form large number of compounds. All these compounds are made of covalent bonds. These compoundsare called **organic compounds.** In this lesson, you will learn about carbon compounds.

GENERAL CHARACTERISTICS OF ORGANIC COMPOUNDS

Everything in this world has unique character, similarly organic compounds are unique in their characteristics. Some of them are given below:

- Organic compounds have a high molecular weight and a complex structure.
- They are mostly insoluble in water, but soluble in organic solvents such as ether, carbon tetrachloride, toluene, etc.
- They are highly inflammable in nature
- Organic compounds are less reactive compared to inorganic compounds. Hence, the reactions involving organic compounds proceed at slower rates.
- Mostly organic compounds form covalent bonds in nature.
- They have lower melting point and boiling point when compared to inorganic compounds
- They exhibit the phenomenon of isomerism, in which a single molecular formula represents several organic compounds that differ in their physical and chemical properties
- They are volatile in nature.
- Organic compounds can be prepared in the laboratory

CLASSIFICATION OF ORGANIC COMPOUNDS BASED ON THE PATTERN OF CARBON CHAIN

What is the significance of classification? There are millions of organic compounds known and many new organic compounds are discovered every year in nature or synthesized in laboratory. This may mystify organic chemistry to a large extent. However, a unique molecular structure can be assigned to each compound and it can be listed by using systematic methods of classification and eventually named on the basis of its structural arrangements. In early days, chemists recognised that compounds having similar structural features have identical chemical properties. So they began to classify compounds based on the common structural arrangements found among them.

Organic chemistry is the chemistry of catenated carbon compounds. The carbon atoms present in organic compounds are linked with each other through covalent bonds and thus exist as chains. By this way, organic compounds are classified into two types as follows:

1. **Acyclic or Open chain compounds:**

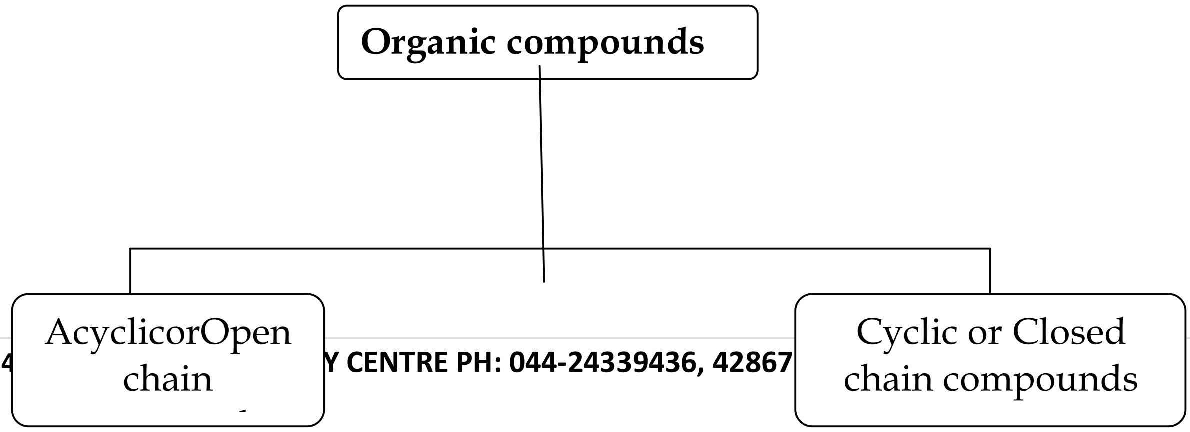
   These are the compounds in which the carbon atoms are linked in a linear pattern to form the chain. If all the carbon atoms in the chain are connected by single bonds, the compound is called as saturated. If one or more double bonds or triple bonds exist between the carbon atoms, then the compound is said to unsaturated.

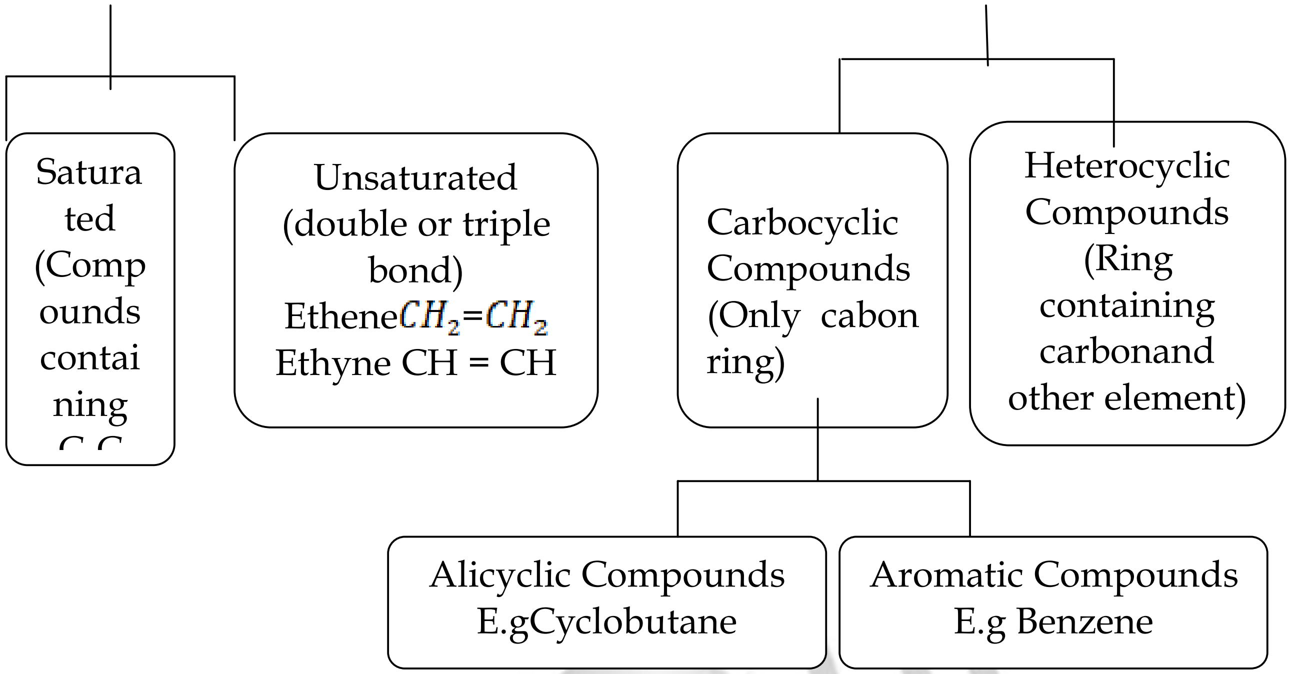
CH3-CH2-CH3 **Propene** **Unsaturated compound**	**CH3-CH=CH2** **Propane** **Saturated compound**

2. **Cyclic Compounds:**

   Organic compounds in which the chain of carbon atoms is closed or cyclic are called **cyclic compounds.** If the chain contains only carbon atoms, such compounds are called **carbocyclic compounds.** If the chain contains carbon and other atoms like oxygen, **compounds.** Carbocyclic compounds are further subdivided into **alicyclic** and **aromatic compounds.** Alicyclic compounds contain one or more carbocyclic rings which may be saturated or unsaturated whereas aromatic compounds contain one or more benzene rings (ring containing alternate double bonds between carbon atoms). E.g.

Figure 11.1 depicts the classification of organic compounds based on the pattern of carbon arrangements and their bonding in organic compounds:





Classification of organic compounds

CLASSES OF ORGANIC COMPOUNDS (BASED ON THE KIND OF ATOMS)

Other than carbon, organic compounds contain atoms like hydrogen, oxygen, nitrogen, etc., bonded to the carbon. Combination of these kinds of atoms with carbon gives different classes of organic compounds. In the following section, let us discuss various classes of organic compounds.

Hydrocarbons

The organic compounds that are composed of only carbon and hydrogen atoms are called **hydrocarbons.** The carbon atoms join together to form the framework of the compounds. These are regarded as the parent organic compounds and all other compounds are considered to be derived from hydrocarbons by replacing one or more hydrogen atoms with other atoms or group of atoms. Hydrocarbons are, further, sub divided into three classes such as:

(a) Alkanes: These are hydrocarbons, which contain only single bonds. They are represented by the general formula **CnH2n + 2** (where n = 1,2, 3, ……). The simplest alkane (for n=1) is methane (CH4). Since, all are single bonds in alkanes, they are saturated compounds.

(b) Alkenes: The hydrocarbons, which contain one or more C=C bonds are called alkenes. These are unsaturated compounds. They are represented by the general formula **CnH2n.** The simplest alkene contains two carbon atoms (n=2) and is called ethylene (C2H4).

(c) Alkynes: The hydrocarbons containing carbon to carbon triple bond are called **alkynes.** They are also unsaturated as they contain triple bond between carbon atoms. They have the general formula **C_nH_{2n-2}.** Acetylene (C_2H_2) is the simplest alkyne, which contains two carbon atoms. Table 11.1 lists the first five hydrocarbons of each class:

Hydrocarbons containing 1to 5 carbon atoms

No. of carbon atoms	Alkane (C_nH_{2n+2})	Alkene (C_nH_{2n})	Alkyne (C_nH_{2n-2})
1	Methane (CH_4)	-	-
2	Ethane (C_2H_6)	Ethene (C_2H_4)	Ethyne (C_2H_2)
3	Propane (C_3H_8)	Propene (C_3H_6)	Propyne (C_3H_4)
4	Butane (C_4H_{10})	Butene (C_4H_8)	Butyne (C_4H_6)
5	Pentane (C_5H_{12})	Pentene (C_5H_{10})	Pentyne (C_5H_8)

Characteristics of hydrocarbons:

- Lower hydrocarbons are gases at room temperature E.g. methane, ethane are gases.
- They are colourless and odourless.
- The boiling point of hydrocarbons increases with an increase in the number of carbon atoms.
- They undergo combustion reaction with oxygen to form CO_2 and water.
- Alkanes are least reactive when compared to other classes of hydrocarbons.
- Alkynes are the most reactive due to the presence of the triple bond.
- Alkanes are saturated whereas alkenes and alkynes are unsaturated.
- They are insoluble in water.

Test to identify saturated and unsaturated compounds:

- Take the given sample solution in a test tube.
- Add a few drops of bromine water and observe any characteristic change in colour.
- If the given compound is unsaturated, it will decolourise bromine water.
- Saturated compounds do not decolourise bromine.

Test to identify unsaturated compounds

Classification of organic compounds based on functional groups

The structural frameworks of organic compounds are made of carbon and hydrogen, which are relatively less reactive. But, the presence of some other atoms or group of atoms makes the compounds more reactive and thus determines the chemical properties of the compound. These groups are called **functional groups.**

A functional group is an atom or group of atoms in a molecule, which gives its characteristic chemical properties.

The chemical properties of an organic compound depend on its functional group whereas its physical properties rely on remaining part of the structure. Carbon to carbon multiple bonds (C=C, C C) also are considered as functional groups as many of the properties are influenced by these bonds. Other functional groups include atoms of halogens, –OH, –CHO, –COOH, etc.

For example, ethane is a hydrocarbon having molecular formula C2H6. If one of its hydrogen is replaced by –OH group, you will get an alcohol. Leaving the functional group, the rest of the structure is represented by '**R'.** Thus an alcohol is represented by 'R-OH'

$CH_3 - CH_3CH_3 - CH_2 -$ $\boxed{OH}$ ← Functional Group

Ethane Ethanol

HydrocarbonAlcohol

A series of compounds containing the same functional group is called a **class of organic compounds.** Table 11.2 shows various classes or families of organic compounds and their functional groups:

Classes of organic compounds based on functional group

Class of the compound	Functional group	Common Formula	Examples
Alcohols	-OH	R-OH	Ethanol, CH_3CH2_2OH
Aldehydes	$-\overset{\text{O}}{\overset{\Vert}{\text{C}}}-\text{H}$	R-CHO	Acetaldehyde, CH_3CHO
Ketones	$-\overset{\text{O}}{\overset{\Vert}{\text{C}}}-$	R–CO-R	Acetone, CH_3COCH_3
Carboxylic acids	$-\overset{\text{O}}{\overset{\Vert}{\text{C}}}-\text{OH}$	R-COOH	Acetic acid, CH_3COOH
Ester	$-\overset{\text{O}}{\overset{\Vert}{\text{C}}}-\text{OR}$	R-COOR	Methyl acetate, CH_3COOCH_3

Ether	–O–R	R-O-R	Dimethyl ether, CH_3OCH_3

HOMOLOGOUS SERIES

Homologous series is a group or a class of organic compounds having same general formula and similar chemical properties in which the successive members differ by a - CH2 group.

Let us consider members of alkanes given in Table 11.1. Their condensed structural formulas are given below:

Methane - CH4
Ethane - CH3CH3
Propane - CH3CH2CH3
Butane - CH3(CH2)2CH3
Pentane - CH3(CH2)3CH3

If you observe the above series.you can notice that each successive member has one methylene group more than the precedent member of the series and hence they are called homologs.

Characteristics of homologous series

- Each member of the series differs from the preceding or succeeding member by one methylene group (–CH2) and hence by a molecular mass of 14 amu.
- All members of a homologous series contain the same elements and functional group.
- They are represented by a general molecular formula. e.g. Alkanes, CnH2n + 2.
- The members in each homologous series show a regular gradation in their physical properties with respect to their increase in molecular mass.
- Chemical properties of the members of a homologous series are similar.
- All the members can be prepared by a common method.

NOMENCLATURE OF ORGANIC COMPOUNDS

Why do we need nomenclature?

In ancient days, the names of organic compounds were related to the natural things from which they were obtained. For example, the formic acid was initially obtained by distillation of 'red ants'. Latin name of the red ant is 'Formica'. So, the name of the formic acid was derived from the Latin name of its source Later, the organic compounds were synthesized from sources other than the natural sources. So scientists framed a systematic method for naming the organic compounds based on their structures. Hence, a set of rules was formulated by IUPAC **(International Union of Pure and Applied Chemistry)** for the nomenclature of chemical compounds.

Components of an IUPAC name

The IUPAC name of the any organic compound consists of three parts:
i. Root word
ii. Prefix
iii. Suffix
These parts are combined as per the following sequence to get the IUPAC name of the compound:

(i) Root word: It is the basic unit, which describes the carbon skeleton. It gives the number of carbon atoms present in the parent chain of the compound and the pattern of their arrangement. Based on the number of carbon atoms present in the carbon skeleton, most of the names are derived from Greek numerals (except the first four). Table 11.3 shows the root words for the parent chain of hydrocarbons containing 1to10 carbon atoms:

Root words of hydrocarbons

No. of carbon atoms	**Root word**
1	Meth-
2	Eth-
3	Prop-
4	But-
5	Pent-
6	Hex-
7	Hept-
8	Oct-
9	Non-
10	Dec-

(ii) Prefix: The prefix represents the substituents or branch present in the parent chain. Atoms or group of atoms, other than hydrogen, attached to carbon of the parent chain are called substituents. Table 11.4 presents the major substituents of organic compounds and respective prefix used for them:

Prefix for IUPAC Name

Substituent	**Prefix used**
-F	**Fluoro**
-Cl	**Chloro**
-Br	**Bromo**
-I	**Iodo**
-NH2	**Amino**
-CH3	**Methyl**
-CH2CH3	**Ethyl**

(iii) Suffix

The suffix forms the end of the name. It is divided into two parts such as
(a) Primary suffix and
(b) Secondary suffix.

The primary suffix comes after the root word. **It represents the nature in carbon to carbon bonding of the parent chain**. If all the bonds between the carbon atoms of the parent chain are single, then suffix **'ane'** has to be used. Suffix **'ene'** and **'yne'** are used for the compounds containing double
and triple bonds respectively. The secondary suffix describes the functional group of the compound.

Suffix for IUPAC Name

Class of the Compound	Functional group	Suffix used
Alcohols	−OH	-ol
Aldehydes	−CHO	-al
Ketones	O || −C−	-one
Carboxylic acids	−COOH	-oic acid

IUPAC rules for naming organic compounds:

- **Rule1:** Identify the longest chain of carbon atoms to get the parent name (root word).
- **Rule 2:** Number the carbon atoms of the parent chain, **beginning at the closest end of the substituent or functional group**. These are called **locant numbers**. *If both functional group and substituent are present, then the priority will be given to the functional group.*
- **Rule 3:** In case of alkenes and alkynes, locate the double bond or triple bond and use its locant number followed by a dash and a primary suffix. The carbon chain is numbered in such a way that the multiple bonds have the lowest possible locant number.
- **Rule 4:** If the compound contains functional group, locate it and use its locant number followed by a dash and a secondary suffix.
- **Rule 5:** When the primary and secondary suffixes are joined, the terminal 'e' of the primary suffix is removed.
- **Rule 6:** Identify the substituent and use a number followed by a dash and a prefix tospecify its location and identity.

IUPAC Nomenclature of hydrocarbons – Solved examples

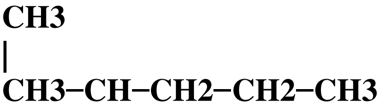
Let us try to name, systematically, some of the linear and substituted hydrocarbons by following IUPAC rules:

Example 1:CH3-CH2-CH2-CH2-CH3

Step 1: It is a five- carbon chain and hence the root word is 'Pent'. (Rule 1)

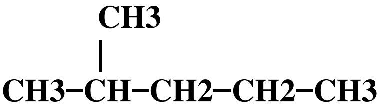
Step 2: All the bonds between carbon atoms are single bonds, and thus the suffix is 'ane'.
So, its name is Pent + ane = Pentane

Example 2:



$$\begin{array}{l} CH_3 \\ | \\ CH_3-CH-CH_2-CH_2-CH_3 \end{array}$$

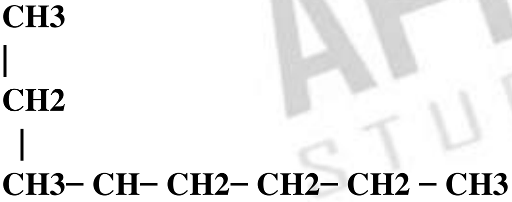
Step 1: The longest chain contains five carbon atoms and hence the root word is 'Pent'.
Step 2: There is a substituent. So, the carbon chain is numbered from the left end, which is closest to the substituent. (Rule 2)



$$\begin{array}{l} \quad\;\; CH_3 \\ \quad\;\; | \\ CH_3-CH-CH_2-CH_2-CH_3 \end{array}$$

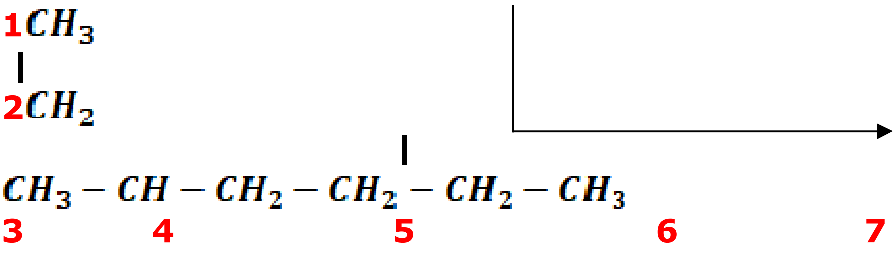
Step 2: All are single bonds between the carbon atoms and thus the suffix is 'ane'.
Step 3: The substituent is a methyl group and it is located at second carbon atom. So, its locant number is 2. Thus the prefix is '2-Methyl'. (Rule 6).
The name of the compound is
2-Methyl + pent +ane = 2-Methylpentane

Example 3:



$$\begin{array}{l} CH_3 \\ | \\ CH_2 \\ \;| \\ CH_3-CH-CH_2-CH_2-CH_2-CH_3 \end{array}$$

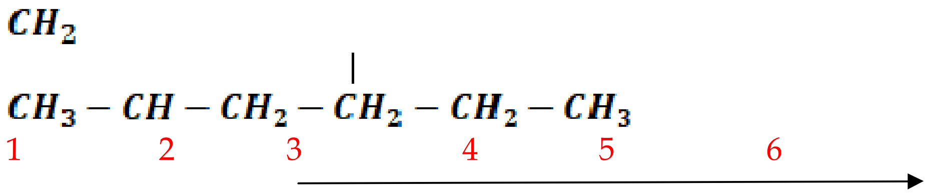
Step 1: The longest chain contains seven carbon atoms and hence the root word is 'Hept'.
Step 2: There is a substituent. So, thecarbon chain is numbered from the end, which is closest to substituent. (Rule 2)



$$\begin{array}{l} 1CH_3 \\ \;| \\ 2CH_2 \\ CH_3-CH-CH_2-CH_2-CH_2-CH_3 \end{array}$$

CORRECT

$$\begin{array}{l} CH_3 \\ \qquad\qquad | \end{array}$$



$$\begin{array}{l} CH_2 \\ \qquad\qquad\qquad\quad | \\ CH_3-CH-CH_2-CH_2-CH_2-CH_3 \end{array}$$

WRONG

Step 2: All are single bonds between the carbon atoms and thus the suffix is 'ane'.
Step 3: The substituent is a methyl group and it is located at third carbon. So, its locant number is 3. Thus the prefix is '3-Methyl'. (Rule 6)
Hence the name of the compound is **3-Methyl + hept + ane = 3 –Methylheptane**

Example 4: CH3-CH2-CH2-CH=CH2
Step 1: It is a 'five- carbon atoms chain' and hence the root word is 'Pent'. (Rule 1)
Step 2: There is a carbon to carbon double bond. The suffix is 'ene'.
Step 3: The carbon chain is numbered from the end such that double bond has the lowest locant number as shown below: (Rule 3)

5 4 3 2 1
CH3-CH2-CH2-CH=CH2

Step 4: The locant number of the double bond is 1 and thus the suffix is '-1-ene'. So, the name of the compound is **Pent + (-1-ene) = Pent-1-ene**

IUPAC Nomenclature of other classes – Solved examples
Example 1: CH3-CH2-CH2-OH

Step1: The parent chain consists of 3 carbon atoms. The root word is 'Prop'.
Step 2: There are single bonds between the carbon atoms of the chain. So, the primary suffix is 'ane'.
Step 3: Since, the compound contains – OH group, it is an alcohol. The carbon chain is numbered from the end which is closest to –OH group. (Rule 3)

3 2 1
CH3– CH2– CH2– OH

Step 4: The locant number of –OH group is 1 and thus the secondary suffix is '1-ol'.
The name of the compound is **Prop + ane + (1-ol) = Propan-1-ol**
Note: Terminal 'e' of 'ane' is removed as per Rule 5

Example 2: CH3COOH
Step1: The parent chain consists of 2 carbon atoms. The root word is 'Eth'.

Step 2: All are single bonds between the carbon atoms of the chain. So the primary suffix is ‘ane’.
Step 3: Since the compound contains the–COOH group, it is a carboxylic acid. The secondary suffix is ‘oic acid’
The name of the compound is Eth + ane + oic acid) = Ethanoic acid
Table 11.6 lists IUPAC names homologs of various classes of organic compounds

Test yourself:
Obtain the IUPAC name of the following compounds systematically:

(a) CH3CHO
(b) CH3CH3COCH3
(c) ClCH2-CH2-CH2-CH3

No. of carbons atoms	**IUPAC Name**			
	Alcohols	**Aldehydes**	**Ketones**	**Carboxylic acid**
1	**Methanol (CH3OH)**	**Methanal (HCHO)**	**-**	**Methanoic acid (HCOOH)**
2	**Ethanol (CH3CH2OH)**	**Ethanal (CH3CHO)**	**-**	**Ethanoic acid (CH3COOH)**
3	**Propanol (CH3CH2CH2OH)**	**Propanal (CH3CH2CHO)**	**Propanone CH3COCH3**	**Propanoic acid CH3CH2COOH**
4	**Butanol CH3CH2CH2CH2H**	**Butanal CH3CH2CH2CO**	**Butanone CH3COCH2CH3**	**Butanoic acid (CH3CH2CH2COOH)**
5	**Pentanol(CH3CH2CH2CH2 CH2OH)**	**Pentanal(CH3 CH2CH2CH2 CHO)**	**Pentanone(CH3 COCH2CH2 CH3)**	**Pentanoic acid (CH3CH2CH2CH2 COOH)**

ETHANOL (CH3CH2OH)

Ethanol is commonly known as alcohol. All alcoholic beverages and some cough syrups contain ethanol. Its molecular formula is C2H5OH. Its structural formula is

Ethanol

H H

| |

H-C-C-O-H

| | C_2H_5OH

H H

Manufacture of ethanol

Ethanol is manufactured in industries by the fermentation of molasses, which is a by-product obtained during the manufacture of sugar from sugarcane. Molasses is a dark coloured syrupy liquid left after the crystallization of sugar from the concentrated sugarcane juice. Molasses contain about 30% of sucrose, which cannot be separated by crystallization. It is converted into ethanol by the following steps:

(i) Dilution of molasses

Molasses is first diluted with water to bring down the concentration of sugar to about 8 to 10 percent.

(ii) Addition of Nitrogen source

Molasses usually contains enough nitrogenous matter to act as food for yeast during the fermentation process. If the nitrogen content of the molasses is poor, it may be fortified by the addition of ammonium sulphate or ammonium phosphate.

(iii) Addition of Yeast

The solution obtained in step (ii) is collected in large 'fermentation tanks' and yeast is added to it. The mixture is kept at about 303K for a few days. During this period, the enzymes invertase and zymase present in yeast, bring about the conversion of sucrose into ethanol.

invertase

$$C_{12}H_{22}O_{11}+H_2OC_6H_{12}O_6+C_6H_{12}O_6 \longrightarrow$$

Sugar glucose fructose

zymase

$$C_6H_{12}O_6 2C_2H_5OH+2CO_2 \longrightarrow$$

Glucose or fructose ethanol

The fermented liquid is technically called **wash**.

(iv) Distillation of 'Wash'

The fermented liquid (i.e. wash), containing 15 to 18 percent alcohol, is now subjected to fractional distillation. The main fraction drawn is an aqueous solution of ethanol which contains95.5% of ethanol and 4.5% of water. This is called rectified spirit. This mixture is then refluxed over quicklime for about 5 to 6 hours and then allowed to stand for 12 hours. On distillation of this mixture, pure alcohol (100%) is obtained. This is called absolute alcohol.

Yeast and Fermentation: Yeasts are single–celled microorganisms, belonging to the class of fungi. The enzymes present in yeasts catalyse many complex organic reactions. Fermentation is conversion of complex organic molecules into simpler molecules by the action of enzymes. E.g. Curdling of milk

Physical properties

i) Ethanol is a colourless liquid, having a pleasant smell and a burning taste.
ii) It is a volatile liquid. Its boiling point is 780 C (351K), which is much higher than that of its corresponding alkane, i.e. ethane (Boiling Point = 184 K).
iii) It is completely miscible with water in all proportions.

Chemical Properties

(i) Dehydration (Loss of water)

When ethanol is heated with con H2SO4 at 443K, it loses a water molecule i.e. dehydrated to form ethene.

conc H2SO4

CH3CH2OHCH~~2 = CH2 + H2O~~ →
Ethanol 443k ethane

(ii) **Reaction with sodium**:
Ethanol reacts with sodium metal to form sodium ethoxide and hydrogen gas.

2C2H5OH + 2Na2C2~~H5ONa + H2 ↑~~ →
Sodium ethoxide

(iii) **Oxidation:**
Ethanol is oxidized to ethanoic acid with alkaline KMnO4 or acidified K2Cr2O7

K2Cr2O7 / H^+
CH3CH2OHCH3~~COOH +H2O~~ →
2[O]ethanoic acid

cu

Uses of ethanol CH3CH2OH ⟶ 573k CH3CHO + H2↑

Ethanol is used

- in medical wipes, as an antiseptic.
- as an anti-freeze in automobile radiators.
- for effectively killing micro organisms like bacteria, fungi, etc., by including it in many hand sanitizers.
- as an antiseptic to sterilize wounds in hospitals.
- as a solvent for drugs, oils, fats, perfumes, dyes, etc.

During this reaction, the orange colour of K2Cr2O7 changes to green. Therefore, this reaction can be used for the identification of alcohols.

(iv) **Esterification:**

The reaction of an alcohol with a carboxylic acid gives a compound having fruity odour. This compound is called an **ester** and the reaction is called esterification. Ethanol reacts with ethanoic acid in the presence of conc. H2SO4 to form ethyl ethanoate, an ester.

conc H2SO4

C2H5OH + CH3COOHCH3COOC2H5 + H2O ⟶

Ethanol Ethanoic acid Ethyl ethanoate

(v) **Dehydrogenation:**

When the vapour of ethanol is passed over heated copper, used as a catalyst at 573 K, it is dehydrogenated to acetaldehyde.

Ethanol Acetaldehyde

vi) **Combustion:**

Ethanol is highly inflammable liquid. It burns with oxygen to form carbon dioxide and water.

C2H5OH + 3O22CO2 + 3H2O ⟶

Ethanol Carbondioxide

to enhance the flavour of food extracts, for example vanilla extract; a common food flavour, which is made by processing vanilla beans in a solution of ethanol and water

in the preparation of methylated spirit (mixture of 95% of ethanol and 5% of methanol) rectified spirit (mixture of 95.5% of ethanol and 4.5% of water), power alcohol (mixture of petrol and ethanol) and denatured spirit (ethanol mixed with pyridine).

ETHANOIC ACID (CH_3COOH)

Ethanoic acid or acetic acid is one of the most important members of the carboxylic acid family. Its molecular formula is C2H4O2. Its structural formula is

```
   H  O
   |  ||
H--C--C—OH
```

|
H

Manufacture of ethanoicacid

Ethanoic acid is prepared in large scale, by the oxidation of ethanol in the presence of alkaline potassium permanganate or acidified potassium dichromate.

KMnO4/OH-
CH3CH2OH2[O]~~CH3COOH + H2O~~→
Ethanol Ethanoic acid

Physical Properties

(i) Ethanoic acid is a colourless liquid having an unpleasant odour.
(ii) It is sour in taste.
(iii) It is miscible with water in all proportions.

Chemical Properties
(i) **Reaction with metal:** Ethanoic acid reacts with active metals like Na, Zn, etc., to liberate hydrogen and form sodium ethanoate.

2CH3COOH + Zn → (CH3COO)2 Zn + H2 ↑
2CH3COOH + 2Na → 2CH3COONa + H2 ↑

ii) Reaction with carbonates and **bicarbonates:** Ethanoic acid reacts with sodium carbonate and sodium bicarbonate, which are weaker bases and liberates CO2, with brisk effervescence.
2CH3COOH + Na2CO3 → 2CH3COONa + CO2↑ + H2O

Uses of ethanoic acid

Acetic acid, in lower concentration, is used as a food additive, a flavoring agent and a preservative.

Ethanoic acid is used

- in the manufacture of plastic.
- in making dyes, pigments and paint.
- in printing on fabrics.
- as a laboratory reagent.
- for coagulating rubber from latex.
- in the production of pharmaceuticals.

ORGANIC COMPOUNDS IN DAILY LIFE

Organic compounds are inseparable in human life. They are used by mankind or associated at all stages of life right from one's birth to death. Various classes of organic compounds and their uses in our daily life as follows:
Hydrocarbons

- Fuels like LPG, Petrol, Kerosene.
- Raw materials for various important synthetic materials.
- Polymeric materials like tyre, plastic containers.

Soap

Soaps and the Detergents are materials that are used by us for cleaning purposes because pure water alone cannot remove all types of dirt or any oily substance from our body or clothes. They contain 'surfactants', which are compounds with molecules that line up around water to break the 'surface tension'. Both of them having a different chemical nature. Soap is a cleaning agent that is composed of one or more salts of fatty acids. Detergent is a chemical compound or a mixture of chemical compounds, which is used as a cleaning agent, also. They perform their cleaning actions in certain specific conditions. You will learn more about this in detail, in the following units

Soaps are sodium or potassium salts of some long chain carboxylic acids, called fatty acids. Soap requires two major raw materials: i) fat and ii) alkali. The alkali, most commonly used in the preparation of soap is sodium hydroxide. Potassium hydroxide can also be used. A potassium-based soap creates a more water-soluble product than a sodium-based soap. Based on these features, there are two types of soaps:

A. HARD SOAP

Soaps, which are prepared by the ***saponification of oils or fats with caustic soda*** (sodium hydroxide), are known as hard soaps. They are usually used for washing purposes.

B. SOFT SOAP
Soaps, which are prepared by the ***saponification of oils or fats with potassium salts***, are known as soft soaps. They are used for cleansing the body.

Manufacture of soap
KETTLE PROCESS:

This is the oldest method. But, it is still widely used in the small scale preparation of soap. There are mainly, two steps to be followed in this process.

i) Saponification of oil:
The oil, which is used in this process, is taken in an iron tank (kettle). The alkaline solution (10%) is added into the kettle, a little in excess. The mixture is boiled by passing steam through it. The oil gets hydrolysed after several hours of boiling. This process is called Saponification

ii) Salting out of soap:
Common salt is then added to the boiling mixture. Soap is finally precipitated in the tank. After several hours the soap rises to the top of the liquid as a 'curdy mass'. The neat soap is taken off from the top. It is then allowed to cool down

Effect of hard water on soap

Hard water contains calcium and magnesium ions (Ca2+ and Mg2+) that limit the cleaning action of soap. When combined with soap, hard water develops a thin layer (precipitates of the metal ions) called 'scum', which leaves a deposit on the clothes or skin and does not easily rinse away. Over time, this can lead to the deterioration of the fabric and eventually ruin the clothes. On the other hand, detergents are made with chemicals that are not affected by hard water.

Detergents

Development of synthetic detergents is a big achievement in the field of cleansing.These soaps possess the desirable properties of ordinary soaps and also can be used with hard water and in acidic solutions. These are salts of sulphonic acids or alkyl hydrogen sulphates in comparison to soap, which are salts of carboxylic acids. The detergents do not form precipitates with Ca2+ and Mg2+ present in hard water. So, the cleansing action of detergents is better than that of soaps.

Preparation of detergents

Detergents are prepared by adding sulphuric acid to the processed hydrocarbon obtained from petroleum. This chemical reaction result in the formation of molecules similar to the fatty acid in soap. Then, an alkali is added to the mixture to produce the 'surfactant molecules', which do not bond with the minerals present in the hard water, thus preventing the formation of their precipitates. In addition to a 'surfactant', the modern detergent contains several other ingredients. They are listed as follows:

i) Sodium silicate, which prevents the corrosion and ensures that the detergent does not damage the washing machine.
ii) Fluorescent whitening agents that give a glow to the clothes.
iii) Oxygen bleaches, such as 'sodium perborate', enable the removal of certain stains from the cloth.
iv) Sodium sulphate is added to prevent the caking of the detergent powder.
v) Enzymes are added to break down some stains caused by biological substances like blood and vegetable juice.
vi) Certain chemicals that give out a pleasant smell are also added to make the clothes fragrant after they are washed with detergents.

Cleansing action of soap

A soap molecule contains two chemically distinct parts that interact differently with water. It has one polar end, which is a short head with a carboxylate group (–COONa) and one non-polar end having the long tail made of the hydrocarbon chain.
The polar end is hydrophilic (Water loving) in nature and this end is attracted towards water. The non-polar end is hydrophobic (Water hating) in nature and it is attracted towards dirt or oil on the cloth, but not attracted towards water. Thus, the hydrophobic part of the soap molecule traps the dirt and the hydrophilic part makes the entire molecule soluble in water.

When a soap or detergent is dissolved in water, the molecules join together as clusters called 'micelles'. Their long hydrocarbon chains attach themselves to the oil and dirt. The dirt is thus surrounded by the non-polar end of the soap molecules (Figure 11.3). The charged carboxylate end of the soap molecules makes the micelles soluble in water. Thus, the dirt is washed away with the soap.

Advantages of detergents over soaps

Detergents are better than soaps because they:

- can be used in both hard and soft water and can clean more effectively in hard water than soap.
- can also be used in saline and acidic water.
- do not leave any soap scum on the tub or clothes.
- dissolve freely even in cool water and rinse freely in hard water.
- can be used for washing woollen garments, where as soap cannot be used.
- have a linear hydrocarbon chain, which is biodegradable.
- are active emulsifiers of motor grease.
- do an effective and safe cleansing, keeping even synthetic fabrics brighter and whiter.

Biodegradable and Non-biodegradable detergents:

a) Biodegradable detergents:
They have straight hydrocarbon chains, which can be easily degraded by bacteria.

b) Non-biodegradable detergents:
They have highly branched hydrocarbon chains, which cannot be degraded by bacteria.

Disadvantages of Detergents

1. Some detergents having a branched hydrocarbon chain are not fully biodegradable by micro-organisms present in water. So, they cause water pollution.
2. They are relatively more expensive than soap.

Comparison between soap and detergents

Soap	Detergent
It is a sodium salt of long chain fatty acids.	It is sodium salts of sulphonic acids.
The ionic part of a soap is	The ionic part in a detergent is

$-COO-Na+$.	$-SO-3Na+$.
It is prepared from animal fats or vegetable oils	It is prepared from hydrocarbons obtained from crude oil.
Its effectiveness is reduced when used in hard water.	It is effective even in hard water.
It forms a scum in hard water.	Does not form a scum in hard water.
It has poor foaming capacity.	It has rich foaming capacity.
Soaps are biodegradable.	Most of the detergents are non-biodegradable.

Have you noticed the term "TFM" in soap

TFM means TOTAL FATTY MATTER. It is the one of the important factors to be considered to assess the quality of soap. A soap, which has higher TFM, is a good bathing soap.

11th Physics
1st lesson- NATURE OF PHYSICAL WORLD AND MEASUREMENT

The Scientific Method

The scientific method is a step-by-step approach in studying natural phenomena and establishing laws which govern these phenomena. Any scientific method involves the following general features.

(i) Systematic observation
(ii) Controlled experimentation
(iii) Qualitative and quantitative reasoning
(iv) Mathematical modelling
(v) Prediction and verification or falsification of theories

Example

Consider a metalic rod being heated. When one end of the rod is heated, heat is felt at the other end. The following questions can be asked on this observation

a) What happens within the rod when it is heated?
b) How does the heat reach the other end?
c) Is this effect true for all materials?
d) If heat flows through the material, is it possible to visualize heat?

The process of finding the answers to these queries is scientific investigation.

The basic phenomenon of heat is discussed in unit 8.

PHYSICS - INTRODUCTION

The word 'physics' is derived from the Greek word "Fusis", meaning nature. The study of nature and natural phenomena is dealt within physics. Hence physics is considered as the most basic of all sciences.

Unification and **Reductionism** are the two approaches in studying physics. Attempting to explain diverse physical phenomena with a few concepts and laws is unification. For example, Newton's universal law of gravitation (in unit 6) explains the motion of freely falling bodies towards the Earth, motion of planets around the Sun, motion of the Moon around the Earth, thus unifying the fundamental forces of nature.

An attempt to explain a macroscopic system in terms of its microscopic constituents is reductionism. For example, thermodynamics (unit 8) was developed to explain macroscopic properties like temperature, entropy, etc., of bulk systems. The above properties have been interpreted in terms of the molecular constituents (microscopic) of the bulk system by kinetic theory (unit 9) and statistical mechanics.

Branches of Physics

Physics as a fundamental science helps to uncover the laws of nature. The language of its expression is mathematics. In ancient times, humans lived with nature – their lifestyles were integrated with nature. They could understand the signals from the movement of the stars and other celestial bodies. They could determine the time to sow and reap by watching the sky. Thus, astronomy and mathematics were the first disciplines to be developed. The chronological development of various branches of physics is presented in Appendix A1.1. The various branches of physics are schematically shown in figure 1.1. The essential focus of different areas is given in

Some of the fundamental concepts of basic areas of physics are discussed in higher secondary first year physics books volume 1 and 2. Mechanics is covered in unit 1 to 6. Unit 1 gives an idea of the development of physics along with discussion on basic elements such as measurement, units etc. Unit 2 gives the basic mathematics needed to express the impact of physical principles and their governing laws. The impact of forces acting on objects in terms of the fundamental laws of motion of Newton are very systematically covered in unit 3. Work and energy which are the basic parameters of investigation of the mechanical world are presented in unit 4. Unit 5 deals with the mechanics of rigid bodies

Classical Physics	**Refers to traditional physics that was recognized and developed before the beginning of the 20th century**
Branch	**Major focus**
1. Classical mechanics	The study of forces acting on bodies whether at rest or in motion
2. Thermodynamics	The study of the relationship between heat and other forms of energy
3. Optics	The study of light
4. Electricity and magnetism	The study of electricity and magnetism and their mutual relationship
5. Acoustics	The study of the production and propagation of sound waves
6. Astrophysics	The branch of physics which deals with the study of the physics of astronomical bodies

7. Relativity	One of the branches of theoretical physics which deals with the relationship between space, time and energy particularly with respect to objects moving in different ways.

Modern Physics	**Refers to the concepts in physics that have surfaced since the beginning of the 20th century.**
1. *Quantum mechanics	The study of the discrete nature of phenomena at the atomic and subatomic levels
2. Atomic physics	The branch of physics which deals with the structure and properties of the atom
3. Nuclear physics	The branch of physics which deals with the structure, properties and reaction of the nuclei of atoms.
4. Condensed matter physics	The study of the properties of condensed materials (solids, liquids and those intermediate between them and dense gas). It branches into various sub-divisions including developing fields such as Nano science, photonics etc. It covers the basics of materials science, which aims at developing new material with better properties for promising applications.
5. High energy physics	The study of the nature of the particles.

(in contrast, objects are viewed as point objects in units 3 and 4). The basics of gravitation and its consequences are discussed in unit 6. Older branches of physics such as different properties of matter are discussed in unit 7.

The impact of heat and investigations of its consequences are covered in units 8 and 9. Important features of oscillations and wave motion are covered in units 10 and 11.

Scope and Excitement of Physics

Discoveries in physics are of two types; accidental discoveries and well-analysed research outcome in the laboratory based on intuitive thinking and prediction. For example, magnetism was accidentally observed but the reason for this strange behavior of magnets was later analysed theoretically. This analysis revealed the underlying phenomena of magnetism. With this knowledge, artificial magnets were prepared in the laboratories. Theoretical predictions are the most important contribution of physics to the developments in technology and medicine. For example, the famous equation of Albert Einstein, E=mc2 was a theoretical prediction in 1905 and experimentally proved in 1932 by Cockcroft and Walton. Theoretical predictions aided with recent simulation and computation procedures are widely used to identify the most suited materials for robust applications. The pharmaceutical industry uses this technique very effectively to design new drugs. Biocompatible materials for organ replacement are predicted using quantum prescriptions of physics before fabrication. Thus, experiments and theory work hand in hand complimenting one another.

Physics has a huge scope as it covers a tremendous range of magnitude of various physical quantities (length, mass, time, energy etc). It deals with systems of very large magnitude as in astronomical phenomena as well as those with very small magnitude involving electrons and protons. „

- Range of time scales: astronomical scales to microscopic scales, 10^{18}s to 10^{-22}s.
- Range of masses: from heavenly bodies to electron, 10^{55} kg (mass of known observable universe) to 10^{-31}kg (mass of an electron) [the actual mass of an electron is 9.11×10^{-31} kg].

The study of physics is not only educative but also exciting in many ways.

- A small number of basic concepts and laws can explain diverse physical phenomena.
- The most interesting part is the designing of useful devices based on the physical laws.

For example

i. use of robotics

ii. journey to Moon and to nearby planets with controls from the ground

iii. Technological advances in health sciences etc.

- Carrying out new challenging experiments to unfold the secrets of nature and in verifying or falsifying the existing theories.
- Probing and understanding the science behind natural phenomena like the eclipse, and why one feels the heat when there is a fire? (or) What causes the wind, etc.

In today's world of technological advancement, the building block of all engineering and technical education is physics which is explained with the help of mathematical tools.

PHYSICS IN RELATION TO TECHNOLOGY AND SOCIETY

Technology is the application of the principles of physics for practical purposes. The application of knowledge for practical purposes in various fields to invent and produce useful products or to solve problems is known as technology. Thus, physics and technology can both together impact our society directly or indirectly.

For example,

i. Basic laws of electricity and magnetism led to the discovery of wireless communication technology which has shrunk the world with effective communication over large distances.
ii. The launching of satellite into space has revolutionized the concept of communication.
iii. Microelectronics, lasers, computers, superconductivity and nuclear energy have comprehensively changed the thinking and living style of human beings.

Physics being a fundamental science has played a vital role in the development of all other sciences. A few examples:

1. **Physics in relation to Chemistry:**

In physics, we study the structure of atom, radioactivity, X-ray diffraction etc. Such studies have enabled researchers in chemistry to arrange elements in the periodic table on the basis of their atomic numbers. This has further helped to know the nature of valency, chemical bonding and to understand the complex chemical structures. Inter-disciplinary branches like Physical chemistry and Quantum chemistry play important roles here.

2. Physics in relation to biology:

Biological studies are impossible without a microscope designed using physics principles. The invention of the electron microscope has made it possible to see even the structure of a cell. X-ray and neutron diffraction techniques have helped us to understand the structure of nucleic acids, which help to control vital life processes. X-rays are used for diagnostic purposes. Radio-isotopes are used in radiotherapy for the cure of cancer and other diseases. In recent years, biological processes are being studied from the physics point of view.

3. Physics in relation to mathematics:

Physics is a quantitative science. It is most closely related to mathematics as a tool for its development.

4. Physics in relation to astronomy:

Astronomical telescopes are used to study the motion of planets and other heavenly bodies in the sky. Radio telescopes have enabled the astronomers to observe distant points of the universe. Studies of the universe are done using physical principles.

5. Physics in relation to geology:

Diffraction techniques help to study the crystal structure of various rocks. Radioactivity is used to estimate the age of rocks, fossils and the age of the Earth.

6. Physics in relation to oceanography:

Oceanographers seek to understand the physical and chemical processes of theoceans. They measure parameters such as temperature, salinity, current speed, gas fluxes, chemical components.

7. Physics in relation to psychology:

All psychological interactions can be derived from a physical process. The movements of neurotransmitters are governed by the physical properties of diffusion and molecular motion. The functioning of our brain is related to our underlying wave-particle dualism.

Nature teaches true science with physics as an efficient tool. Science and technology should be used in a balanced manner so that they do not become weapons to destroy nature which taught us science. Global warming and other negative impacts of technology need to be checked. Safe science with moderate and appropriate use of technology is the need of this century.

The scope and opportunities for higher education in physics and various fellowships offered is given in the beginning of the book.

MEASUREMENT

The comparison of any physical quantity with its standard unit is known as measurement.

Measurement is the basis of all scientific studies and experimentation. It plays an important role in our daily life. Physics is a quantitative science and physicists always deal with numbers which are the measurement of physical quantities.

Definition of Physical Quantity

Quantities that can be measured, and in terms of which, laws of physics are described are called physical quantities. Examples are length, mass, time, force, energy, etc.

Types of Physical Quantities

Physical quantities are classified into two types. They are fundamental and derived quantities.

Fundamental or base quantities are quantities which cannot be expressed in terms of any other physical quantities. These are length, mass, time, electric current, temperature, luminous intensity and amount of substance.

Quantities that can be expressed in terms of fundamental quantities are called derived quantities. For example, area, volume, velocity, acceleration, force, etc.

Definition of Unit and its Types

The process of measurement is basically a process of comparison. To measure a quantity, we always compare it with some reference standard. For example, when we state that a rope is 10 meter long, it is to say that it is 10 times as long as an object whose length is defined as 1 metre. Such a standard is known as the unit of the quantity. Here 1 metre is the unit of the quantity 'length'.

An arbitrarily chosen standard of measurement of a quantity, which is accepted internationally is called unit of the quantity.

The units in which the fundamental quantities are measured are called fundamental or base units and the units of measurement of all other physical quantities, which can be obtained by a suitable multiplication or division of powers of fundamental units, are called derived units.

Different types of Measurement Systems

A complete set of units which is used to measure all kinds of fundamental and derived quantities is called a system of units. Here are the common system of units used in mechanics:

(a) **The f.p.s. system** is the British Engineering system of units, which uses **foot, pound** and **second** as the three basic units for measuring length, mass and time respectively.

(b) **The c.g.s system** is the Gaussian system, which uses **centimeter**, **gram** and second as the three basic units for measuring length, mass and time respectively.

(c) **The m.k.s system** is based on metre, **kilogram** and **second** as the three basic units for measuring length, mass and time respectively.

SI unit System

The system of units used by scientists and engineers around the world is commonly called *the metric system* but, since 1960, it has been known officially as the International System, or SI (the abbreviation for its French name, Système International). The SI with a standard scheme of symbols, units and abbreviations, were developed and recommended by the General Conference on Weights and Measures in 1971 for international usage in scientific, technical, industrial and commercial work. The advantages of the SI system are,

i. This system makes use of only one unit for one physical quantity, which means a rational system of units.

ii. In this system, all the derived units can be easily obtained from basic and supplementary units, which means it is a coherent system of units.

iii. It is a metric system which means that multiples and submultiples can be expressed as powers of 10.

In SI, there are seven fundamental units as given in Table

Base Quantity	**SI Units**		
	Unit	**Symbol**	**Definition**
Length	metre	m	One metre is the length of the path travelled by light in vacuum in 1/299,792,458 of a second (1983)
Mass	kilogram	kg	One kilogram is the mass of the prototype cylinder of platinum iridium alloy (whose height is equal to its diameter), preserved at the International Bureau of Weights and Measures at Serves, near Paris, France. (1901)
Time	second	s	One second is the duration of 9,192,631,770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground

			state of Cesium-133 atom.(1967)
Electric current	ampere	A	One ampere is the constant current, which when maintained in each of the two straight parallel conductors of infinite length and negligible cross section, held one metre apart in vacuum shall produce a force per unit length of 2 × 10−7 N/m between them. (1948)
Temperature	kelvin	K	One kelvin is the fraction $\left(\frac{1}{273.16}\right)$of the thermodynamic temperature of the triple point* of the water. (1967)
Amount of substance	mole	mol	One mole is the amount of substance which contains as many elementary entities as there are atoms in 0.012 kg of pure carbon-12. (1971)
Luminous intensity	candela	cd	One candela is the luminous intensity in a given direction, of a source that emits monochromatic radiation of frequency 5.4 × 10^{14} Hz and that has a radiant intensity of $\left(\frac{1}{683}\right)$ watt/steradian in that direction. (1979)

Lists some of the derived quantities and their units

Physical quantity	Expression	Unit
Plane angle	arc / radius	rad
Solid angle	surface area/radius^2	sr
Area	length × breadth	m^2
Volume	area × height	m^3
Velocity	displacement / time	ms^{-1}
Acceleration	velocity / time	ms^{-2}

Angular velocity	angular displacement / time	rad s^{-1}
Angular acceleration	angular velocity / time	rad s^{-2}
Density	mass / volume	Kg m^{-3}
Linear momentum	mass × velocity	Kg m s^{-1}
Moment of inertia	mass × (distance)^2	Kg m^2
Force	mass × acceleration	Kg m s^{-2} or N
Pressure	force / area	N m^{-2} or Pa
Energy (work)	force × distance	N m^{-2} or J
Power	Work / time	J s^{-1} or watt(W)
Impulse	force × time	N s
Surface tension	force / length	N m^{-1}
Moment of force (torque)	force × distance	N m
Electric charge	current × time	A s or C
Current density	current / area	A m^{-2}
Magnetic induction	force / (current × length)	N A^{-1} m^{-1} or tesla
Force constant	force / displacement	N m^{-1}
Plank's constant	energy of photon / frequency	J s
Specific heat (S)	heat energy / (mass × temperature)	J kg^{-1} K^{-1}
Boltzmann constant (k)	energy/temperature	J K^{-1}

Note:
π radian = 180°

$$1\,radian = \frac{180^\circ}{\pi} = \frac{180^\circ \times 7}{22} = 57.27^\circ$$

Also, 1° (degree of arc) = 60′ (minute of arc) and 1′ (minute of arc) = 60″ (seconds of arc)

Relations between radian, degree and minutes:

$$1^{\circ} = \frac{\pi}{180} rad = 1.745 \times 10^{-2} rad$$

$$\therefore 1^{\circ} = \frac{1^{\circ}}{60} = \frac{1.745 \times 10^{-2}}{60} = 2.908 \times 10^{-4} rad$$
$$= 2.91 \times 10^{-4} rad$$

$$\therefore 1^{\circ} = \frac{1^{\circ}}{3600} = \frac{1.745 \times 10^{-2}}{3600} = 4.847 \times 10^{-6} rad$$

$$= 4.85 \times 10^{-6} rad$$

MEASUREMENT OF BASIC QUANTITIES

Measurement of length

The concept of length in physics is related to the concept of distance in everyday life. Length is defined as the distance between any two points in space. The SI unit of length is metre. The objects of our interest vary widely in sizes. For example, large objects like the galaxy, stars, Sun, Earth, Moon etc., and their distances constitute a macrocosm. It refers to a large world, in which both objects and distances are large. On the contrary, objects like molecules, atoms, proton, neutron, electron, bacteria etc., and their distances constitute ***microcosm***, which means a small world in which both objects and distances are small-sized.

The Radian (rad): One radian is the angle subtended at the centre of a circle by an arc equal in length to the radius of the circle.

The Steradian (sr): One steradian is the solid angle subtended at the centre of a sphere, by that surface of the sphere, which is equal in area, to the square of radius of the sphere

Distances ranging from 10^{-5} m to 10^{2} m can be measured by direct methods. For example, a metre scale can be used to measure the distance from 10^{-3} m to 1 m, verniercalipers up to 10^{-4} m,a screw gauge up to 10^{-5} m and so on. The atomic and astronomical distances cannot be measured by any of the above mentioned direct methods. Hence, to measure the very small and the very large distances, indirect methods have to be devised and used. In Table, a list of powers of 10 (both positive and negative powers) is given. Prefixes for each power are also mentioned. These prefixes are used along with units of length, and of mass.

Prefixes for Powers of Ten

Multiple	Prefix	Symbol	Sub multiple	Prefix	Symbol
10^{1}	deca	da	10^{-1}	deci	d
10^{2}	hecto	h	10^{-2}	centi	c
10^{3}	kilo	k	10^{-3}	milli	m
10^{6}	mega	M	10^{-6}	micro	µ
10^{9}	giga	G	10^{-9}	nano	n
10^{12}	tera	T	10^{-12}	pico	p
10^{15}	peta	P	10^{-15}	femto	f
10^{18}	exa	E	10^{-18}	atto	a
10^{21}	zetta	Z	10^{-21}	zepto	z
10^{24}	yotta	Y	10^{-24}	yocto	y

i) **Measurement of small distances: screw gauge and verniercaliper**

Screw gauge*:* The screw gauge is an instrument used for measuring accurately the dimensions of objects up to a maximum of about 50 mm. The principle of the instrument is the magnification of linear motion usingthe circular motion of a screw. The least count of the screw gauge is 0.01 mm

Verniercaliper*:* A verniercaliper is a versatile instrument for measuring the dimensions of an object namely diameter of a hole, or a depth of a hole. The least count of the verniercaliper is 0.01 cm

ii) **Measurement of large distances**

For measuring larger distances such as the height of a tree, distance of the Moon or a planet from the Earth, some special methods are adopted. Triangulation method, parallax method and radar method are used to determine very large distances.

Triangulation method for the height of an accessible object

Let AB = h be the height of the tree or tower to be measured. Let C be the point of observation at distance x from B. Place a range finder at C and measure the angle of elevation, ∠ACB = θ

From right angled triangle ABC, $\tan\theta = \frac{AB}{BC} = \frac{h}{x}$ (or)**height h = x tan θ**

Knowing the distance x, the height h can be determined.

EXAMPLE

From a point on the ground, the top of a tree is seen to have an angle of elevation 60°. The distance between the tree and a point is 50 m. Calculate the height of the tree?

Solution

Angle θ = 60°

The distance between the tree and a point x = 50 m

Height of the tree (h) = ?

For triangulation method tan θ = h/x

h = x tan θ

= 50 × tan 60°

= 50 × 1.732

h = 86.6 m

The height of the tree is 86.6 m.

Parallax method

Very large distances, such as the distance of a planet or a star from the Earth can be measured by the parallax method. Parallax is the name given to the apparent change in the position of an object with respect to the background, when the object is seen from two different positions. The distance between the two positions (i.e., points of observation) is called the basis (b). Consider any object at the location O (Figure 1.4)

Let L and R represent the positions of the left and right eyes of the observer respectively.

The object (O) is viewed with the left eye (L) keeping the right eye closed and the same object (O) is viewed with the right eye (R) keeping the left eye closed.

In Figure 1.4, LO and RO are the lines drawn from the positions of the left and right eyes to the object. These two lines make an angle θ at O. This angle θ is called the angle of parallax.

OL and OR are considered as the radii (x) of a circle. For astronomical calculation, the distance LR = b (basis) can be treated as an arc of this circle, then

$$OL = OR = x$$
$$\text{as } LR = b$$

$$\theta = b/x$$

Knowing b and θ, x can be calculated which is approximately the distance of the object from the observer.

If the object is the Moon or any nearby star, then the angle θ will be too small due to the large astronomical distance and the place of observation. In this case, the two points of observation should be sufficiently spaced on the surface of the Earth.

Determination of distance of Moon from Earth

In Figure 1.5, C is the centre of the Earth. A &B are two diametrically oppositeplaces on the surface of the Earth. From A and B, the parallaxes θ1 and θ2 respectively of Moon M with respect to some distant star are determined with the help of an astronomical telescope. Thus, the total parallax of the Moon subtended on Earth

$\angle AMB = \theta_1 + \theta_2 = \theta$.

If θ is measured in radians, then $\theta = \frac{AB}{AM}$; AM≈MC

(AM is approximately equal to MC)

$\theta = \frac{AB}{MC}$ or $MC = \frac{AB}{\theta}$; Knowing the values of AB and θ, we can calculate the distance MC of Moon from the Earth.

Example

The Moon subtends an angle of 1° 55′ at the base line equal to the diameter of the Earth. What is the distance of the Moon from the Earth? (Radius of the Earth is 6.4 × 106m)

Solution

$$\text{angle } \theta = 1° 55' = 115'$$

$$= (115 \times 60)'' \times (4.85 \times 10^{-6}) \text{ rad}$$

$$= 3.34 \times 10^{-2} \text{ rad}$$

$$\text{since } 1'' = 4.85 \times 10^{-6} \text{ rad}$$

Radius of the Earth = 6.4×10^6m

From the Figure 1.5, AB is the diameter of the Earth (b)= $2 \times 6.4 \times 10^6$m
Distance of the Moon from the Earth x = ?

$$X = \frac{b}{\theta} = \frac{2 \times 6.4 \times 10^6}{3.34 \times 10^{-2}}$$

$$x = 3.83 \times 10^8 \text{m}$$

RADAR method

The word RADAR stands for radio detection and ranging. A radar can be used to measure accurately the distance of a nearby planet such as Mars. In this method, radio waves are sent from transmitters which, after reflection from the planet, are detected by the receiver. By measuring, the time interval (t) between the instants the radio waves are sent and received, the distance of the planet can be determined as

Speed = distance travelled / time taken
(Speed is explained in unit 2)

Distance(d) = Speed of radio waves × time taken

$$d = \frac{v \times t}{2}$$

where v is the speed of the radio wave. As the time taken (t) is for the distance covered during the forward and backward path of the radio waves, it is divided by 2to get the actual distance of the object. This method can also be used to determine the height, at which an aeroplane flies from the ground.

Example

A RADAR signal is beamed towards a planet and its echo is received 7 minutes later. If the distance between the planet and the Earth is
6.3×10^{10} m. Calculate the speed of the signal?

Solution

The distance of the planet from the Earth d = 6.3×10^{10} m

Time t = 7 minutes = 7 × 60 s.

the speed of signal v = ?

The speed of signal

$$v = \frac{2d}{t} = \frac{2 \times 6.3 \times 10^{10}}{7 \times 60} = 3 \times 10^{8} ms^{-1}$$

Range and Order of Lengths

Size of objects and distances	Length (m)
Distance to the boundary of observable universe	10^{26}
Distance to the Andromeda galaxy	10^{22}
Size of our galaxy	10^{21}
Distance from Earth to the nearest star (other than the Sun)	10^{16}
Average radius of Pluto's orbit	10^{12}
Distance of the Sun from the Earth	10^{11}
Distance of Moon from the Earth	10^{8}
Radius of the Earth	10^{7}
Height of the Mount Everest above sea level	10^{4}
Length of a football field	10^{2}
Thickness of a paper	10^{-4}
Diameter of a red blood cell	10^{-5}
Wavelength of light	10^{-7}
Length of typical virus	10^{-8}
Diameter of the hydrogen atom	10^{-10}

Size of atomic nucleus	10^{-14}
Diameter of a proton	10^{-15}

Some Common Practical Units

(i) Fermi = 1 fm = 10^{-15} m

(ii) 1 angstrom = 1 Å = 10^{-10} m

(iii) 1 nanometer = 1 nm = 10^{-9} m

(iv) 1 micron = 1µm = 10^{-6} m

(v) 1 Light year (Distance travelled by light in vacuum in one year) 1 Light Year = 9.467×10^{15} m

(vi) 1 astronomical unit (the mean distance of the Earth from the Sun) 1 AU = 1.496×10^{11} m

(vii) 1 parsec (Parallactic second) (Distance at which an arc of length 1 AU subtends an angle of 1 second of arc)

1 parsec = 3.08×10^{16} m =3.26 light year

v Chandrasekhar Limit (CSL) is the largest practical unit of mass.
1 CSL = 1.4 times the mass of the Sun

v The smallest practical unit of time is Shake. 1 Shake = 10^{-8} s

Measurement of mass

Mass is a property of matter. It does not depend on temperature, pressure and location of the body in space. Mass of a body is defined as the quantity of matter contained in a body. The SI unit of mass is kilogram (kg). The masses of objects which we shall study in this course vary over a wide range. These may vary from a tiny mass of electron (9.11×10^{-31}kg) to the huge mass of the known universe ($=10^{55}$ kg). The order of masses of various objects is shown in Table

Ordinarily, the mass of an object is determined in kilograms using a common balance like the one used in a grocery shop. For measuring larger masses like

Range of masses

Object	**Order of mass (kg)**
Electron	10^{-30}
Proton or Neutron	10^{-27}
Uranium atom	10^{-25}
Red blood corpuscle	10^{-14}
A cell	10^{-10}
Dust particle	10^{-9}
Raindrop	10^{-6}
Mosquito	10^{-5}
Grape	10^{-3}
Frog	10^{-1}
Human	10^{2}
Car	10^{3}
Ship	10^{5}
Moon	10^{23}
Earth	10^{25}
Sun	10^{30}
Milky way	10^{41}
Observable Universe	10^{55}

that of planets, stars etc., we make use of gravitational methods. For measurement of small masses of atomic/subatomic particles etc., we make use of a mass spectrograph.

Some of the weighing balances commonly used are common balance, spring balance, electronic balance, etc.

Measurement of Time intervals

A clock is used to measure the time interval. An atomic standard of time, is based on the periodic vibration produced in a Cesium atom. Some of the clocks developed later are electric oscillators, electronic oscillators, solar clock, quartz crystal clock, atomic clock, decay of elementary particles, radioactive dating etc. The order of time intervals are tabulated in

Order of Time Intervals

Event	Order of time interval (s)
Lifespan of the most unstable particle	10^{-24}
Time taken by light to cross a distance of nuclear size	10^{-22}
Period of X-rays	10^{-19}
Time period of electron in hydrogen atom	10^{-15}
Period of visible light waves	10^{-15}
Time taken by visible light to cross through a window pane	10^{-8}
Lifetime of an excited state of an atom	10^{-8}
Period of radio waves	10^{-6}
Time period of audible sound waves	10^{-3}
Wink of an eye	10^{-1}
Time interval between two successive heart beats	10^{0}
Travel time of light from Moon to Earth	10^{0}
Travel time of light from Sun to Earth	10^{2}
Halflife time of a free neutron	10^{3}
Time period of a satellite	10^{4}
Time period of rotation of Earth around its axis (one day)	10^{5}
Time period of revolution of Earth	10^{7}

around the Sun (one year)	
Average life of a human being	10^{9}
Age of Egyptian pyramids	10^{11}
Age of Universe	10^{17}

THEORY OF ERRORS

The foundation of all experimental science and technology is measurement. The result obtained from any measurement will contain some uncertainty. Such an uncertainty is termed error. Any calculation made using the measured values will also have an error. It is not possible to make exact measurements in an experiment. In measurements, two different terms, accuracy and precision are used and need to be distinguished at this stage. Accuracy refers to how far we are from the true value, and precision refers to how well we measure.

Accuracy and Precision

Let us say, you know your true height is exactly 5′9″. You first measure your height with a yardstick and get the value 5′0″. Your measurement is hence not accurate. Now you measure your height with a laser yardstick and get 5′9″ as the value. Now your measurement is accurate. The true value is also called theoretical value. The level of accuracy required for each application varies greatly. Highly accurate data can be very difficult to produce and compile. For example, if you consistently measure your height as 5′0″ with a yard stick, your measurements are precise. The level of precision required for different applications vary to a great extent. Engineering projects such as road and utility construction require very precise information measured to the millimeter or one-tenth of an inch.

If a measurement is precise, that does not necessarily mean that it is accurate. However, if the measurement is consistently accurate, it is also precise.

For example, if the temperature outside a building is 40oC as measured by a weather thermometer and if the real outsidetemperature is 40oC, the thermometer is accurate. If the thermometer consistently registers this exact temperature in a row, the thermometer is precise.

Consider another example. Let the temperature of a refrigerator repeatedly measured by a thermometer be given as 10.4^{o}C, 10.2^{o}C,
10.3^{o}C, 10.1^{o}C, 10.2^{o}C, 10.1^{o}C, 10.1^{o}C, 10.1^{o}C. However, if the real temperature inside the refrigerator is 9oC, we say that the thermometer is not accurate (it is almost one degree off the true value), but since all the measured values are close to 10^{o}C, hence it is precise.

A visual example:

Target shooting is an example which explains the difference between accuracy and precision. In Figure 1.9 (a), the shots are focused so as to reach the bull's eye (midpoint), but the arrows have reached only around this point. Hence the shots are not accurate and also not precise.

In Figure 1.9 (b), all the shots are close to each other but not at the central point. Hence the shots are said to be precise but not accurate. In Figure 1.9 (c), the shots are closer and also at the central point. Hence the shots are both precise and accurate.

A numerical example

The true value of a certain length is nearly 5.678 cm. In one experiment, using a measuring instrument of resolution 0.1 cm, the measured value is found to be 5.5 cm. In another experiment using a measuring instrument of greater resolution, say 0.01 cm, the length is found to be 5.38 cm. We find that the first measurement is more accurate as it is closer to the true value, but it has lesser precision. On the contrary, the second measurement is less accurate, but it is more precise.

Errors in Measurement

The uncertainty in a measurement is called an error. Random error, systematic error and gross error are the three possible errors.

i) Systematic errors

Systematic errors are reproducible inaccuracies that are consistently in the same direction. These occur often due to a problem that persists throughout the experiment. Systematic errors can be classified as follows

1) Instrumental errors

When an instrument is not calibrated properly at the time of manufacture, instrumental errors may arise. If a measurement is made with a meter scale whose end is worn out, the result obtained will have errors. These errors can be corrected by choosing the instrument carefully.

2) Imperfections in experimental technique or procedure

These errors arise due to the limitations in the experimental arrangement. As an example, while performing experiments with a calorimeter, if there is no proper insulation, there will be radiation losses. This results in errors and to overcome these, necessary correction has to be applied.

3) Personal errors

These errors are due to individuals performing the experiment, may be due to incorrect initial setting up of the experiment or carelessness of the individual making the observation due to improper precautions.

4) **Errors due to external causes**

The change in the external conditions during an experiment can cause error in measurement. For example, changes in temperature, humidity, or pressure during measurements may affect the result of the measurement.

5) **Least count error**

Least count is the smallest value that can be measured by the measuring instrument, and the error due to this measurement is least count error. The instrument's resolution hence is the cause ofthis error. Least count error can be reduced by using a high precision instrument for the measurement.

ii) Random errors

Random errors may arise due to random and unpredictable variations in experimental conditions like pressure, temperature, voltage supply etc. Errors may also be due to personal errors by the observer who performs the experiment. Random errors are sometimes called **"chance error".** When different readings are obtained by a person every time herepeats the experiment, personal error occurs. For example, consider the case of the thickness of a wire measured using a screw gauge. The readings taken may be different for different trials. In this case, a large number of measurements are made and then the arithmetic mean is taken.

If n number of trial readings are taken in an experiment, and the readings are a_1, a_2, a_3,………………… a_n. The arithmetic mean is

$$a_m = \frac{a_1 + a_2 + a_3 + \dots a_n}{n}$$

$$a_m = \frac{1}{n}\sum_{i=1}^{n} a_i$$

Usually this arithmetic mean is taken as the best possible true value of the quantity.
Certain procedures to be followed to minimize experimental errors, along with examples

iii) Gross Error

The error caused due to the shear carelessness of an observer is called gross error.

For example

(i) Reading an instrument without setting it properly.

(ii) Taking observations in a wrong manner without bothering about the sources of errors and the precautions.

(iii) Recording wrong observations.

(iv) Using wrong values of the observations in calculations.

These errors can be minimized only when an observer is careful and mentally alert.

Minimizing Experimental Error

Type of error	Example	How to minimize it
Random error	Suppose you measure the mass of a ring three times using the same balance and get slightly different values. 15.46 g, 15.42 g, 15.44 g	Take more data. Random errors can be evaluated through statistical analysis and can be reduced by averaging over a large number of observations.
Systematic error	Suppose the cloth tape measure that you use to measure the length of an object has been stretched out from years of use. (As a result all of the length measurements are not correct).	Systematic errors are difficult to detect and cannot be analysed statistically, because all of the data is in the same direction. (Either too high or too low)

Error Analysis

i. Absolute Error

The magnitude of difference between the true value and the measured value of a quantity is called absolute error. If a_1, a_2, a_3, ……….a_n are the measured values of any quantity 'a' in an experiment performed n times, then the arithmetic mean of these values is called the true value (a_m) of the quantity.

$$a_m = \frac{a_1 + a_2 + a_3 + ...a_n}{n}$$

Or

$$a_m = \frac{1}{n}\sum_{i=1}^{n} a_i$$

The absolute error in measured values is given by

$$\left|\Delta a_1\right| = \left|a_m - a_1\right|$$

$$\left|\Delta a_2\right| = \left|a_m - a_2\right|$$

…………….

…………….

$$\left|\Delta a_n\right| = \left|a_m - a_n\right|$$

ii. Mean Absolute error

The arithmetic mean of absolute errors in all the measurements is called the mean absolute error.

$$\Delta a_m = \frac{\left|\Delta a_1\right| + \left|\Delta a_2\right| + \left|\Delta a_3\right| + ... + \left|\Delta a_n\right|}{n}$$

Or $= \frac{1}{n}\sum_{i=1}^{n}\left|a_i\right|$

If a_m is the true value and Δa_m is the mean absolute error then the magnitude of the quantity may lie between am + Δa_m and $a_m - \Delta a_m$

iii. Relative error

The ratio of the mean absolute error to the mean value is called relative error. This is also called as fractional error. Thus

Relative error $= \frac{Mean\,absolute\,error}{Mean\,value}$

$$= \frac{\Delta a_m}{a_m}$$

Relative error expresses how large the absolute error is compared to the total size of the object measured. For example, a driver's speedometer shows that his car is travelling at 60

km h^{-1} when it is actually moving at 62 km h^{-1}. Then absolute error of speedometer is 62-60 km h^{-1} = 2 km h^{-1} Relative error of the measurement is
2 km h^{-1} / 60 km h^{-1} = 0.033.

iv. Percentage error

The relative error expressed as a percentage is called percentage error.

Percentage error $= \dfrac{\Delta a_m}{a_m} \times 100\%$

A percentage error very close to zero means one is close to the targeted value, which is good and acceptable. It is always necessary to understand whether error is due to impression of equipment used or a mistake in the experimentation.

EXAMPLE

In a series of successive measurements in an experiment, the readings of the period of oscillation of a simple pendulum were found to be 2.63s, 2.56 s, 2.42s, 2.71s and2.80s. Calculate (i) the mean value of the period of oscillation (ii) the absolute error in each measurement (iii) the mean absolute error (iv) the relative error (v) the percentage error. Express the result in proper form.

Solution

t_1 = 2.63s, t_2 = 2.56s, t_3 = 2.42s,
t_4 = 2.71s, t_5 = 2.80s

(i) $T_m = \dfrac{t_1 + t_2 + t_3 + t_4 + t_5}{5}$

$$T_m = \frac{13.12}{5} = 2.624s$$

$T_m = 2.62s$ (Rounded off to 2nd decimal place)

(ii) Absolute error |ΔT| = |Tm - t|

$$|\Delta T_1| = |2.62 - 2.63| = +0.01s$$

$$|\Delta T_2| = |2.62 - 2.56| = +0.06s$$

$$|\Delta T_3| = |2.62 - 2.42| = +0.20s$$

$$\left|\Delta T_4\right| = \left|2.62 - 2.71\right| = +0.09s$$

$$\left|\Delta T_5\right| = \left|2.62 - 2.80\right| = +0.18s$$

(iii) Mean absolute error $= \dfrac{\sum\left|\Delta T_i\right|}{n}$

$$\Delta T_m = \frac{0.01 + 0.06 + 0.20 + 0.09 + 0.18}{5}$$

$\Delta T_m = \dfrac{0.54}{5} = 0.108s = 0.11s$ (Rounded off to 2nd decimal place)

(iv) Relative error:

$$S_r = \frac{\Delta T_m}{T_m} = \frac{0.11}{2.62} = 0.0419s$$

$$S_r = 0.04s$$

(v) Percentage error in T = 0.04 × 100% = 4%

(vi) Percentage error in T = 0.04 × 100% = 4% (vi) Time period of simple pendulum = T = (2.62 ± 0.11)s

Propagation of errors

A number of measured quantities may be involved in the final calculation of an experiment. Different types of instruments might have been used for taking readings. Then we may have to look at the errors in measuring various quantities, collectively.

The error in the final result depends on

(i) The errors in the individual measurements

(ii) On the nature of mathematical operations performed to get the final result. So we should know the rules to combine the errors.

The various possibilities of the propagation or combination of errors in different mathematical operations are discussed below:

(i) Error in the sum of two quantities Let ΔA and ΔB be the absolute errors in the two quantities A and B respectively. Then, Measured value of A = A ± ΔA

Measured value of B = B ± ΔB

Consider the sum, $Z = A + B$

The error ΔZ in Z is then given by

$Z \pm \Delta Z = (A \pm \Delta A) + (B \pm \Delta B)$

$= (A + B) \pm (\Delta A + \Delta B)$

$= Z \pm (\Delta A + \Delta B)$

(or) $\Delta Z = \Delta A + \Delta B$

- The maximum possible error in the sum of two quantities is equal to the sum of the absolute errors in the individual quantities

EXAMPLE

Two resistances $R_1 = (100 \pm 3)\ \Omega$, $R_2 = (150 \pm 2)\ \Omega$, are connected in series. What is their equivalent resistance?

Solution

$R_1 = 100 \pm = 3\Omega$; $R_2 = 150 \pm 2\Omega$

Equivalent resistance R =?

Equivalent resistance $R = R_1 + R_2$

$= (100 \pm 3) + (150 \pm 2)$

$= (100 + 150) \pm (3 + 2)$

$R = (250 \pm 5)\ \Omega$

(ii) Error in the difference of two quantities

Let ΔA and ΔB be the absolute errors in the two quantities, A and B, respectively. Then,

Measured value of A = A ± ΔA

Measured value of B = B ± ΔB

Consider the difference, $Z = A - B$

The error ΔZ in Z is then given by $Z \pm \Delta Z = (A \pm \Delta A) - (B \pm \Delta B)$

$$= (A - B) \pm \Delta A \pm \Delta B$$

$$= Z \pm \Delta A \pm \Delta B$$

$$\text{(or) } \mathbf{\Delta Z = \Delta A + \Delta B}$$

- The maximum error in difference of two quantities is equal to the sum of the absolute errors in the individual quantities.

EXAMPLE

The temperatures of two bodies measured by a thermometer are $t_1 = (20 + 0.5)°C$, $t_2 = (50 \pm 0.5)°C$. Calculate the temperature difference and the error therein.

Solution

$t_1 = (20 \pm 0.5)\ °C$ $\quad$ $t_2 = (50 \pm 0.5)\ °C$

Temperature difference t=?

$$t = t_2 - t_1 = (50 \pm 0.5) - (20 \pm 0.5)\ °C$$

(Using equation $\Delta Z = \Delta A + \Delta B$)

$$= (50 - 20) \pm (0.5 + 0.5)$$

$$t = (30 \pm 1)\ °C$$

(iii) Error in the product of two quantities

Let ΔA and ΔB be the absolute errors in the two quantities A, and B, respectively. Consider the product $Z = AB$

The error ΔZ in Z is given by $Z \pm \Delta Z = (A \pm \Delta A)(B \pm \Delta B)$

$$= (AB) \pm (A\,\Delta B) \pm (B\,\Delta A) \pm (\Delta A \,.\, \Delta B)$$

Dividing L.H.S by Z and R.H.S by AB, we get,

$$1 \pm \frac{\Delta Z}{Z} = 1 \pm \frac{\Delta B}{B} \pm \frac{\Delta A}{A} \pm \frac{\Delta A}{A}.\frac{\Delta B}{B}$$

As ΔA /A, ΔB / B are both small quantities, their product term $\frac{\Delta A}{A}.\frac{\Delta B}{B}$ can be neglected. The maximum fractional error in Z is

$$\frac{\Delta Z}{Z} = \pm\left(\frac{\Delta A}{A}.\frac{\Delta B}{B}\right)$$

- The maximum fractional error in the product of two quantities is equal to the sum of the fractional errors in the individual quantities.

EXAMPLE

The length and breadth of a rectangle are (5.7 ± 0.1) cm and (3.4 ± 0.2) cm respectively. Calculate the area of the rectangle with error limits.

Solutions

Length l = (5.7 ± 0.1) cm

Breadth b =(3.4 ± 0.2) cm

Area A with error limit = A ± ΔA = ?

Area A = l × b = 5.7 × 3.4 = 19.38 = 19.4 cm^2

$$\frac{\Delta A}{A} = \frac{\Delta l}{l} + \frac{\Delta b}{b}$$

$$\Delta A = \left(\frac{\Delta l}{l} + \frac{\Delta b}{b}\right)A$$

$$\Delta A = \left(\frac{0.1}{5.7} + \frac{0.2}{3.4}\right)19.4$$

= (0.0175+0.0588) × 19.4

= 1.48 = 1.5

Area with error limit

A = (19.4±1.5) cm^2

(iv) Error in the division or quotient of two quantities

Let ΔA and ΔB be the absolute errors in the two quantities A and B respectively.

Consider the quotient, $Z = \frac{A}{B}$

The error ΔZ in Z is given by

$$Z \pm \Delta Z = \frac{A \pm \Delta A}{B \pm \Delta B} = \frac{A\left(1 \pm \frac{\Delta A}{A}\right)}{B\left(1 \pm \frac{\Delta B}{B}\right)}$$

$$= \frac{A}{B}\left(1 \pm \frac{\Delta A}{A}\right)\left(1 \pm \frac{\Delta B}{B}\right)^{-1}$$

$$\text{Or } Z \pm \Delta Z = Z\left(1 \pm \frac{\Delta A}{A}\right)\left(1 \mp \frac{\Delta B}{B}\right)$$

[Using $(1+x)^n \approx 1+nx$, when $x<<1$]

Dividing both sides by Z, we get,

$$1 \pm \frac{\Delta Z}{Z} = \left(1 \pm \frac{\Delta A}{A}\right)\left(1 \mp \frac{\Delta B}{B}\right)$$

$$= 1 \pm \frac{\Delta A}{A} \mp \frac{\Delta B}{B} \pm \frac{\Delta A}{A}.\frac{\Delta B}{B}$$

As the terms ΔA/A and ΔB/B are small, their product term can be neglected.

The maximum fractional error in Z is given by $\frac{\Delta Z}{Z} = \frac{\Delta A}{A} + \frac{\Delta B}{B}$

- The maximum fractional error in the quotient of two quantities is equal to the sum of their individual fractional errors.

EXAMPLE

The voltage across a wire is (100 ± 5)V and the current passing through it is (10±0.2) A. Find the resistance of the wire.

Solution

Voltage V = (100±5)V

Current I = (10±0.2) A

Resistance R = ?

Then resistance R is given by Ohm's law, R = V/ I

$$=\frac{100}{10}=10\Omega$$

$$\frac{\Delta R}{R}=\left(\frac{\Delta V}{V}+\frac{\Delta I}{I}\right)$$

$$\Delta R=\left(\frac{\Delta V}{V}+\frac{\Delta I}{I}\right)R$$

$$=\left(\frac{5}{100}+\frac{0.2}{10}\right)10$$

$$=(0.05+0.02)10$$

$$=0.7$$

The resistance R = (10 ± 0.7) Ω

(v) Error in the power of a quantity

Consider the n^{th} power of A, $Z = A^n$

The error ΔZ in Z is given by

$$Z\pm\Delta Z=(A\pm\Delta A)^n=A^n\left(1\pm\frac{\Delta A}{A}\right)^n$$

$$=Z\left(1\pm n\frac{\Delta A}{A}\right)$$

We get $[(1+x)n \approx 1+nx$, when $x<<1]$ neglecting remaining terms, Dividing both sides by Z

$$1\pm\frac{\Delta Z}{Z}=1\pm n\frac{\Delta A}{A} \text{ or } \frac{\Delta Z}{Z}=n.\frac{\Delta A}{A}$$

- The fractional error in the nth power of a quantity is n times the fractional error in that quantity.

General rule: If $Z = \frac{A^p B^q}{C^r}$ Then maximum fractional error in Z is given by

$$\frac{\Delta Z}{Z} = p\frac{\Delta A}{A} + q\frac{\Delta B}{B} + r\frac{\Delta C}{C}$$

The percentage error in Z is given by

$$\frac{\Delta Z}{Z}\times 100 = p\frac{\Delta A}{A}\times 100 + q\frac{\Delta B}{B}\times 100 + r\frac{\Delta C}{C}\times 100$$

EXAMPLE

A physical quantity x is given by $x = \frac{a^2 b^3}{c\sqrt{d}}$.

If the percentage errors of measurement in a, b, c and d are 4%, 2%, 3% and 1% respectively, then calculate the percentage error in the calculation of x. (NEET 2013)

Solution

Given $x = \frac{a^2 b^3}{c\sqrt{d}}$

The percentage error in x is given by

$$\frac{\Delta x}{x}\times 100 = 2\frac{\Delta a}{a}\times 100 + 3\frac{\Delta b}{b}\times 100 + \frac{\Delta c}{c}\times 100 + \frac{1}{2}\frac{\Delta d}{d}\times 100$$

$$=(2\times 4\%)+(3\times 2\%)+(1\times 3\%)+\left(\frac{1}{2}\times 1\%\right)$$

=8%+6%+3%+0.5%

The percentage error is x = 17.5%

SIGNIFICANT FIGURES

Definition and Rules of Significant Figures

Suppose we ask three students to measure the length of a stick using metre scale (the least count for metre scale is 1 mm or 0.1 cm). So, the result of the measurement (length of stick) can be any of the following, 7.20 cm or 7.22 cm or 7.23 cm. Note that all the three students measured first two digits correctly (with confidence) but last digit varies from person to person. So, the number of meaningful digits is 3 which communicate both measurement (quantitative) and also the precision of the instrument used. Therefore, significant number or significant digit is 3. It is defined as **the number of meaningful digits which contain numbers that are known reliably and first uncertain number.**

Examples:

The significant figure for the digit 121.23 is 5, significant figure for the digit 1.2 is 2, significant figure for the digit 0.123 is 3, significant digit for 0.1230 is 4, significant digit for 0.0123 is 3, significantdigit for 1230 is 3, significant digit for 1230 (with decimal) is 4 and significant digit for 20000000 is 1 (because 20000000=2 × 10^7 has only one significant digit, that is, 2).

In physical measurement, if the length of an object is l = 1230 m, then significant digit for l is 4.

The rules for counting significant figures are given in Table.

EXAMPLE

State the number of significant figures in the following

i) 600800 iv) 5213.0
ii) 400 v) 2.65 × 1024 m
iii) 0.007 vi) 0.0006032

Solution:

i) fourii) one iii) one
iv) fivev) three vi) four

Rounding Off

Calculators are widely used now-a-days to do calculations. The result given by a calculator has too many figures. In no case should the result have more significant figures than the figures involved in the data used for calculation. The result of calculation with numbers containing more than one uncertain digit should be rounded off. The rules for rounding off are shown in Table.

EXAMPLE

Round off the following numbers as indicated

i) 18.35 up to 3 digits
ii) 19.45 up to 3 digits
iii) 101.55 × 106 up to 4 digits
iv) 248337 up to digits 3 digits
v) 12.653 up to 3 digits

Solution i) 18.4 ii) 19.4 iii) 101.6 × 106 iv) 248000 v) 12.7

Arithmetical Operations with Significant Figures

(i) Addition and subtraction

In addition and subtraction, the final result should retain as many decimal places as there are in the number with the smallest number of decimal places.

Example:

1. 3.1 + 1.780 + 2.046 = 6.926

   Here the least number of significant digits after the decimal is one. Hence the result will be 6.9.

2. 12.637 – 2.42 = 10.217

   Here the least number of significant digits after the decimal is two. Hence the result will be 10.22

(ii) Multiplication and Division

In multiplication or division, the final result should retain as many significant figures as there are in the original number with smallest number of significant figures.

Example:

1. 1.21 × 36.72 = 44.4312 = 44.4

   Here the least number of significant digits in the measured values is three. Hence the result when rounded off to three significant digits is 44.4

2. 36.72 ÷ 1.2 = 30.6 = 31

   Here the least number of significant digits in the measured values is two. Hence the result when rounded off to significant digit becomes 31.

DIMENSIONAL ANALYSIS

Dimension of Physical Quantities

In mechanics, we deal with the physical quantities like mass, time, length, velocity, acceleration, etc. which can be expressed in terms of three independent base quantities such as M, L and T. So, the dimension of a physical quantity can be defined as 'any physical quantity which is expressed in terms of base quantities whose exponent (power) represents the dimension of the physical quantity'. The notation used to denote the dimension of a physical quantity is [(physical quantity within square bracket)]. For an example, [length] means dimension of length, [area] means dimension of area, etc. The dimension of length can be expressed in terms of base quantities as

[length] = $M^0 LT^0 = L$

Similarly, [area] = $M^0 L^2 T^0 = L^2$

Similarly, [volume] = $M^0 L^3 T^0 = L^3$

Note that in all the cases, the base quantity L is same but exponent
(power) are different, which means dimensions are different. For a pure number, exponent of base quantity is zero. For example, consider the number 2, which has no dimension and can be expressed as

$$\Rightarrow [2] = M^0 L^0 T^0 \text{ (dimensionless)}$$

Let us write down the dimensions of a few more physical quantities.

$$Speed, s = \frac{distance}{time\ taken} \Rightarrow [s] \frac{L}{T} = LT^{-1}$$

$$Speed, s = \frac{displacement}{time\ taken} \Rightarrow \left[\vec{v}\right] = \frac{L}{T} = LT^{-1}$$

Note that speed is a scalar quantity and velocity is a vector quantity (scalar and vector will be discussed in Unit 2) but both of them have the same dimensional formula.

$$Acceleration, \vec{a} = \frac{velocity}{time\ taken} \Rightarrow \left[\vec{a}\right] = \frac{LT^{-1}}{T} = LT^{=2}$$

Acceleration is velocity per time.
Linear momentum or Momentum,

$$\left[\vec{p}\right] = m\vec{v} \Rightarrow [p] = MLT^{-1}$$

$$Force, \vec{F} = m\vec{a} \Rightarrow \left[\vec{F}\right] = MLT^{-2} = \frac{Momentum}{time}$$

This is true for any kind of force. There are only four types of forces that exist in nature viz strong force, electromagnetic force, weak force and gravitational force. Further, frictional force, centripetal force, centrifugal force, all have the dimension MLT^{-2}.

$$\text{Im}\ pulse, \vec{I} = \vec{F}t \Rightarrow \left[\vec{I}\right] = MLT^{-1}$$

=dimension of momentum

Angular momentum is the moment of linear momentum (discussed in unit 5).

$$Angular\ Momentum, \vec{L} = \vec{r} \times \vec{p} \Rightarrow \left[\vec{L}\right] - ML^2T^{-1}$$

Work done,

$$W = \vec{F} \bullet \vec{d} \Rightarrow [W] = ML^2T^{-2}$$

Kinetic enrgy

$$KE = \frac{1}{2}mv^2 \Rightarrow [KE] = \left[\frac{1}{2}\right][m]\left[v^2\right]$$

Since, number $\frac{1}{2}$ is dimensionless, the dimension of kinetic energy.

$[KE] = [m]\left[v^2\right] = ML^2T^{-2}$. Similarly, to get the dimension of potential energy, let us consider the gravitational potential energy, $PE = mgh \Rightarrow [PE] = [m][g][h]$,, where, m is the mass of the particle, g is the
acceleration due to gravity and h is the height from the ground

level. Hence, $[PE] = [m][g][h] = ML^2T^{-2}$. Thus, for any kind of energy (such as for internal energy, total energy etc), the dimension is

$$[Energy] = ML^2T^{-2}$$

The moment of force is known as torque, $\vec{\tau} = \vec{r} \times \vec{F} \Rightarrow \left[\vec{\tau}\right] = ML^2T^{-2}$ (Read the symbol τ as tau – Greek alphabet). Note that the dimension of torque and dimension of energy are identical but they are different physical quantities. Further one of them is a scalar (energy) and another one is a vector (torque). This means that the dimensionally same physical quantities need not be the same physical quantities.

Dimenstonal Formula

Physical quantity	Expression	Dimension Formula
Area (Rectangle)	Length×breadth	$[L^2]$
Volume	Area×height	$[L^3]$
Density	Mass/volume	$[ML^{-3}]$
Velocity	Displacement/time	$[LT^{-1}]$
Acceleration	Velocity/time	$[LT^{-2}]$
Momentum	mass×velocity	$[MLT^{-1}]$
Force	mass×acceleration	$[MLT^{-2}]$
Work	force×distance	$[ML^2T^{-2}]$
Power	Work/time	$[ML^2T^{-3}]$
Energy	work	$[ML^2T^{-2}]$
Impulse	Force/time	$[MLT^{-1}]$
Radius of gyration	Distance	$[L]$
Pressure (or) stress	Force/area	$[ML^{-1}T^{-2}]$
Surface tension	force / length	$[ML^{-1}T^{-2}]$
Frequency	1 / time period	$[T^{-1}]$
Moment of Inertia	mass × (distance)^2	$[ML^2]$
Moment of force (or torque)	force × distance	$[ML^2T^{-2}]$
Angular velocity	angular displacement / time	$[T^{-1}]$
Angular acceleration	angular velocity / time	$[T^{-2}]$
Angular momentum	linear momentum × distance	$[ML^2T^{-1}]$
Co-efficient of Elasticity	stress/strain	$ML^{-1}T^{-2}]$

Co-efficient of viscosity	(force × distance) / (area × velocity)	[$ML^{-1}T^{-1}$]
Surface energy	work / area	[MT^{-2}]
Heat capacity	heat energy / temperature	[ML2T−2K−1]
Charge	current × time	[AT]
Magnetic induction	force / (current × length)	[$MT^{-2}A^{-1}$]
Force constant	force / displacement	[MT^{-2}]
Gravitational constant	[force × (distance)^2] / (mass)^2	[$M^{-1}L^3 T^{-2}$]
Planck's constant	energy / frequency	[$ML^2 T^{-1}$]
Faraday constant	avogadro constant × elementary charge	[AT mol^{-1}]
Boltzmann constant	energy / temperature	[$ML^2 T^{-2} K^{-1}$]

Dimensional Quantities, Dimensionless Quantities, Principle of Homogeneity

On the basis of dimension, we can classify quantities into four categories.

(1) Dimensional variables

Physical quantities, which possess dimensions and have variable values are called dimensional variables. Examples are length, velocity, and acceleration etc.

(2) Dimensionless variables

Physical quantities which have no dimensions, but have variable values are called dimensionless variables. Examples are specific gravity, strain, refractive index etc.

(3) Dimensional Constant

Physical quantities which possess dimensions and have constant values are called dimensional constants. Examples are Gravitational constant, Planck's constant etc.

(4) Dimensionless Constant

Quantities which have constant values and also have no dimensions are called dimensionless constants. Examples are π, e (Euler's number), numbers etc.

Principle of homogeneity of dimensions

The principle of homogeneity of dimensions states that the dimensions of all the terms in a physical expression should be the same. For example, in the physical expression $v^2 = u^2 + 2as$, the dimensions of v^2, u^2 and 2 as are the same and equal to $[L^2T^{-2}]$.

Application and Limitations of the Method of Dimensional Analysis

This method is used to

I. Convert a physical quantity from one system of units to another.

II. Check the dimensional correctness of a given physical equation.

III. Establish relations among various physical quantities.

(i) To convert a physical quantity from one system of units to another

This is based on the fact that the product of the numerical values (n) and its corresponding unit (u) is a constant. i.e, n [u] = constant (or) $n_1[u_1] = n_2[u_2]$.

Consider a physical quantity which has dimension '*a*' in mass, '*b*' in length and '*c*' in time. If the fundamental units in one system are M_1, L_1 and T_1 and the other system are M_2, L_2 and T_2 respectively, then we can write, $n_1 [M_1^a L_1^b T_1^c] = n_2 [M_2^a L_2^b T_2^c]$

We have thus converted the numerical value of physical quantity from one system of units into the other system.

EXAMPLE

Convert 76 cm of mercury pressure into Nm−2 using the method of dimensions.

Solution

In cgs system 76 cm of mercury pressure = 76 × 13.6 × 980 dyne cm^{-2}

The dimensional formula of pressure P is $[ML^{-1}T^{-2}]$

$$P_1\left[M_1{}^a L_1{}^b T^c{}_1\right] = P_2\left[M_2{}^a L_2{}^b T_2{}^c\right]$$

$$\text{We have } p_2 = p_1\left[\frac{M_1}{M_2}\right]^a\left[\frac{L_1}{L_2}\right]^b\left[\frac{T_1}{T_2}\right]^c$$

$$M_1 = 1_g, M_2 = 1kg$$

$$L_1 = 1cm, L_2 = 1m$$

$$T_1 = 1\,s, T_2 = 1s$$

$$As\ a = 1, b = -1, and\ c = -2$$

Then

$$p_2 = 76\times13.6\times980\left[\frac{1g}{1kg}\right]^1\left[\frac{1cm}{1m}\right]^{-1}\left[\frac{1s}{1s}\right]^{-1}$$

$$= 76\times13.6\times980\left[\frac{10^{-3}kg}{1kg}\right]^1\left[\frac{10^{-2}m}{1m}\right]^{-1}\left[\frac{1s}{1s}\right]^{-2}$$

$$= 76\times13.6\times980\times\left[10^{-3}\right]\times10^2$$

$$p_2 = 1.01\times10^5\,Nm^{-2}$$

EXAMPLE

If the value of universal gravitational constant in SI is $6.6\text{x}10^{-11}$ $Nm^2\ kg^{-2}$, then find its value in CGS System?

Solution

Let GSI be the gravitational constant in the SI system and G_{cgs} in the cgs system. Then

$$G_{SI} = 6.6\times10^{-11}\,Nm^2kg^{-2}$$

$$G_{cgs} = ?$$

$$n_2 = n_1\left[\frac{M_1}{M_2}\right]^a\left[\frac{L_1}{L_2}\right]^b\left[\frac{T_1}{T_2}\right]^c$$

$$G_{cgs} = G_{SI}\left[\frac{M_1}{M_2}\right]^a\left[\frac{L_1}{L_2}\right]^b\left[\frac{T_1}{T_2}\right]^c$$

M_1 = 1 kg L_1 = 1m T_1 = 1s
M_2 = 1 g L_2 = 1 cm T_2 = 1s

The dimensional formula for G is $M^{-1}L^3T^{-2}$

a = -1 b = 3 and c = -2

$$G_{cgs} = 6.6\times10^{-11}\left[\frac{1kg}{1g}\right]^{-1}\left[\frac{1m}{1cm}\right]^3\left[\frac{1s}{1s}\right]^{-2}$$

$$= 6.6\times10^{-11}\left[\frac{1kg}{10^{-3}kg}\right]^{-1}\left[\frac{1m}{10^{-2}m}\right]^{3}\left[\frac{1s}{1s}\right]^{-2}$$

$= 6.6 \times 10^{-11} \times 10^{-3} \text{x } 10^{6} \times 1$

$G_{cgs} = 6.6 \times 10^{-8}$dyne cm^2 g^{-2}

(ii) To check the dimensional correctness of a given physical equation

Let us take the equation of motion v = u + at
Apply dimensional formula on both sides

$[LT^{-1}] = [LT^{-1}] + [LT^{-2}]\,[T]$

(Quantities of same dimension only can be added)
We see that the dimensions of both sides are same. Hence the equation is dimensionally correct.

EXAMPLE

Check the correctness of the equation $\frac{1}{2}mv^2 = mgh$ using dimensional analysis method.

Solution

Dimensional formula for

$$\frac{1}{2}mv^2 = [M]\left[LT^{-2}\right]^2 = \left[ML^2T^{-2}\right]$$

Dimensional formula for

$$mgh = [M]\left[LT^{-2}\right]^2[L] = \left[ML^2T^{-2}\right]$$

$$\left[ML^2T^{-2}\right] = \left[ML^2T^{-2}\right]$$

Both sides are dimensionally the same, hence the equations $\frac{1}{2}mv^2 = mgh$ is dimensionally correct.

(iii) To establish the relation among various physical quantities

If the physical quantity Q depends upon the quantities Q_1, Q_2 and Q_3ie. Q is proportional to Q_1, Q_2 and Q_3.

Then,

$$Q \,\alpha\, Q_1^a\, Q_2^b\, Q_3^c$$

$$Q = k\, Q_1^a\, Q_2^b\, Q_3^c$$

Where k is a dimensionless constant .When the dimensional formula of Q, Q_1, Q_2 and Q_3 are substituted, then according to the principle of homogeneity, the powers of M, L, T are made equal on both sides of the equation. From this, we get the values of a, b, c

EXAMPLE

Obtain an expression for the time period T of a simple pendulum. The time period T depends on

(i) mass '*m*' of the bob

(ii) length '*l*' of the pendulum and

(iii) Acceleration due to gravity *g* at the place where the pendulum is suspended. (Constant k = 2π) i.e

Solution

$$T \,\alpha\, m^a l^b g^c$$
$$T = k.m^a l^b g^c$$

Here k is the dimensionless constant. Rewriting the above equation with dimensions

$$\left[T^1\right] = \left[M^a\right]\left[L^b\right]\left[LT^{-2}\right]^c$$

$$\left[M^0 L^0 T^1\right] = \left[M^a L^{b+c} T^{-2c}\right]$$

Comparing the powers of M, L and T on both sides, a=0, b+c=0,
-2c=1

Solving for a,b and c a = 0, b = 1/2, and c = −1/2

From the above equation T = k. $m^0 l^{1/2}\, g^{-1/2}$

$$T = k\left(\frac{l}{g}\right)^{1/2} = k\sqrt{\frac{l}{g}}$$

Experimentally k = 2π, hence $T = 2\pi\sqrt{\frac{l}{g}}$

Limitations of Dimensional analysis

1. This method gives no information about the dimensionless constants in the formula like 1, 2, ……..π, e (Euler number), etc.
2. This method cannot decide whether the given quantity is a vector or a scalar.
3. This method is not suitable to derive relations involving trigonometric, exponential and logarithmic functions.
4. It cannot be applied to an equation involving more than three physical quantities.
5. It can only check on whether a physical relation is dimensionally correct but not the correctness of the relation. For example using dimensional analysis, $s = ut + 1/3\ at^2$ is dimensionally correct whereas the correct relation is $s = ut + 1/2\ at^2$.