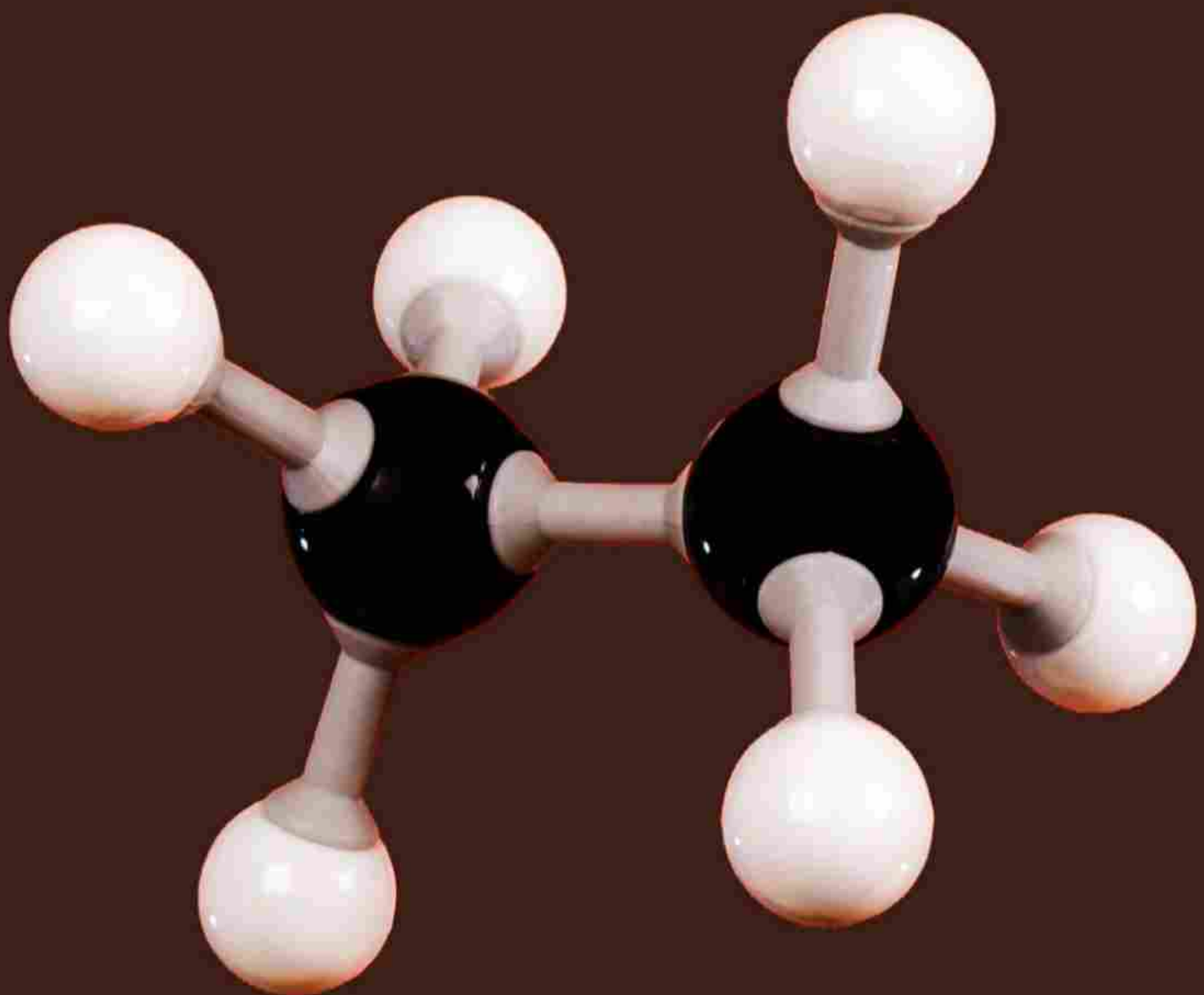
Chemistry

for Secondary Schools

Student's Book

Form Four



Tanzania Institute of Education

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Chemistry

for Secondary Schools

Student's Book
Form Four

THE UNITED REPUBLIC OF TANZANIA
MINISTRY OF EDUCATION,
SCIENCE AND TECHNOLOGY

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Dr Lyabwene M. Mtahabwa
Commissioner for Education

Tanzania Institute of Education

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Director General,
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Preface

This textbook, *Chemistry for Secondary Schools* is written specifically for Form Four students in the United Republic of Tanzania. It is prepared in accordance with the 2007 Chemistry Syllabus for Secondary Schools, Form I-IV, issued by the then, Ministry of Education and Vocational Training.

The book consists of five chapters namely Non-metals and their compounds, Introduction to organic chemistry, Soil chemistry, Pollution, and Qualitative analysis. The chapters comprise of illustrations, activities, tasks, projects, exercises, and revision exercises. You are encouraged to do all the activities, projects, and exercises together with any other assignment provided. Doing so, will promote the development of the intended competencies.

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Chapter One

Non-metals and their compounds

Introduction

Elements in the Periodic Table can be grouped as metals, metalloids, and non-metals depending on their properties. Non-metals are chemical elements that lack the characteristics of metals to form ionic compounds. They usually gain one or more electrons when reacting with metals. The compounds of some non-metals form important industrial products with versatile applications in daily life and in the environment. Some of these products and their by-products have detrimental effects to the environment. In this chapter, you will learn about the concept of non-metals, chemical properties of non-metals, chlorine, hydrogen chloride, sulphur, sulphur dioxide, sulphuric acid, nitrogen, ammonia, carbon, and carbon dioxide. The competencies developed will enable you to use non-metals and their compounds in daily life and apply appropriate skills to control their environmental effects.

Concept of non-metals

Non-metals refer to chemical elements which do not display the properties of metals. They either gain or share electrons during chemical reactions. Most non-metals exist in gaseous state or liquid state, and a few such as carbon and sulphur exist in solid state. Other examples of non-metals are chlorine, and nitrogen. Non-metals are elements located in the upper right-hand portion of the Periodic Table. However, hydrogen is located at different positions in the Periodic Table due to its ability to loose or gain one electron in its valency shell. Figure 1.1 shows the position of non-metals in the Periodic Table. The following are some of the physical properties of non-metals:

Physical properties of non-metals

1. They are generally poor conductors of heat and electricity.
2. They are brittle and cannot be rolled into wires or made into sheets.
3. They have little or no lustre.
4. They have low melting and boiling points.
5. They are electronegative in nature. This means they have a tendency to gain electrons.
6. They are non-sonorous.

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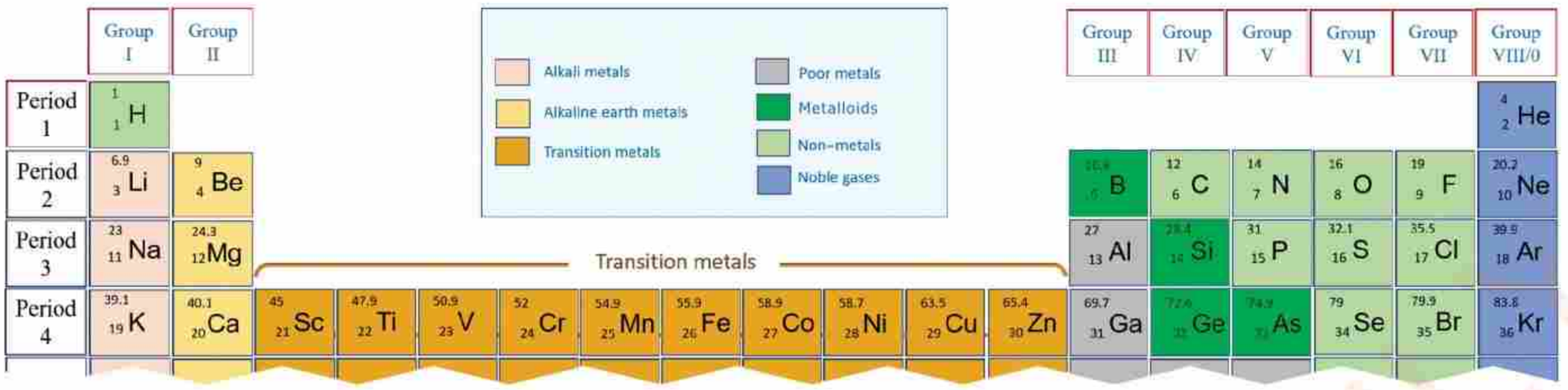


Figure 1.1: *Position of non-metals in the Periodic Table*

Task 1.1

Consider the following materials: aluminium wires, copper wires, iron nails, charcoal, roll sulphur, and zinc strips. Describe each material in terms of:

(a) appearance. (b) malleability. (c) tensile strength.
(d) sonority. (e) density.

Chemical properties of non-metals

Non-metals have a wide range of chemical properties. These properties can be described in terms of oxidising properties (power) and displacement reactions.

Oxidising properties of non-metals

One of the properties of non-metals is their tendency to gain electrons. Most of the non-metals have a range of four to seven electrons in their outermost shells. For example, carbon has 4, nitrogen has 5, oxygen has 6, and chlorine has 7 electrons in their outermost shells. Their electronic configurations are 2:4, 2:5, 2:6, and 2:8:7, respectively. To become stable, the outermost shell has to be half or full filled with electrons. It is easier for non-metals to gain electrons than to lose them. For example, chlorine, oxygen, and nitrogen gain 1, 2 and 3 electrons, respectively. After gaining the electron(s), their stable electronic configurations become 2:8:8, 2:8, and 2:8, respectively.

A chemical substance that gains electron(s) is an *oxidising agent*, and it is also known as an *oxidant* or an *oxidiser*. Non-metals are therefore oxidising agents. The number of electrons gained signifies the valency of the element.

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Strong and weak oxidants

Non-metals react by accepting electrons. The ability of an element to accept electrons is called *electronegativity*. Some elements have higher electronegativity than others. In the Periodic Table, electronegativity generally increases from left to right across the period and decreases down the group. As a result, the most electronegative elements are found on the top right of the Periodic Table, while the least electronegative elements are found on the bottom left. The order of electronegativity of some non-metal elements is as follows:

Fluorine > Oxygen > Chlorine > Nitrogen > Bromine > Iodine > Sulphur > Carbon

The extent of electronegativity indicates the reactivity and hence the oxidising power of the element. In reference to the given trend, fluorine is the strongest oxidant, while carbon is a weak oxidant.

Oxidising power of halogens

Halogens are Group VII elements in the Periodic Table. The oxidising power of halogens decreases down the group in the Periodic Table. This is because electronegativity decreases down the group due to an increase in the distance between the nucleus and the valence shell. The increase in atomic size decreases the attractions of electrons by the nucleus of an atom. Table 1.1 shows the increase in the number of shells as depicted from the electronic configurations of halogens.

Table 1.1: *Electronic configurations of halogens*

Element	Atomic number	Electron configuration
Fluorine	9	2:7
Chlorine	17	2:8:7
Bromine	35	2:8:18:7
Iodine	53	2:8:18:18:7
Astatine	85	2:8:18:32:18:7

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Fluorine is the strongest oxidising agent among the halogens, while astatine is the weakest oxidising agent as shown in Table 1.2.

Table 1.2: *Trend of oxidising power of halogens*

Element	Oxidising trend
Fluorine	Strongest oxidising agent
Chlorine	↓
Bromine	
Iodine	
Astatine	Weakest oxidising agent

Displacement reactions of non-metals

In a displacement reaction, one element takes the place of another in a compound. In such cases, a more reactive non-metal displaces the less reactive one from its compounds. That is, elements with high electronegativity displace those with lower electronegativity from their compounds. For instance, in Group VII, the more reactive halogens displace the less reactive halogens from their halide salts. In this case, fluorine displaces chlorine or bromine from their compounds. Such displacement reactions are shown in the following equations:

$$2KCl(aq) + F_2(g) \longrightarrow 2KF(aq) + Cl_2(g)$$

$$PbBr_2(aq) + F_2(g) \longrightarrow PbF_2(aq) + Br_2(l)$$

Similarly, chlorine displaces bromine or iodine from their compounds as shown in the following equations:

$$2KBr(aq) + Cl_2(g) \longrightarrow 2KCl(aq) + Br_2(l)$$

$$2NaI(aq) + Cl_2(g) \longrightarrow 2NaCl(aq) + I_2(s)$$

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Activity 1.1

Aim: To investigate the displacement reactions involving non-metals

Requirements: Test tubes, round-bottomed flask fitted with a thistle funnel and a delivery tube, potassium bromide solution, potassium iodide solution, potassium permanganate crystals, and concentrated hydrochloric acid

Caution: Halogens are poisonous. This experiment should be performed in a fume chamber or using full-face respirator.

Procedure

1. Put some crystals of potassium permanganate in a round-bottomed flask and some concentrated hydrochloric acid in a thistle funnel.
2. Put some potassium bromide solution in a test tube.
3. Set up the apparatus as shown in Figure 1.2.

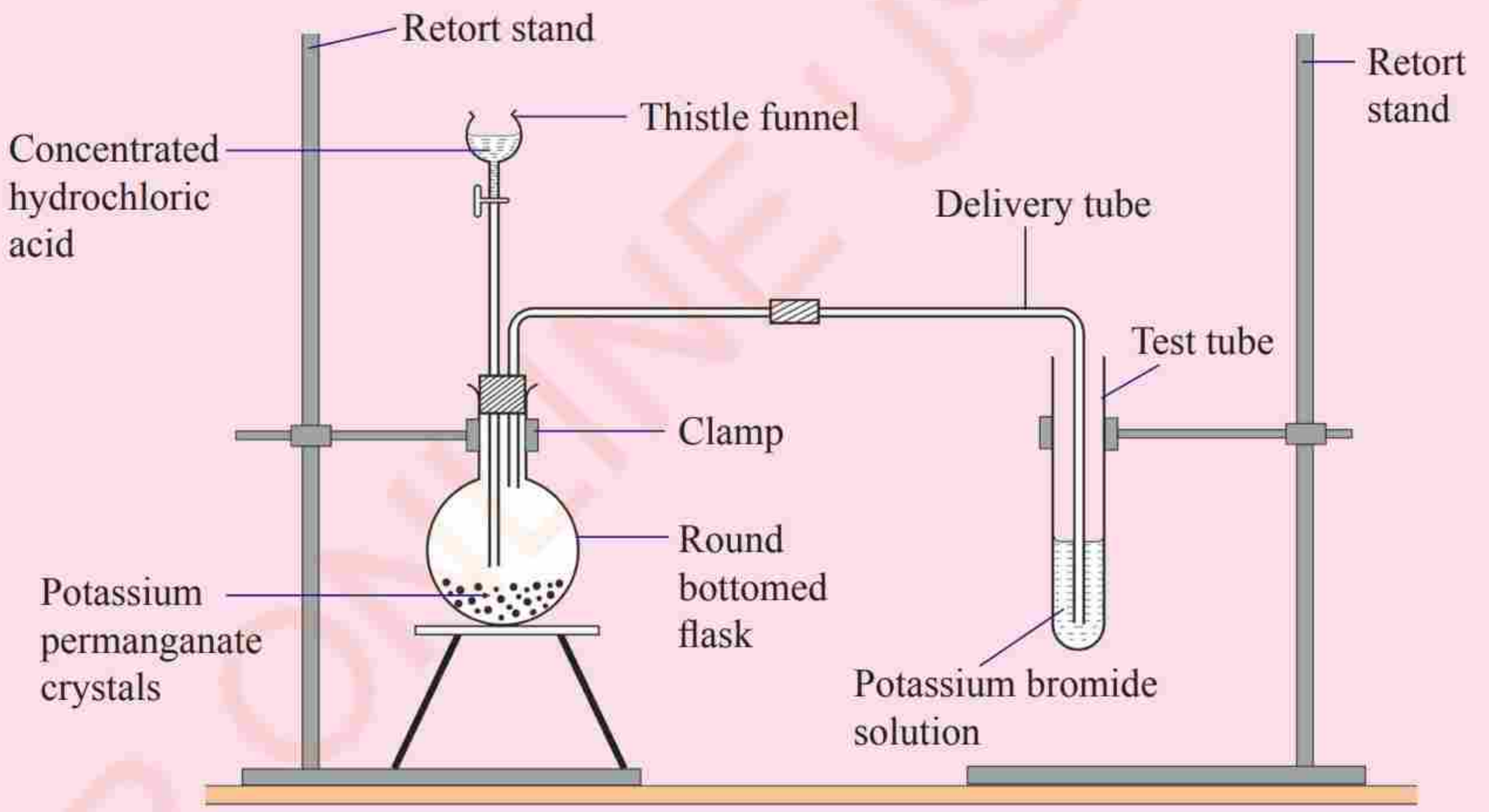


Figure 1.2: *Set-up of the displacement reactions involving non-metals*

4. Open the thistle funnel tap to release concentrated hydrochloric acid dropwise into potassium permanganate crystals. Continue adding the acid until the reaction stops.
5. Observe what happens to the potassium bromide solution in the test tube.
6. Repeat steps 1 to 5 using potassium iodide solution in place of potassium bromide solution. Record the observations.

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Questions

1. What is the importance of the reaction between concentrated hydrochloric acid and potassium permanganate crystals in this experiment?
2. Write an equation for the reaction in (1).
3. Using an equation in 2, explain what was observed in the test tube containing potassium bromide solution when concentrated hydrochloric acid reacted with the potassium permanganate crystals.

Formation of acidic oxides

Non-metals react with oxygen to form acidic oxides as shown in the following examples:

$$C(s) + O_2(g) \longrightarrow CO_2(g)$$
$$S(s) + O_2(g) \longrightarrow SO_2(g)$$

Chlorine

Chlorine exists as a diatomic gas molecule (Cl_2). It is a group VII and period 2 element of the Periodic Table. Its atomic number is 17 and has an electronic configuration of 2:8:7. Chlorine is a very reactive element and the second strongest oxidising agent among the halogens, after fluorine. Chlorine gas is greenish-yellow in colour and exists in nature in combination with other elements in form of chlorides. Sodium chloride is the main source of chlorine in most industrial processes. Chlorine gas is extremely poisonous and is the first poisonous gas that was used during the First World War in 1916. It attacks the nasal and lung membranes and eventually causes death.

Preparation of chlorine gas

Chlorine gas can be prepared in the laboratory by the oxidation of concentrated hydrochloric acid using oxidising agents such as potassium permanganate, manganese(IV) oxide, and lead(IV) oxide. When manganese(IV) oxide and concentrated hydrochloric acid are used to prepare chlorine, gentle heating is required. The set-up for the laboratory preparation of chlorine gas is shown in Figure 1.3. The equation for the chemical reaction that takes place is as follows:

$$MnO_2(s) + 4HCl(l) \longrightarrow Cl_2(g) + MnCl_2(aq) + 2H_2O(l)$$

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Chlorine gas is passed through water in the first conical flask to remove any acid spray and hydrogen chloride gas. The concentrated sulphuric acid in the second flask is for drying the chlorine gas. Chlorine is denser than air and can be collected by the downward delivery method. It is not collected over water because it is fairly soluble in water forming yellow chlorine water.



Activity 1.2

Aim: To prepare chlorine gas

Requirements: Round-bottomed flask, thistle funnel with a tap, 3 two-holed rubber stoppers, 2 conical flasks, gas jar, delivery tubes, retort stand and clamp, Bunsen burner, spatula, blue litmus paper, coloured flowers, manganese(IV) oxide, concentrated sulphuric acid, concentrated hydrochloric acids, and distilled water

Caution: Chlorine gas is very poisonous. This experiment should be done in a fume chamber or using full-face respirator. Concentrated hydrochloric acid and sulphuric acid are very corrosive. Handle them with care.

Procedure

1. Put 4 spatulaful of manganese(IV) oxide in a round-bottomed flask.
2. Set up the apparatus as shown in Figure 1.3.

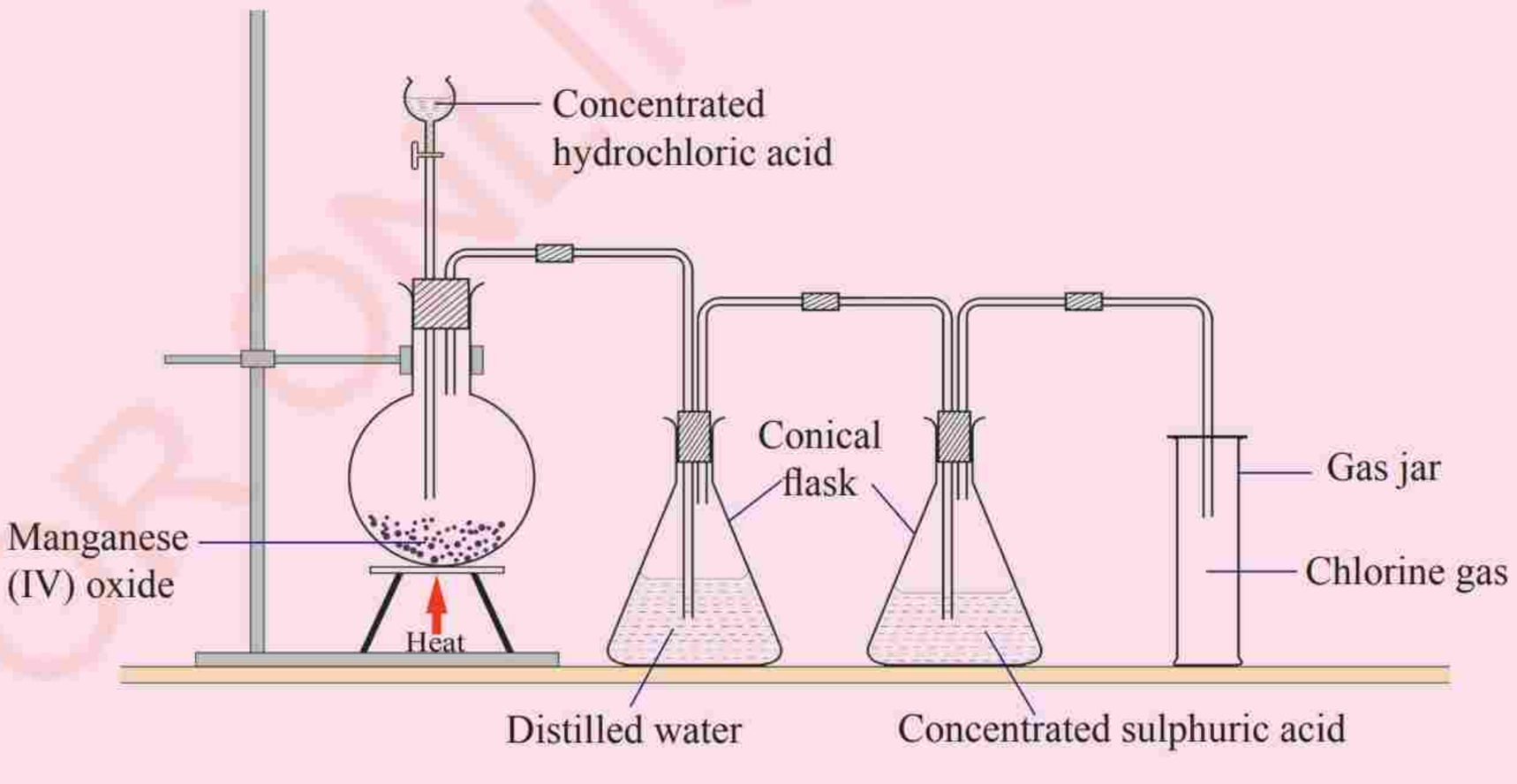


Figure 1.3: *Set-up for the laboratory preparation of chlorine gas*

3. Open the tap on the thistle funnel to release concentrated hydrochloric acid dropwise into the flask containing manganese(IV) oxide.

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4. Gently heat the components in the flask.
5. Allow the reaction to proceed for about 1 minute and then collect the gas being produced.
6. Dip a moist blue litmus paper into the gas jar.
7. Dip coloured flowers into the gas jar containing chlorine gas. Record the observations in steps 3 to 7.

Questions

1. Write an equation for the reaction that took place in the round-bottomed flask.
2. What were the roles of distilled water and concentrated sulphuric acid in this reaction?
3. Why is the heating in Step 4 done gently?
4. Why is chlorine gas collected by upward displacement of air?
5. Comment on the solubility of chlorine gas in water.
6. Why should the litmus paper used for testing chlorine gas be moist?

The other methods of preparing chlorine gas are similar to the one illustrated in Figure 1.3. The main difference is the oxidising agent used and the conditions under which the reactions take place (Table 1.3). For instance;

(a) Potassium manganate(VII), is a very strong oxidising agent and when used instead of manganese(IV) oxide, no heating is needed during the reaction.

(b) Mixing manganese(IV) oxide with sodium chloride is another convenient method of preparing chlorine gas. Concentrated sulphuric acid is added instead of concentrated hydrochloric acid and heating is required during this reaction. The mixture reacts to form respective metal salts, water, and chlorine gas. The overall equation for the reaction is as follows:

$$4NaCl(s) + MnO_2(s) + 4H_2SO_4(l) \xrightarrow{\Delta} MnCl_2(aq) + 4NaHSO_4(aq) + 2H_2O(l) + Cl_2(g)$$

(c) Chlorine can also be prepared by the action of dilute hydrochloric acid on calcium hypochlorite, $Ca(ClO)_2$ (bleaching powder). No heating is required.

$$Ca(ClO)_2(s) + 4HCl(aq) \longrightarrow CaCl_2(aq) + 2H_2O(l) + 2Cl_2(g)$$

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Table 1.3: *Summary of the reagents and conditions for preparing chlorine gas*

Reagents	**Conditions**
Manganese(IV) oxide, MnO_2 and concentrated hydrochloric acid, HCl	Heating is required
Potassium manganate(VII), $KMnO_4$ and concentrated hydrochloric acid, HCl	No heating is required
Mixture of manganese(IV) oxide, MnO_2 and sodium chloride, NaCl and concentrated sulphuric acid, H_2SO_4	Heating is required
Calcium hypochlorite, $Ca(ClO)_2$ and any dilute mineral acid	No heating is required

Exercise 1.1

1. Write **TRUE** for a correct statement and **FALSE** for an incorrect statement. Give a reason for the incorrect statement(s).
   (a) Chlorine gas belongs to Group VII elements and so it loses an electron when it reacts with other substances.
   (b) Chlorine gas is formed by the oxidation of hydrochloric acid.
   (c) Heating is necessary to start the reaction when chlorine is prepared by reacting potassium manganate(VII) and concentrated hydrochloric acid.
   (d) Chlorine gas turns moist blue litmus paper permanently red.
2. Basing on their physical properties, compare non-metals with metals.
3. Explain the following statements:
   (a) Chlorine gas is collected by upward displacement of air.
   (b) The role of potassium permanganate in the preparation of chlorine gas.
4. What will be observed when:
   (a) chlorine gas is passed through moist litmus paper?
   (b) bleaching powder reacts with dilute hydrochloric acid?
5. Chlorine can be prepared by heating a mixture of manganese(IV) oxide, sodium chloride and concentrated sulphuric acid. Write the ionic equation for this reaction.

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Properties of chlorine gas

The following are some of the physical and chemical properties of chlorine gas:

Physical properties

(a) It is a greenish-yellow gas with a pungent irritating smell. It is poisonous if inhaled.

(b) It is denser than air and therefore collected by downward delivery method. The method is also known as upward displacement of air.

(c) It turns moist blue litmus paper red, and then bleaches it.

(d) It is moderately soluble in water.

Chemical properties

Chlorine gas is very reactive. It reacts with various elements and compounds.

(a) When collected in water, chlorine dissolves in it to form a pale-yellow solution known as chlorine water. Chlorine water is a mixture of hypochlorous acid (HOCl) and hydrochloric acid.

$$H_2O(l) + Cl_2(g) \longrightarrow HCl(aq) + HOCl(aq)$$

When hypochlorous acid comes into contact with a dye, it oxidises the dye to a colourless compound.

$$HOCl(aq) + \text{dye} \longrightarrow HCl(aq) + \text{dye-oxygen complex compound } (\textit{colourless})$$

(b) Chlorine oxidises hydrogen sulphide gas to a yellow precipitate of sulphur and is itself reduced to hydrogen chloride gas.

$$H_2S(g) + Cl_2(g) \longrightarrow S(s) + 2HCl(g)$$

The hydrogen chloride gas formed gives dense white fumes of ammonium chloride when reacted with ammonia gas, which settle as a white solid.

$$NH_3(g) + HCl(g) \longrightarrow NH_4Cl(s)$$



Activity 1.3

Aim: To investigate the oxidation of hydrogen sulphide by chlorine gas

Requirements: Gas jar, retort stand and clamp, Kipp's apparatus, boiling tube, rubber bung, beaker, iron(II) sulphide, dilute hydrochloric acid, potassium permanganate, and concentrated hydrochloric acid

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Procedure

1. Prepare chlorine gas following steps 1 to 5 of Activity 1.2.
2. Prepare chlorine water by passing the gas through water as shown in Figure 1.4(a).

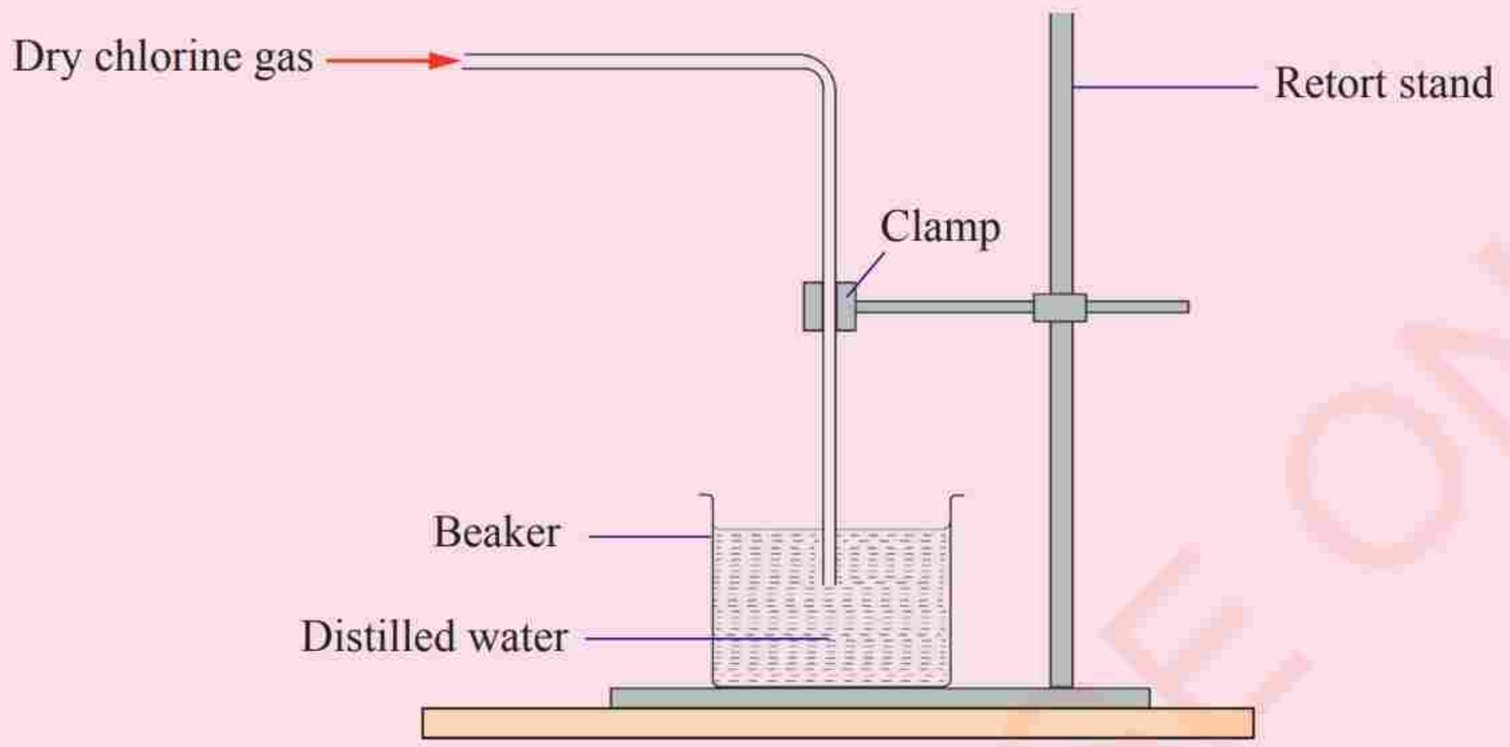


Figure 1.4(a): *Set-up for the preparation of chlorine water*

3. Using the Kipp's apparatus, prepare hydrogen sulphide gas from iron(II) sulphide and dilute sulphuric acid. Set the apparatus as shown in Figure 1.4(b).

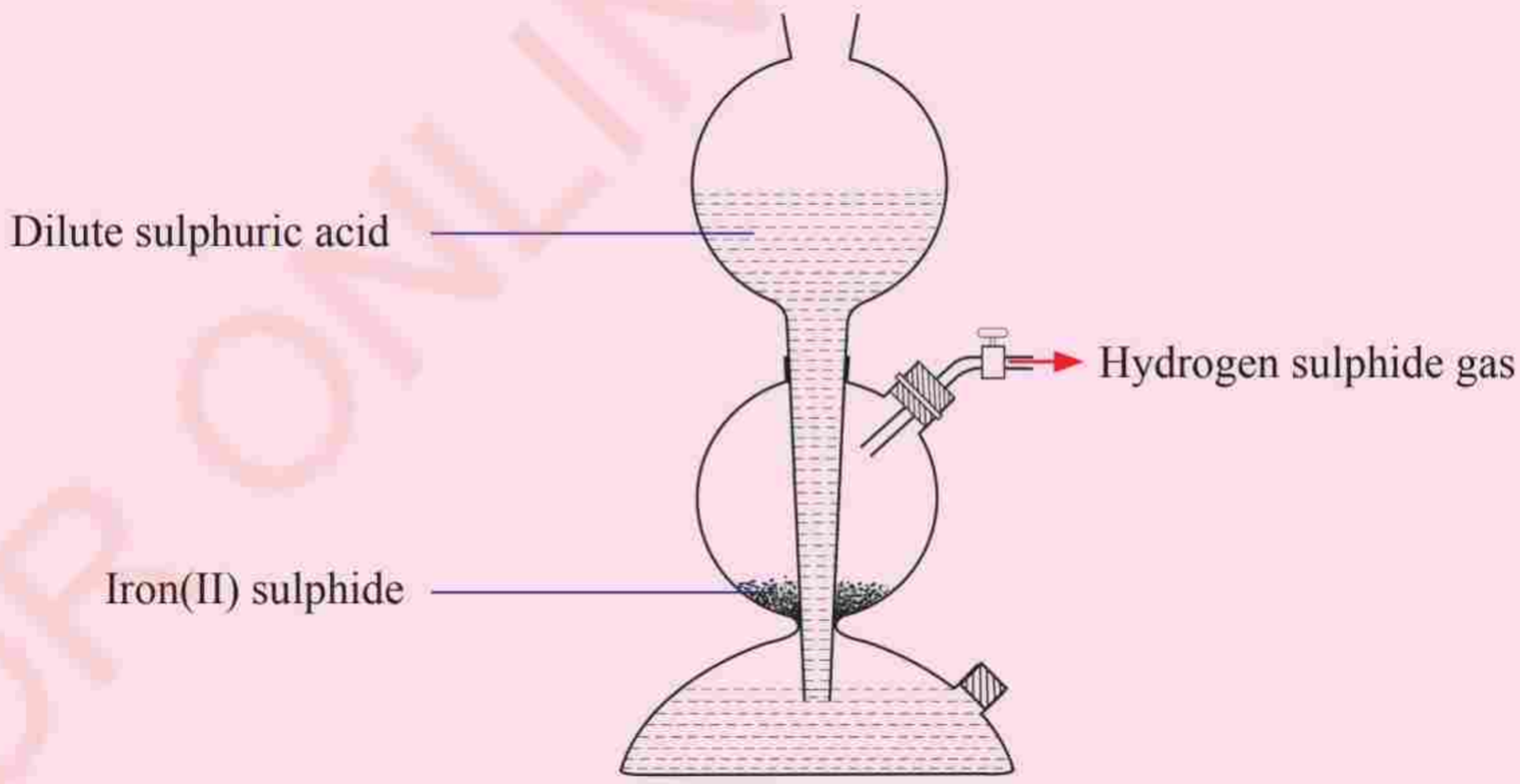


Figure 1.4(b): *Set-up for the preparation of hydrogen sulphide*

4. Pass the hydrogen sulphide gas through the chlorine water.
5. Test for the gas produced using a drop of concentrated aqueous ammonia on a glass rod.

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Questions

1. What was observed when hydrogen sulphide gas was bubbled through chlorine water?
2. Write a balanced chemical equation for the reaction in steps 3 and 4.
3. Describe the smell of hydrogen sulphide and the colour of chlorine water.

(c) Chlorine oxidises iron(II) chloride to iron(III) chloride as shown in the following equation:

$$Cl_2(g) + 2FeCl_2(s) \xrightarrow{\text{heat}} 2FeCl_3(s)$$

The greenish yellow colour of iron(II) chloride turns brown, which is the colour of iron(III) chloride.



Activity 1.4

Aim: To investigate the oxidation of iron(II) chloride by chlorine gas

Requirements: Glass tubes, ignition tube, retort stand and clamp, source of chlorine gas, Bunsen burner, and iron(II) chloride

Procedure

1. Put some iron(II) chloride in an ignition tube.
2. Set up the apparatus as shown in Figure 1.5.

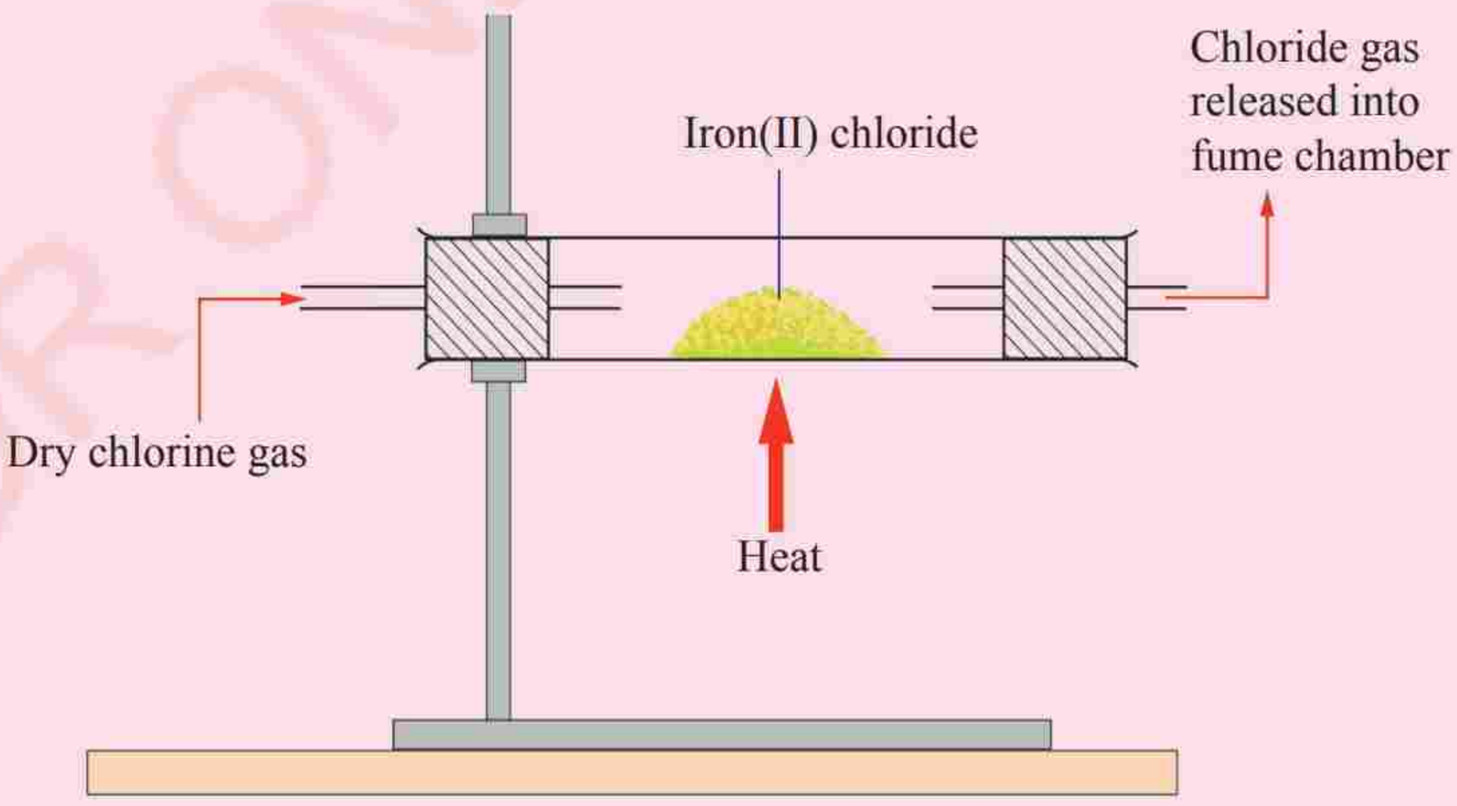


Figure 1.5: *Set-up for the oxidation of iron(II) chloride by chlorine gas*

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3. Gently, heat the iron(II) chloride while passing a stream of dry chlorine gas from the source.
4. Continue passing chlorine gas until no further change is observed on the iron(II) chloride. Record the observations.

Questions

1. What was observed when chlorine gas was passed over heated iron(II) chloride?
2. Write an equation for reaction in Step 3.
3. What type of reaction between chlorine gas and hot iron(II) chloride?

(d) Chlorine gas reacts with hydrogen gas to form hydrogen chloride gas.

$$Cl_2(g) + H_2(g) \longrightarrow 2HCl(g)$$

(e) Chlorine gas oxidises sulphites such as sodium sulphite to produce sulphates.

$$Na_2SO_3(aq) + Cl_2(g) + H_2O(l) \longrightarrow Na_2SO_4(aq) + 2HCl(aq)$$

(f) Chlorine gas reacts with cold sodium or potassium hydroxide solution to form a mixture of chlorides and hypochlorites. The produced sodium hypochlorite is used as a bleaching agent, and potassium hypochlorite is used as a disinfectant in drinking water.

$$2NaOH(aq) + Cl_2(g) \longrightarrow NaCl(aq) + NaOCl(aq) + H_2O(l)$$
$$2KOH(aq) + Cl_2(g) \longrightarrow KCl(aq) + KOCl(aq) + H_2O(l)$$

(g) Chlorine gas reacts with a hot solution of sodium hydroxide or potassium hydroxide to give a chloride, chlorate, and water.

$$6NaOH(aq) + 3Cl_2(g) \longrightarrow 5NaCl(aq) + NaClO_3(aq) + 3H_2O(l)$$
$$6KOH(aq) + 3Cl_2(g) \longrightarrow 5KCl(aq) + KClO_3(aq) + 3H_2O(l)$$

(h) Chlorine oxidises sulphur dioxide gas to sulphuryl chloride.

$$Cl_2(g) + SO_2(g) \longrightarrow SO_2Cl_2(g)$$

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Uses of chlorine

Chlorine has variety of uses as follows:

Bleaching agent: Chlorine is used as a bleaching agent in textile industries. It is also used to bleach wood pulp in the paper industry. Liquid household bleach is a solution of sodium hypochlorite (NaOCl).

Disinfectant: Chlorine can be used as a disinfectant. It is used in water treatment to kill microorganisms in drinking water, swimming pools, and ornamental ponds.

Manufacture of hydrochloric acid: Chlorine is used to prepare hydrogen chloride gas, which is dissolved in water to form hydrochloric acid. The acid is used as a rust remover and a reagent in many industrial processes.

Manufacture of plastics: Chlorine is used in the manufacture of plastics such as polychloroethene, commonly known as polyvinylchloride (PVC). PVC is used in making insulators for wires and cables.

Hydrogen chloride

Hydrogen chloride gas is a compound of chlorine and hydrogen with the molecular formula HCl.

Preparation of hydrogen chloride

Hydrogen chloride gas can be prepared in the laboratory by double decomposition reaction of sodium chloride with concentrated sulphuric acid.

$$NaCl(s) + H_2SO_4(l) \longrightarrow NaHSO_4(aq) + HCl(g)$$



Activity 1.5

Aim: To prepare hydrogen chloride gas

Requirements: Round-bottomed flask, gas jar with a cover, thistle funnel with a tap, delivery tubes, rubber stoppers with holes, wash bottles, blue litmus paper, concentrated sulphuric acid, and sodium chloride crystals

Caution: Use a laboratory reagent for sodium chloride and not table salts since table salts contain iodine which may interfere with the experiment. The reaction mixture contains excess concentrated sulphuric acid, therefore, add water with care when disposing it.

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Procedure

1. Put sodium chloride in a round-bottomed flask.
2. Set up the apparatus as shown in Figure 1.6.

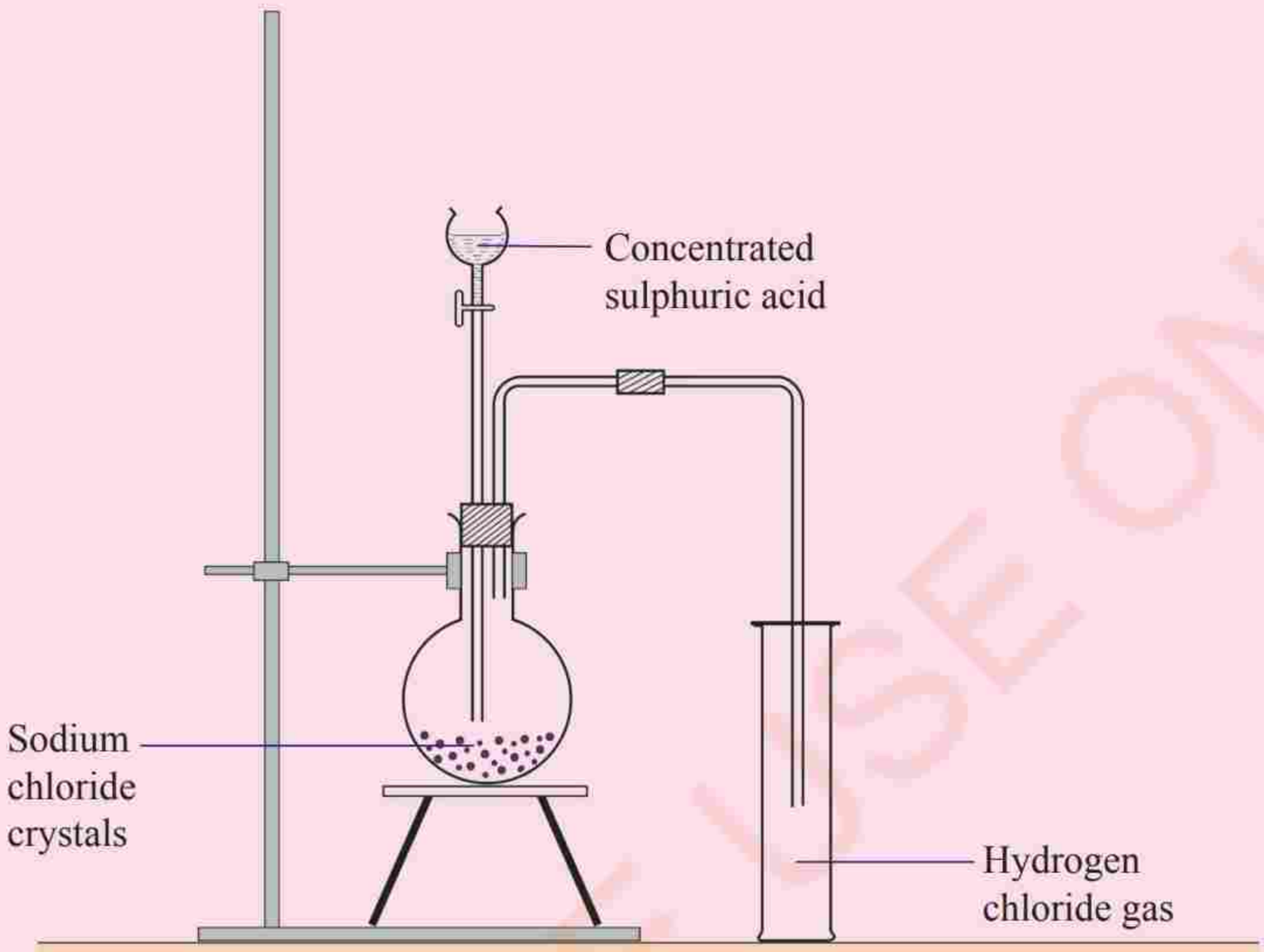


Figure 1.6: *Set-up for preparation of hydrogen chloride gas*

3. Place a dry and a moist blue litmus papers at the mouth of the gas jar.
4. Add concentrated sulphuric acid from the thistle funnel dropwise until enough gas is formed. Record the observations.

Questions

1. Write an equation for the reaction in the round-bottomed flask.
2. Comment on the density of the gas formed in Step 4 with respect to that of air.
3. Explain the observations made on the dry and moist blue litmus papers, when sulphuric acid was added to sodium chloride.

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Properties of hydrogen chloride gas

Some of the physical and chemical properties of hydrogen chloride gas are as follows:

Physical properties

(a) It is a colourless gas.

(b) It has a pungent choking smell.

(c) It turns moist blue litmus paper red showing that the gas is acidic.

(d) It does not burn, but extinguishes a burning wooden splint.

(e) It is denser than air, thus collected by downward delivery or upward displacement of air.

(f) Hydrogen chloride gas is very soluble in water, and forms hydrochloric acid that dissociates into ions when dissolved in water.

$$HCl(g) \xrightarrow{H_2O} HCl(aq)$$

$$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$$

It is possible to test the solubility of hydrogen chloride gas in water. The solubility test is done by passing the gas from the flask through water in a beaker. As the gas flows out from the flask, the pressure in the delivery tube and in the flask is reduced. The atmospheric pressure from outside forces the water in the beaker back into the delivery tube. This effect is called *'sucking back'*. The filter funnel is used to prevent the "suck-back" effect as it provides a large surface area for the gas to dissolve in water.



Activity 1.6

Aim: To investigate the solubility of hydrogen chloride gas in water

Requirements: Round-bottomed flask, gas jar with a cover, thistle funnel with a tap, delivery tubes, rubber stoppers with holes, wash bottles, concentrated sulphuric acid, sodium chloride, glass tube, filter funnel, beaker, and distilled water

Procedure

1. Prepare hydrogen chloride gas following steps 1, 2, and 4 in Activity 1.5.

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2. Pass the gas through water in a beaker as shown in Figure 1.7. Record the observations.

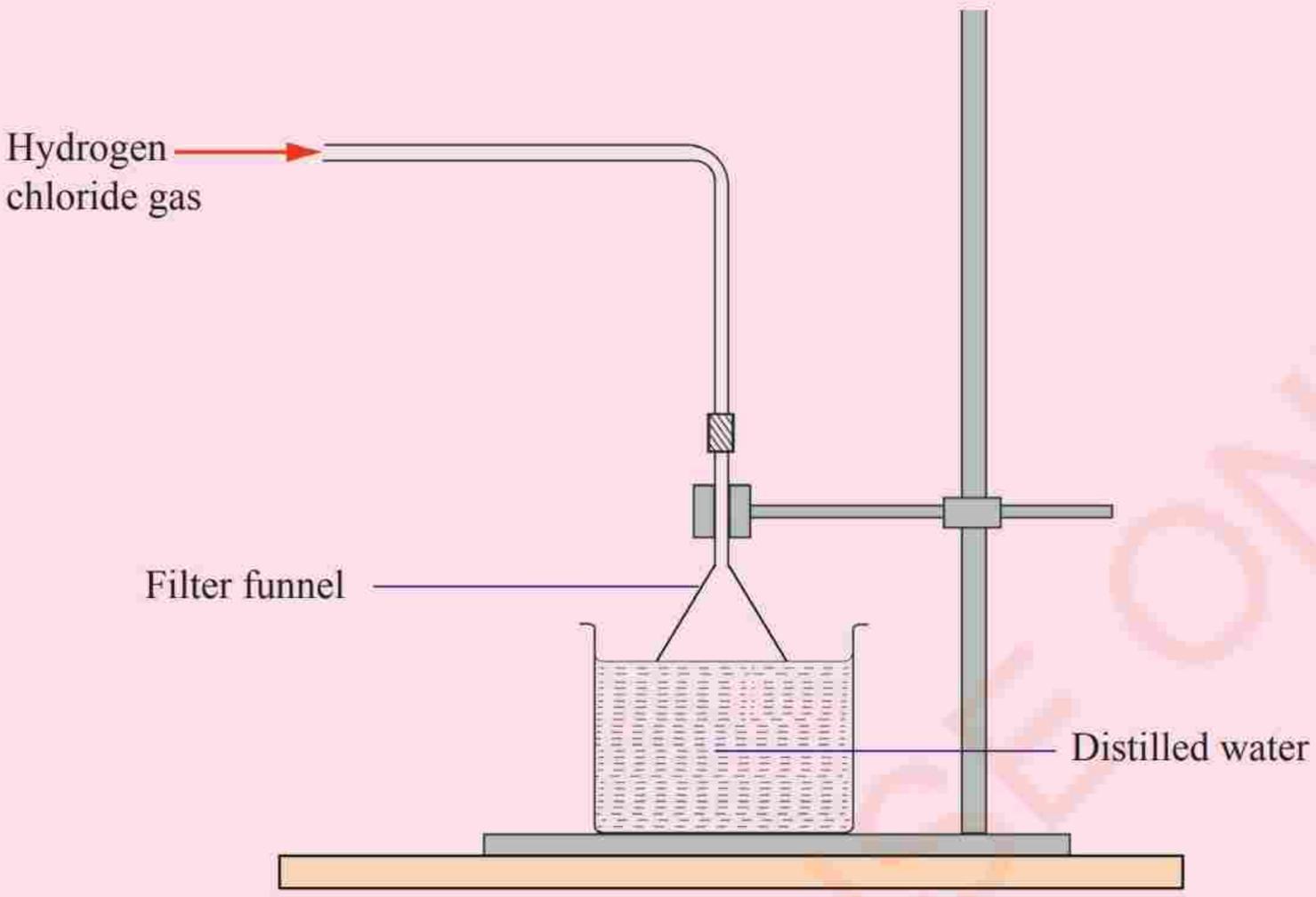


Figure 1.7: *Set-up for testing the solubility of hydrogen chloride gas in water*

Questions

1. What was the use of the filter funnel inverted over water in the beaker?
2. Comment on the solubility of hydrogen chloride gas in water.
3. Explain how the dissolved HCl gas is tested.

Chemical properties

(a) *Reaction with ammonia*: Hydrogen chloride gas reacts with ammonia gas to form dense white fumes of ammonium chloride.



Activity 1.7

Aim: To investigate the reaction of hydrogen chloride gas with ammonia gas

Requirements: Glass rod, gas jar, concentrated aqueous ammonia, and hydrogen chloride gas

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Procedure

1. Dip the glass rod into the solution of ammonia to obtain a drop of the solution.
2. Place the rod over the mouth of the gas jar containing hydrogen chloride gas as shown in Figure 1.8. Record the observations.

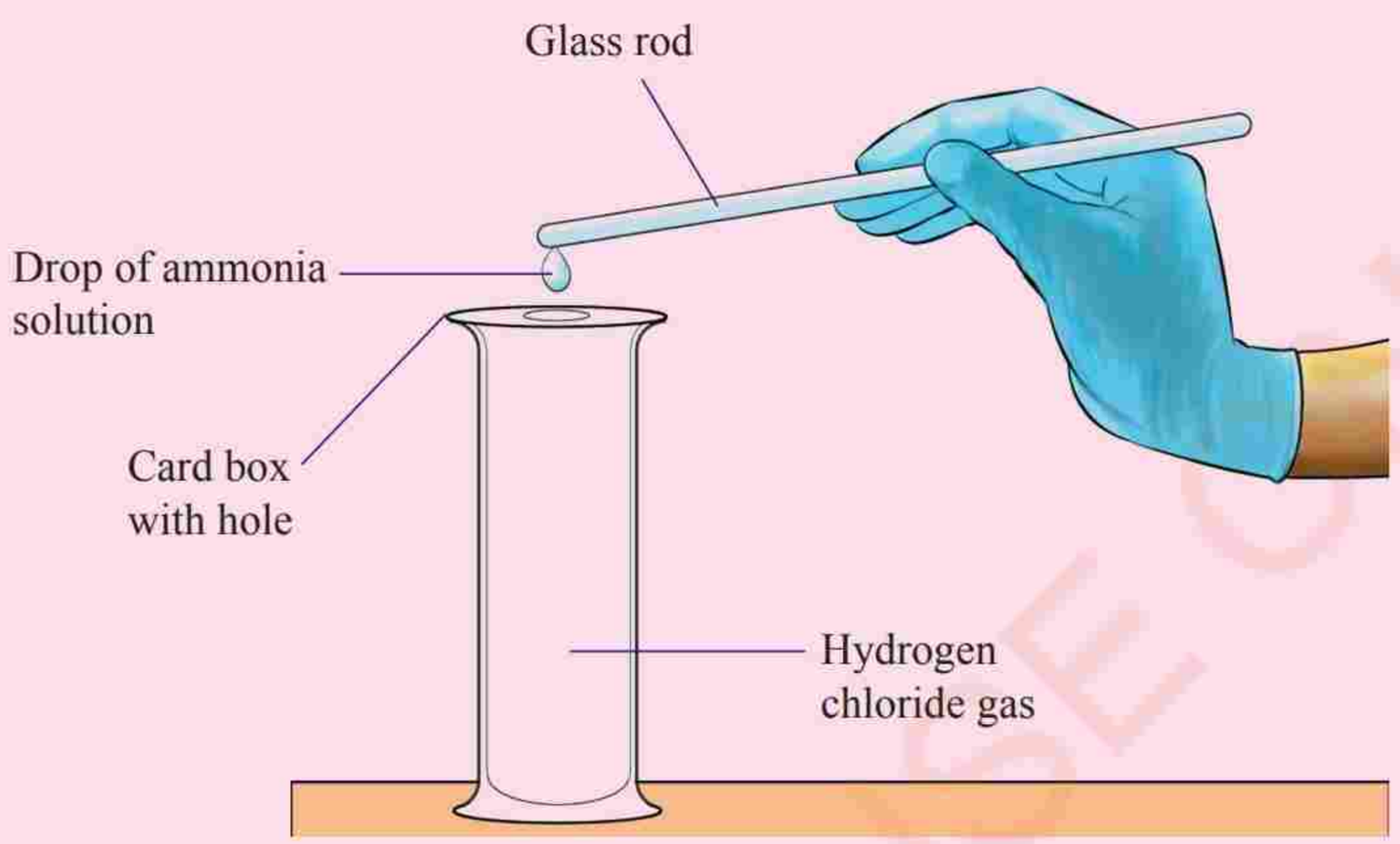


Figure 1.8: *Set-up for the reaction of hydrogen chloride gas with ammonia*

Questions

1. Explain the observations when a drop of concentrated aqueous ammonia was put into the mouth of a gas jar containing hydrogen chloride gas.
2. Write an equation for the reaction that occurred in this experiment.

(b) *Reaction with metals*: Aqueous hydrogen chloride which is actually hydrochloric acid, reacts with metals to produce metal chlorides and hydrogen gas through substitution reactions. For example, dilute hydrochloric acid reacts with zinc metal to form zinc chloride and hydrogen gas. Copper(II) sulphate crystals act as a catalyst.

$$Zn(s) + 2HCl(aq) \xrightarrow{CuSO_4(s)} ZnCl_2(aq) + H_2(g)$$

When a burning wooden splint is lowered into the gas jar containing the collected gas, the gas burns with a 'pop' sound. This confirms that the collected gas is hydrogen. Hydrogen gas is collected over water because it is insoluble in water. Concentrated hydrochloric acid and dilute hydrochloric acid have no effect on copper metal because copper has a higher reduction potential (+0.34 V) than that of hydrogen (0.00 V).

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Therefore, copper cannot replace hydrogen in HCl to form $CuCl_2$. Calcium, magnesium, and iron react with dilute hydrochloric acid even without a catalyst. These reactions are shown in the following equations:

$$Ca(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2(g)$$

$$Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$$

$$Fe(s) + 2HCl(aq) \longrightarrow FeCl_2(aq) + H_2(g)$$

$$Cu(s) + HCl(aq) \longrightarrow \text{No reaction}$$

NOTE: Zinc metal can also react with dilute hydrochloric acid without a catalyst to produce zinc chloride and hydrogen gas, but the reaction is slower than when the catalyst is used.



Activity 1.8

Aim: To investigate the reactions of dilute hydrochloric acid with metals

Requirements: Round-bottomed flask, thistle funnel, gas jar, beehive shelf, trough, delivery tube, retort stand with a clamp, wooden splint, matchbox or gas lighter, dilute hydrochloric acid, zinc granules, copper powder, calcium, magnesium ribbon, iron powder, and copper(II) sulphate crystals

Procedure

1. Put zinc granules and copper(II) sulphate in a round-bottomed flask.
2. Set up the apparatus as shown in Figure 1.9.

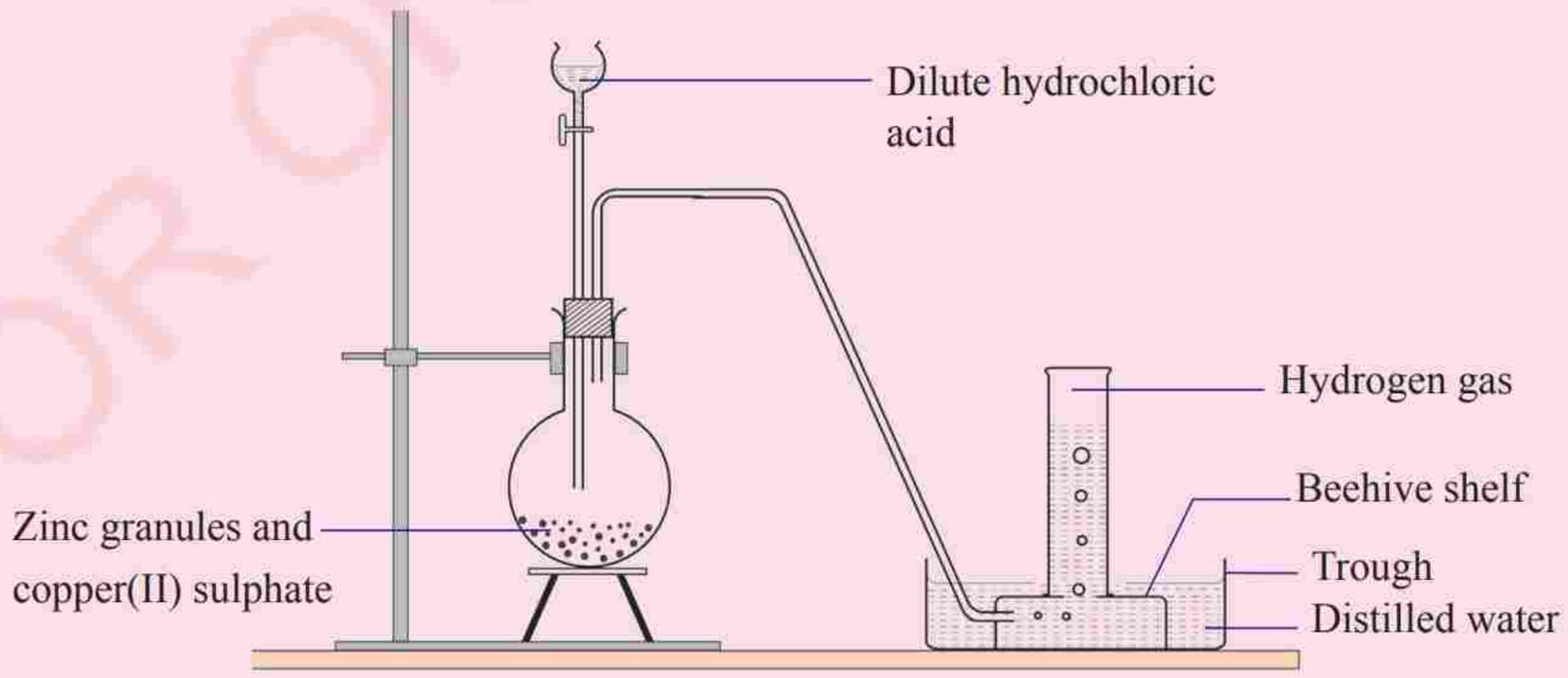


Figure 1.9: *Set-up for the reaction of dilute hydrochloric acid with zinc*

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3. Open the tap of the thistle funnel to allow dilute hydrochloric acid to run dropwise into the mixture in the flask. Continue running the acid until no more effervescence is observed.
4. Test the collected gas using a burning wooden splint.
5. Repeat steps 1 to 4 using calcium, magnesium, copper, and iron metals in place of zinc metal.

Questions

1. What was observed when the acid came into contact with zinc granules?
2. Write the equations for the reactions (if any) of dilute hydrochloric acid with the five metals used.
3. What was the purpose of using copper(II) sulphate crystals?
4. Explain the significance of using a wooden splint in the experiment.
5. What physical property of the gas produced allows it to be collected using the method shown in this experiment?

(c) *Reaction with metal carbonates*: Dilute hydrochloric acid reacts with carbonates of metals to give salt (chloride), water, and carbon dioxide gas. For example, calcium carbonate reacts with dilute hydrochloric acid to give calcium chloride, water, and carbon dioxide gas.

$$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

Magnesium carbonate reacts with dilute hydrochloric acid in the same way as for calcium carbonate to give magnesium chloride, water, and carbon dioxide.

$$MgCO_3(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2O(l) + CO_2(g)$$

(d) *Reaction with metal oxides*: Dilute hydrochloric acid reacts with some metal oxides to give salt and water. For example:

$$CaO(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l)$$

$$MgO(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2O(l)$$

(e) *Reaction with metal hydroxides*: The reactions of dilute hydrochloric acid with metal hydroxides produce salts and water. For example, sodium hydroxide reacts with hydrochloric acid to give sodium chloride and water.

$$NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

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Uses of hydrogen chloride gas

Hydrogen chloride gas is mainly used in solution form of hydrochloric acid. The following are some of the uses of hydrochloric acid:

Controlling pH in some chemical processes: Industries, such as those which manufacture food, medicines, and drinking water use high quality hydrochloric acid to control the pH of the reagents.

Cleaning metals and tiles: Hydrochloric acid is used to remove rust ($Fe_2O_3 \cdot xH_2O$) from iron. The acid dissolves the oxide (the rust) to form a soluble chloride.

$$Fe_2O_3 \cdot xH_2O(s) + 6HCl(aq) \longrightarrow 2FeCl_3(aq) + (3 + x)H_2O(l)$$

Hydrochloric acid is also used in removing limescale from boilers. Limescale is the precipitation of calcium salts in water which causes formation of hard scale in pipes, taps, washing machines, shower heads, and boilers. Hydrochloric acid is used for cleaning tiles in kitchens and bathrooms.

Production of inorganic compounds: Many useful inorganic compounds such as iron(III) chloride and polyaluminium chloride (PAC) can be produced using hydrochloric acid in acid-base reactions. Both iron(III) chloride and PAC are used as flocculation and coagulation agents in the treatment of drinking water and wastewater. They are also used in paper production.

Qualitative and quantitative analysis: Hydrochloric acid is used to analyse substances in laboratories. For example, iron(II) oxide (FeO) is insoluble in water but it can dissolve in hydrochloric acid to form iron(II) chloride solution.

$$FeO(s) + 2HCl(aq) \longrightarrow FeCl_2(aq) + H_2O(l)$$

In quantitative analysis, hydrochloric acid is used in some titration reactions in order to quantify substances present in certain samples.

Production of organic compounds: Hydrochloric acid manufactured in industries is used in the production of organic compounds such as polyvinylchloride (PVC) and dichloromethane.

Other uses: Hydrochloric acid is also used in the following processes:

(a) production of industrial fertilisers, dyes, artificial silk, paper, and paint pigments.

(b) refining of edible oils and fats.

(c) concentration of metal ores.

(d) refining of cane sugar.

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(e) making glue and gelatin.

(f) purification of common salt.

(g) manufacture of aqua regia for extraction of metals such as gold and platinum.

Exercise 1.2

1. Chlorine gas is denser than air and is soluble in water.
   (a) What is the best method used to collect the gas during its preparation?
   (b) Give four uses of chlorine gas.
2. Explain the colour change of the moist blue litmus paper dipped in a gas jar containing hydrogen chloride gas.
3. Write the balanced chemical equation for the reaction between concentrated hydrochloric acid and manganese dioxide.
4. Describe the chemical test that can be used to confirm the presence of hydrogen chloride gas.

Sulphur

Sulphur is a yellow, non-metallic element with atomic number 16. It is a member of Group VI elements that occurs in both free and combined states. A large percent (about three quarter) of sulphur exists in nature as a free element, while a small percent exists in compounds, mainly as sulphides and sulphates. As a free element, sulphur is found in hot springs and volcanic regions in many parts of the world.

Extraction of sulphur

Sulphur is extracted from its underground deposits by the *Frasch process*. The Frasch process is an industrial method used for recovering sulphur from elemental deposits where it is melted underground and forced out by hot compressed air.

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Frasch process

Sulphur deposits are found over 200 metres beneath the rocks and quicksand. Under these conditions, sulphur mining using the open methods is impossible because the sand would collapse and bury the miners. In 1890, the German-born American chemist, Herman Frasch, developed a method of overcoming the depth problem. The method involves melting the sulphur while it is still underground and then forcing it out. The method has since then been called the *Frasch process*. The Frasch process makes use of the relative low melting point (119 ºC) character of sulphur. In this process, three concentric pipes (pipes with a common centre) are used for pumping in hot air and water, and pumping out the froth (Figure 1.10).

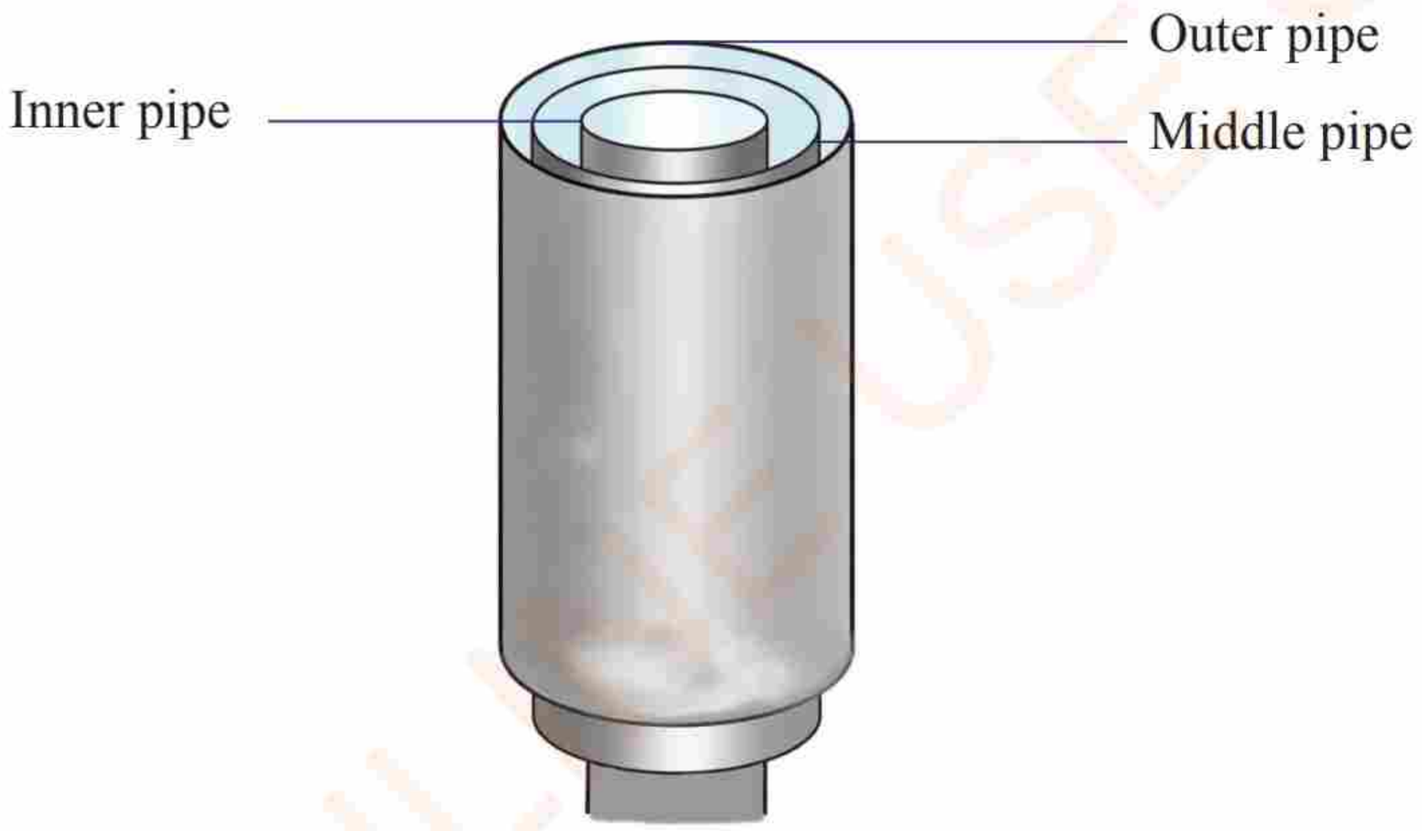


Figure 1.10: *Concentric pipes*

The following are the stages involved in the extraction of sulphur using the Frasch process (Figure 1.11):

1. Super-heated water (at 170 °C) is forced down through the outer pipe to melt the sulphur which then flows into the middle pipe.
2. Hot compressed air is forced down through the inner pipe. The combination of the hot water and the hot air froth the sulphur, making it less dense, and pushing it to the surface.
3. The froth is forced to the earth's surface through the middle pipe by the compressed air. It is then collected in vats, where the water drains off and the sulphur solidifies.

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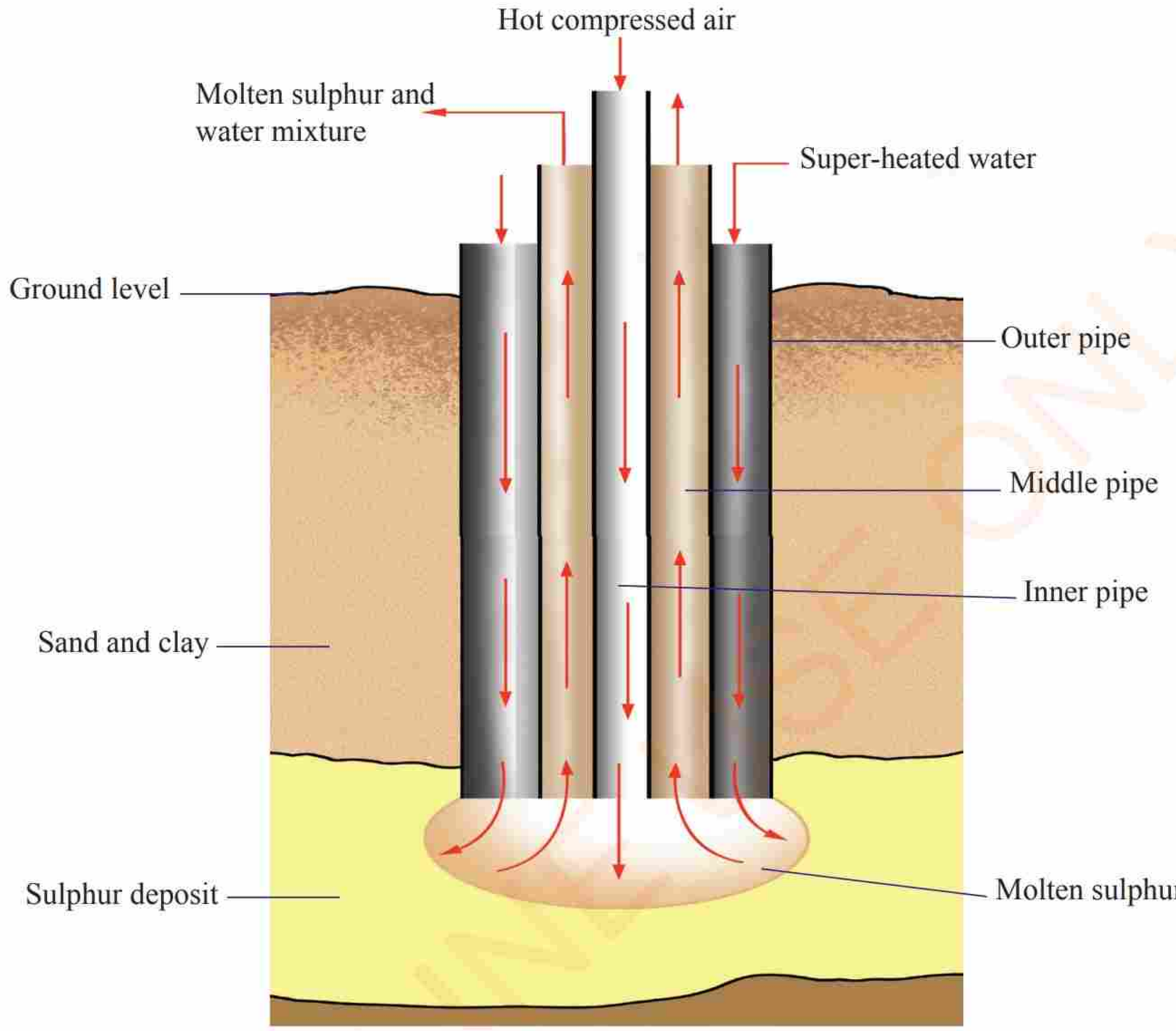


Figure 1.11: *Frasch process for extraction of sulphur*

Allotropy

Allotropy is the existence of an element in two or more different forms in the same physical state. This occurs when atoms of the element are bonded together in different ways. The different forms in which an element can exist are known as *allotropes*. Allotropes always exhibit different physical properties and may have different chemical properties too. The condition of existence of an element in different forms is also known as *polymorphism*. Several elements exhibit this phenomenon. Examples of the elements that exhibit polymorphism are sulphur, carbon, and phosphorus. It should be noted that allotropy exist in pure elements while polymorphism exist for both pure elements and compounds. Thus, allotropy is a subset of polymorphism though both may carry the same meaning.

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Allotropes of sulphur

Sulphur has several allotropes such as *rhombic sulphur*, *monoclinic sulphur*, *plastic sulphur, milk of sulphur,* and *colloidal sulphur*. These allotropes are grouped into either *crystalline* form (they are in the form of crystals) or *amorphous* form. Crystalline forms of sulphur have definite shapes, while amorphous forms do not have definite shapes. In addition, crystalline forms of sulphur comprises of two main types of allotropes which are *monoclinic* sulphur and *rhombic* sulphur. The names are derived from the shapes of the crystals, but both forms are thought to be made up of rings, each containing eight sulphur atoms. These forms are interconvertible; rhombic sulphur changes to monoclinic sulphur when heated above 96 °C and vice versa (Figure 1.12).

Rhombic sulphur or *alpha sulphur* (α-sulphur) is obtained when sulphur crystallises from solution in carbon disulphide. The crystals of rhombic sulphur have an octahedral shape. Rhombic sulphur is stable below 96 °C.

Monoclinic sulphur, also known as *prismatic sulphur* or *beta sulphur* (β-sulphur) is obtained by allowing molten sulphur to solidify. The crystals of monoclinic sulphur are stable above 96 °C and have a needle shaped structure. Monoclinic sulphur melts at a temperature of 120 ºC. At room temperature, it slowly changes to rhombic sulphur.

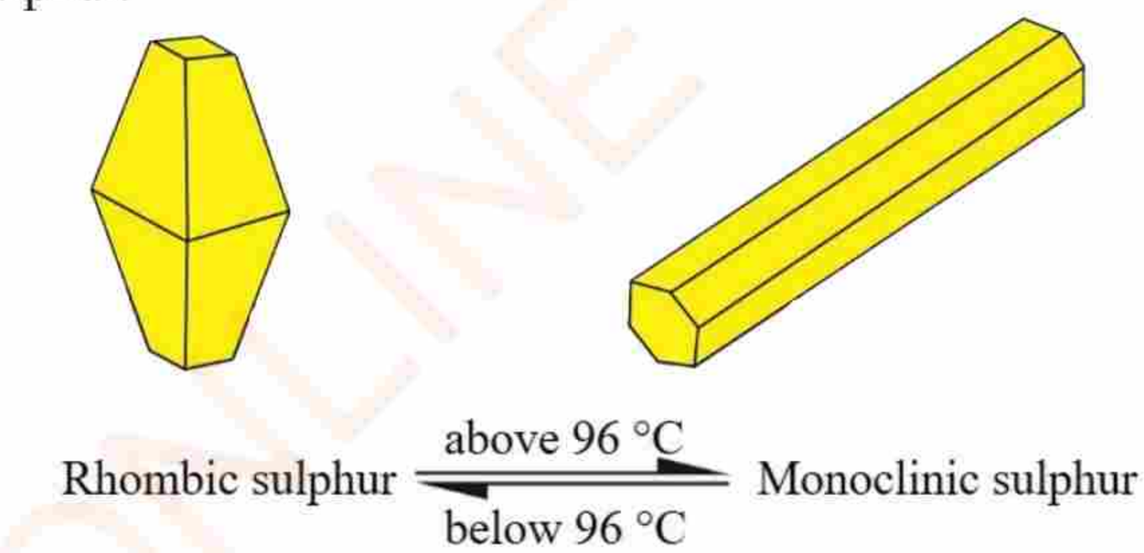


Figure 1.12: *Allotropes of crystalline form of sulphur*

The amorphous forms of sulphur include *plastic sulphur*, *milk of sulphur,* and *colloidal sulphur*. They have no definite shape. Amorphous sulphur is an insoluble white solid that remains when flowers of sulphur are reacted with carbon disulphide. Flowers of sulphur are the fine powder of pure sulphur.

Plastic sulphur is formed when molten sulphur is poured into cold water. Plastic sulphur is yellowish-brown and sticky. It consists of a tangled mass of chains of sulphur atoms. Plastic sulphur is a super-cooled liquid and its molecules are arranged randomly. It does not have the rings of eight sulphur atoms and is insoluble in carbon disulphide. Like other allotropes of sulphur, plastic sulphur hardens with time to form hard, opaque and yellow rhombic sulphur. Preparation

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of plastic sulphur in the laboratory can be achieved by heating powdered sulphur in an evaporating dish to produce molten sulphur which is then poured into cold water (Figure 1.13). During this preparation, monoclinic sulphur is also formed; the crystals formed on the underside of the crust and on the side of the evaporating dish are those of monoclinic sulphur. The crystals have a pale yellow colour and are needle shaped (Figure 1.14).

Milk of sulphur also known as *precipitated sulphur* is obtained by boiling flowers of sulphur with limewater to form a mixture of calcium pentasulphide and calcium thiosulphate. Treating this mixture with hydrochloric acid gives a white precipitate known as milk of sulphur. The compound is used in the treatment of various skin disorders.

Colloidal sulphur is obtained as a consequence of a special treatment of sulphur causing it to dissolve in water to form a colloidal solution.



Activity 1.9

Aim: To prepare a sample of rhombic sulphur

Requirements: Filter paper, two 100-cm^3 beakers, watch glass, spatula, measuring cylinder, hand lens, glass rod, powdered sulphur, and carbon disulphide

Caution: This experiment should be performed in a fume chamber or using full-face respirator. Carbon disulphide vapours are highly flammable and toxic.

Procedure

1. Measure 10 cm^3 of carbon disulphide and put in a beaker.
2. Add a spatulaful of powdered sulphur and stir using a glass rod.
3. Filter the mixture into another beaker.
4. Pour the filtrate into a watch glass and place it in a fume chamber. In case there is no fume chamber, place it at a corner where the air sweeps the fumes away. Leave it for at least three days.
5. Observe the mixture on the third day using a hand lens. Record the observations.

Questions

1. Why was the solution in Step 3 filtered?
2. Describe the observations after three days.
3. Sulphur dissolves in carbon disulphide and not in water. Explain.

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Activity 1.10

Aim: To prepare plastic sulphur

Requirements: Spatula, glass rod, evaporating dish, beaker, clay triangles, tripod stand, Bunsen burner, pair of forceps, powdered sulphur, and water

Caution: This experiment should be performed in a fume chamber. Sulphur vapour may catch fire. Avoid direct exposure of heated sulphur into flame.

Procedure

1. Put four spatulaful of powdered sulphur into a dry evaporating dish.
2. Place the evaporating dish on a clay triangle and heat it over a non-luminous flame as shown in Figure 1.13.

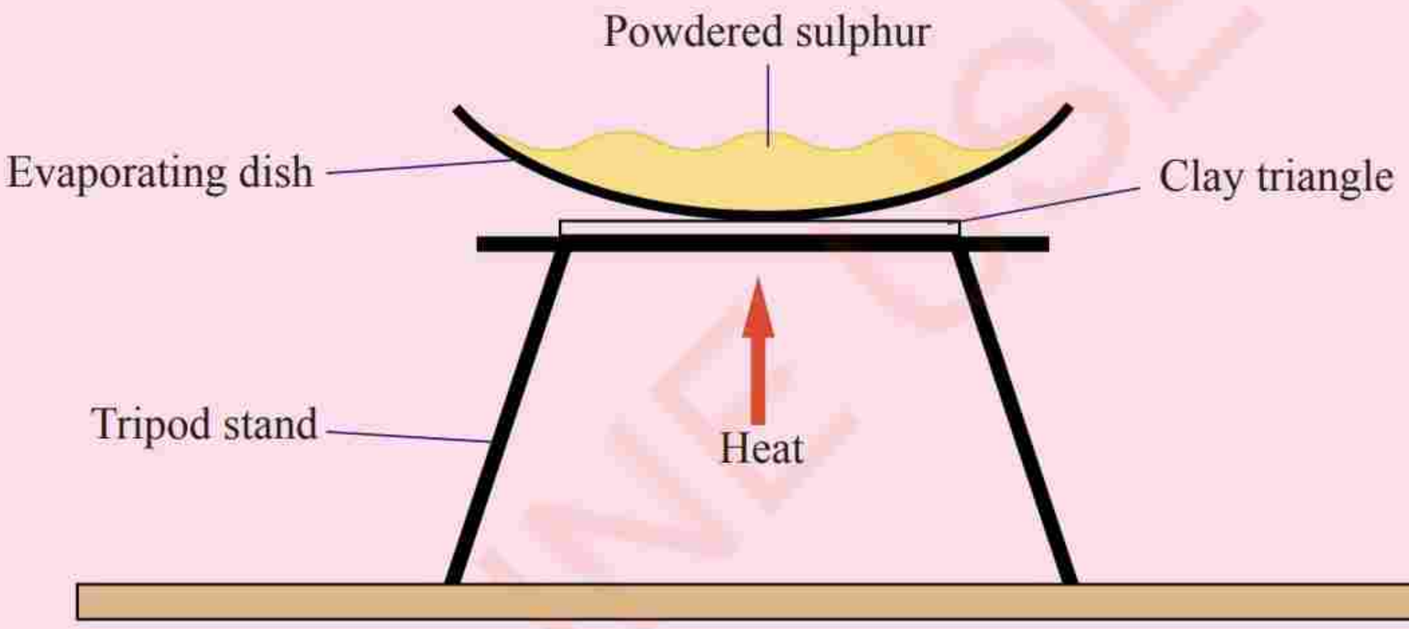


Figure 1.13: *Set-up for heating powdered sulphur*

3. Heat the powdered sulphur until it starts to melt. Keep adding more powdered sulphur as the heating goes on until the dish is almost full and all the sulphur has melted.
4. Leave the sulphur to cool until it forms a thin solid crust on top.
5. Make two holes through the crust as shown in Figure 1.14 using a glass rod.

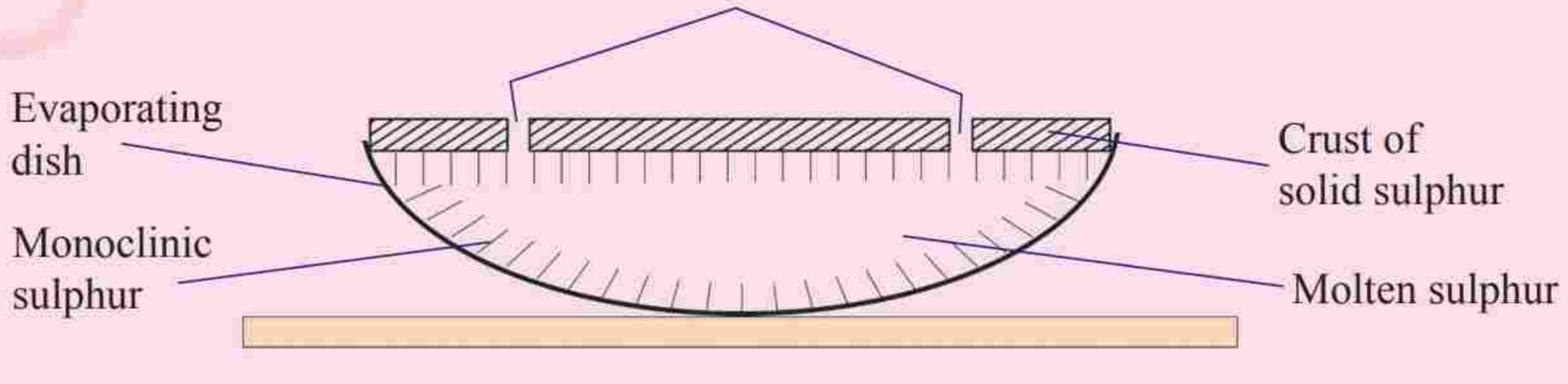


Figure 1.14: *Set-up for the preparation of plastic sulphur*

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6. Pour out liquid sulphur that may be below the crust through one of the holes into a beaker with cold water. Record the observations.
7. Break the crust and obtain crystals from the underside of the crust using a pair of forceps.
8. Observe the crystals using a magnifying glass. Also observe the crystals formed on the sides of the evaporating dish.

Questions

1. Describe the appearance of the crystals obtained from the underside of the sulphur crust and those obtained from the sides of the evaporating dish.
2. What was observed when molten sulphur was poured into the beaker containing cold water?

Properties of sulphur

The allotropes of sulphur exhibit different physical properties and may have different chemical properties. The following are some of the physical and chemical properties of sulphur.

Physical properties

(a) It is a yellow solid.

(b) It is insoluble in water, but soluble in non-polar solvents such as carbon disulphide and methylbenzene.

(c) Rhombic sulphur is stable below 96 °C.

(d) Monoclinic sulphur is stable above 96 °C.

(e) Rhombic sulphur has a density of 2.06 g cm^{-3}.

(f) If rhombic sulphur is melted and partly allowed to crystallise slowly, needle like crystals of monoclinic sulphur are formed.

(g) Monoclinic sulphur has a density of 1.96 g cm^{-3}.

(h) Monoclinic sulphur gradually changes to rhombic sulphur when exposed at room temperature.

(i) Plastic sulphur is insoluble in carbon disulphide.

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Table 1.4 summarises some of the physical properties of crystalline allotropes of sulphur.

Table 1.4: *Physical properties of crystalline allotropes of sulphur*

Property	Rhombic	Monoclinic
Melting point (°C)	112	119
Boiling point (°C)	444	444
Density (g cm^{-3})	2.06	1.96
Thermal conductivity	Poor	Poor
Electrical conductivity	Poor	Poor
Shape	Octahedral	Needle shaped

Chemical properties

Sulphur is a relatively reactive element that readily reacts with other elements to form compounds such as oxides, chlorides, and sulphides. In chemical reactions, sulphur exhibits both reducing and oxidising properties.

(a) *Reaction with metals*: Heated sulphur reacts with metals such as iron, copper, zinc, and tin to give metal sulphides. When a mixture of iron filings and powdered sulphur is heated, the two react exothermically forming black iron(II) sulphide.

$$Fe(s) + S(s) \xrightarrow{heat} FeS(s)$$

The heat given out makes the mixture to continue glowing even after the heating has been stopped. Iron(II) sulphide is not attracted by a magnet. The magnetic property of iron is lost when the compound is formed. In the reaction with iron fillings, sulphur acts as an oxidising agent. It oxidises solid iron to iron(II) ion, and it is reduced to sulphide ion.

$$Fe(s) \longrightarrow Fe^{2+} + 2e^{-}$$

$$S(s) + 2e^{-} \longrightarrow S^{2-}$$

Copper powder reacts with sulphur in the same way as iron(II) to form copper(I) sulphide.

$$2Cu(s) + S(s) \longrightarrow Cu_2S(s)$$

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Activity 1.11

Aim: To investigate the reactions of sulphur with iron and copper

Requirements: Retort stand and clamp, test tube, Bunsen burner, hard paper, spatula, test tube holder, bar magnet, watch glass, iron filings, copper filings, and powdered sulphur

Procedure

1. Mix iron filings with powdered sulphur in the ratio of 7:4 in a watch glass to obtain a uniform mixture.
2. Bring a bar magnet near the mixture. Record the observations.
3. Put the mixture in a test tube. Set up the apparatus as shown in Figure 1.15.

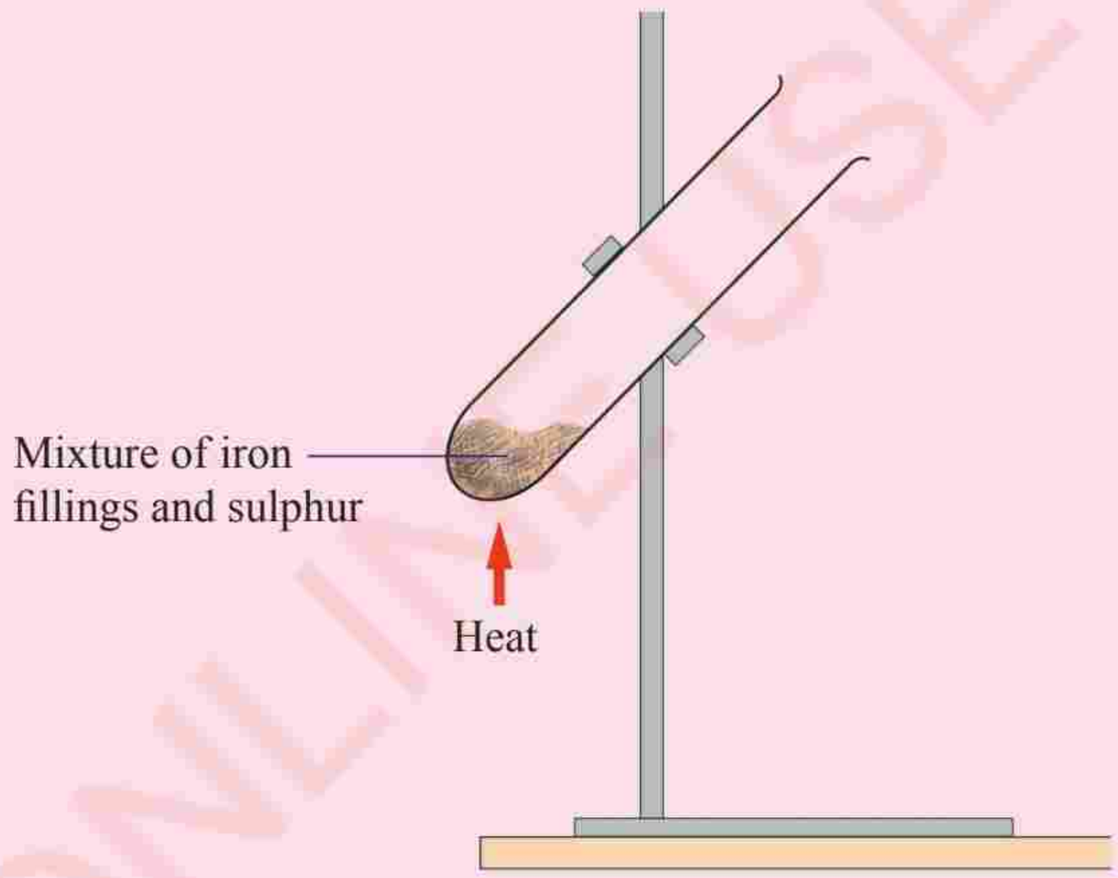


Figure 1.15: *Set-up for the reaction of sulphur with iron*

4. Heat the mixture gently, and then strongly until it glows. Stop heating and leave the mixture until the reaction stops glowing.
5. Transfer the product on a hard paper and leave it to cool to room temperature.
6. Bring a bar magnet near the product and record the observations.
7. Repeat steps 1 to 6 using copper powder in the place of iron filings. Record the observations.

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Questions

1. The heated mixture of iron fillings and sulphur continued to glow even after the reaction had stopped. Explain.
2. What was the colour of the product formed when iron fillings were reacted with powdered sulphur?
3. What was the colour of the product formed when copper fillings were reacted with powdered sulphur?
4. Write an equation for the reaction between iron and sulphur.
5. Write an equation for the reaction between copper and sulphur.
6. Explain the magnetic property of copper before and after the reaction.

(b) *Reaction with acids*: Sulphur is oxidised by strong concentrated acids such as sulphuric acid and nitric acid. In such reactions, sulphur acts as a reducing agent. When sulphur reacts with hot concentrated sulphuric acid, sulphur is oxidised to sulphur dioxide.

$$S(s) + 2H_2SO_4(l) \longrightarrow 3SO_2(g) + 2H_2O(l)$$

When sulphur reacts with hot concentrated nitric acid, brown fumes of nitrogen dioxide are formed. In this reaction, hot concentrated nitric acid is an oxidising agent while sulphur is a reducing agent.

$$S(s) + 6HNO_3(l) \longrightarrow H_2SO_4(aq) + 2H_2O(l) + 6NO_2(g)$$



Activity 1.12

Aim: To investigate the reaction of sulphur with concentrated sulphuric acid and nitric acid

Requirements: Two test tubes, measuring cylinder, retort stand and clamp, Bunsen burner, pair of tongs, potassium dichromate paper, concentrated sulphuric acid, concentrated nitric acid, and sulphur powder

Caution: This reaction should be carried out in a fume chamber or using full-face respirator. Concentrated sulphuric acid and nitric acid are very corrosive, thus the experiment should be done carefully in a fume chamber.

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Procedure

1. Put one spatulaful of powdered sulphur in a test tube
2. Add 2 cm^3 of concentrated sulphuric acid. Set up the apparatus as shown in Figure 1.16.

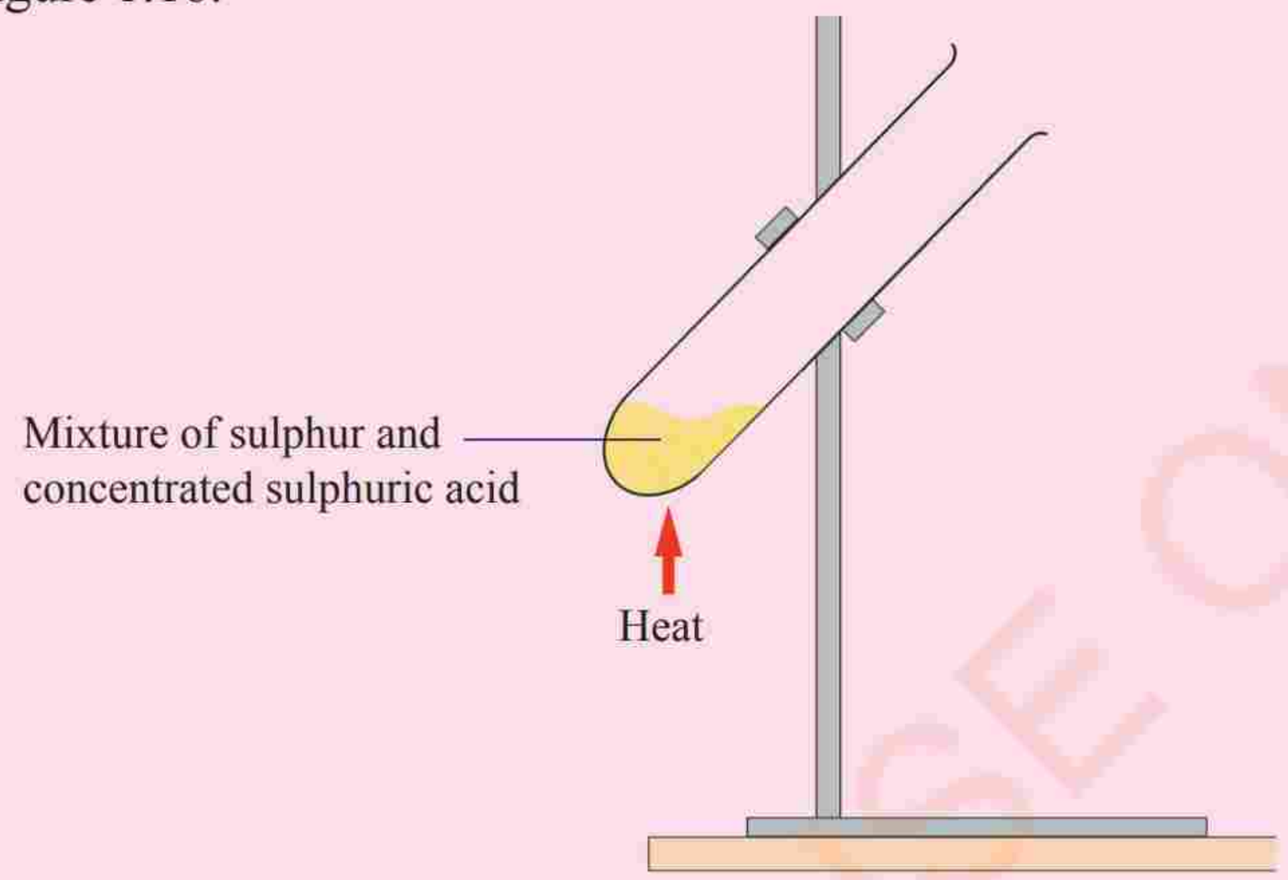


Figure 1.16: *Set-up for the reaction of sulphur with concentrated sulphuric acid*

3. Heat the mixture gently.
4. Using a pair of tongs, place a potassium dichromate paper at the top of the test tube. Record the observations.
5. Repeat steps 1 to 4 using concentrated nitric acid in place of the concentrated sulphuric acid. Record the observations.

Questions

1. What was the aim of Step 4?
2. What was observed when sulphur was heated in concentrated nitric acid?
3. Write an equation for the reaction when sulphur was mixed with concentrated nitric acid and heated.

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(c) *Reaction with hydrogen gas*: When hydrogen gas is bubbled through molten sulphur, hydrogen sulphide is formed. However, it should be noted that, this is not a convenient method of preparing hydrogen sulphide.

$$H_2(g) + S(l) \longrightarrow H_2S(g)$$

(d) *Reaction with strong alkalis*: Sulphur dissolves in sodium hydroxide or potassium hydroxide to form a mixture of sulphite, (SO_3^{2-}) and sulphide, (S^{2-}).

$$3S(s) + 6NaOH(aq) \longrightarrow 2Na_2S(aq) + Na_2SO_3(aq) + 3H_2O(l)$$

$$3S(s) + 6KOH(aq) \longrightarrow 2K_2S(aq) + K_2SO_3(aq) + 3H_2O(l)$$

(e) *Reaction with other non-metals*: Sulphur directly combines with fluorine, chlorine and carbon.

$$S(s) + 3F_2(g) \longrightarrow SF_6(l)$$
Sulphur hexafluoride

$$2S(s) + Cl_2(g) \longrightarrow S_2Cl_2(l)$$
Disulphur dichloride

$$2S(s) + C(s) \longrightarrow CS_2(l)$$
Carbon disulphide

Uses of sulphur

Sulphur has various uses in daily life, including the following:

Manufacture of sulphuric acid: Sulphur is used to make sulphuric acid, which is an important reagent in many industrial processes.

Manufacture of sulphur dioxide and sodium sulphite: Sulphur is used in the manufacture of sulphur dioxide and sodium sulphite, which are used for bleaching straw and wood fibres. They are also used in removing lignin from wood pulp in the paper industry.

Manufacture of gunpowder: Gunpowder is a mixture of potassium nitrate, carbon and sulphur. Sulphur and carbon act as fuels while potassium nitrate is an oxidiser.

Vulcanisation of rubber: Sulphur is used in the *vulcanisation* of natural rubber. Vulcanisation is the process of hardening natural soft rubber by reacting it with sulphur.

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Manufacture of medicine and fungicides: Sulphur is used in the manufacture of useful organic materials such as antifungal compounds (Figure 1.17). It is also used to dust vines and cashew to prevent the growth of fungus.



Figure 1.17: *Antifungal ointments containing sulphur*

Manufacture of safety matches: The head of safety matches are made of an oxidising agent such as potassium chloride mixed with sulphur, fillers, and glass powder.

Manufacture of other organic compounds: Sulphur is used in the manufacture of various organic compounds such as plastics.

Exercise 1.3

1. Write **TRUE** for a correct statement and **FALSE** for an incorrect statement. Give a reason for the incorrect sentence(s).
   (a) Liquid sulphur is yellow.
   (b) The most stable allotrope of sulphur is rhombic sulphur.
   (c) Plastic sulphur is used as a substitute for plastics.
   (d) Sulphur has a low melting point because its intermolecular attractions are weak.
   (e) Iron and sulphur react to form a sulphide which displays both the properties of sulphur and iron.
   (f) Safety matches contain sulphur in its elemental form.

2. (a) Why does a mixture of iron and sulphur after heating, starts to glow and continues to glow even after the external source of heat is removed?
   (b) Write the balanced equation for the reaction that takes place in 2 (a).

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3. Explain the uses of sulphur in the following areas:
   (a) Automobile industry.
   (b) Treatment of diseases.
   (c) Photography.
   (d) Agriculture.

Sulphur dioxide

Sulphur dioxide is a binary compound of sulphur and oxygen formed when sulphur burns in air (oxygen).

$$S(s) + O_2(g) \longrightarrow SO_2(g)$$

Preparation of sulphur dioxide

In the laboratory, sulphur dioxide may be prepared by reacting a metal with hot concentrated sulphuric acid or by reacting a metal sulphite with dilute sulphuric acid or dilute hydrochloric acid.

$$Cu(s) + 2H_2SO_4(l) \longrightarrow CuSO_4(aq) + SO_2(g) + 2H_2O(l)$$

$$Na_2SO_3(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + H_2O(l) + SO_2(g)$$

$$Na_2SO_3(aq) + 2HCl(aq) \longrightarrow 2NaCl(aq) + H_2O(l) + SO_2(g)$$

The ionic equations for the reactions are respectively shown as follows:

$$Cu(s) + SO_4^{2-}(aq) + 4H^+(aq) \longrightarrow Cu^{2+}(aq) + 2H_2O(l) + SO_2(g)$$

$$SO_3^{2-}(aq) + 2H^+(aq) \longrightarrow SO_2(g) + H_2O(l)$$

In the preparation set-up (Figure 1.18), a piece of filter paper soaked in acidified potassium dichromate can be placed at the mouth of the gas jar to test the presence of sulphur dioxide. Sulphur dioxide change the colour of the filter paper from orange to green. During its collection, sulphur dioxide is passed through concentrated sulphuric acid to dry it. The gas cannot be collected over water because of its high solubility in water.

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Activity 1.13

Aim: To prepare sulphur dioxide gas

Requirements: Round-bottomed flask, thistle funnel with a tap, conical flask, retort stand and clamp, Bunsen burner, delivery tubes, gas jar with lid, spatula, rubber bungs, sodium sulphite, dilute sulphuric acid or dilute hydrochloric acid, concentrated sulphuric acid, and dichromate indicator paper or acidified potassium dichromate solution

Procedure

1. Put about three spatulaful of sodium sulphite in a round-bottomed flask.
2. Set up the apparatus as shown in Figure 1.18.

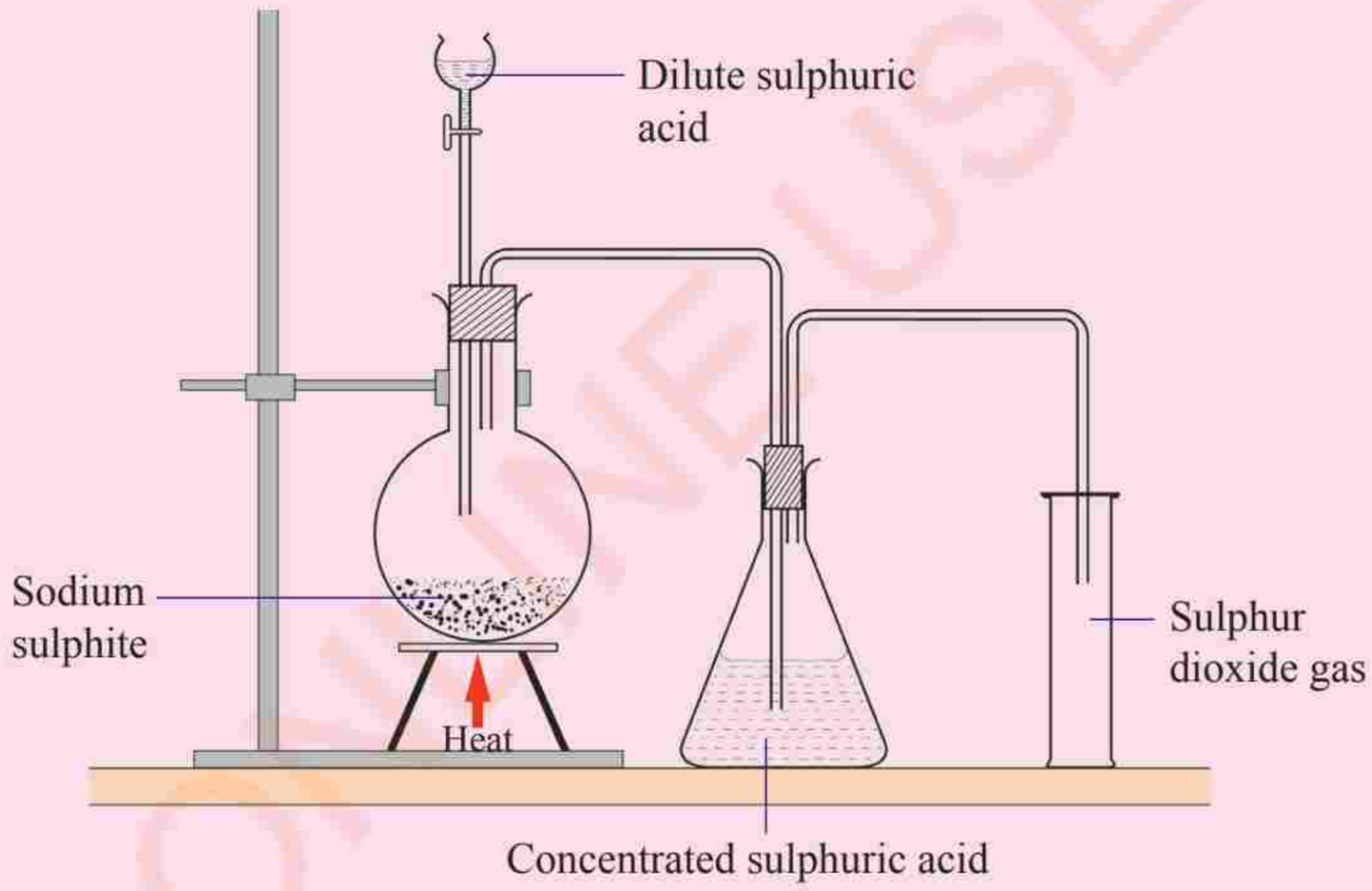


Figure 1.18: *Set-up for the preparation of sulphur dioxide gas*

3. Pour dilute sulphuric acid through the thistle funnel onto the sodium sulphite.
4. Gently, heat the mixture and pass the gas produced through concentrated sulphuric acid.
5. Collect the gas by downward delivery method.
6. Hold a piece of dichromate indicator paper at the mouth of the gas jar and replace the lid when the indicator paper changes its colour. The gas can also be passed through acidified potassium dichromate solution. Record the observations.

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Questions

1. Explain the purpose of placing a piece of dichromate indicator paper at the mouth of the gas jar or passing the gas through acidified potassium dichromate solution.
2. What was the role of concentrated sulphuric acid in this experiment?
3. Explain the reason for collecting sulphur dioxide by downward delivery method.

Exercise 1.4

1. Write **TRUE** for a correct statement and **FALSE** for an incorrect statement. For the false statement(s), write its corresponding correct statement(s).
   (a) The IUPAC name for sulphur dioxide is sulphur(IV) oxide.
   (b) Sulphur dioxide is collected by upward displacement of air because it is denser than air.
   (c) Sulphur dioxide is passed through concentrated sulphuric acid to remove traces of impurities.
   (d) Sulphur dioxide may be collected over water.
   (e) The reaction between hydrochloric acid and sodium sulphite gives sulphur dioxide gas among other products.
2. What will be observed when:
   (a) acidified potassium dichromate reacts with sulphur dioxide gas?
   (b) copper turnings react with concentrated sulphuric acid?
3. Why is anhydrous copper(II) sulphate formed when copper turnings are reacted with hot concentrated sulphuric acid?

Properties of sulphur dioxide

The following are some of the physical and chemical properties of sulphur dioxide:

Physical properties

(a) It is a colourless gas with an irritating choking smell.
(b) It is a poisonous gas and therefore should be prepared in a fume chamber or using a full-face respirators.

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(c) It is denser than air and therefore should be collected by downward delivery method.

(d) It is readily liquefied. Liquid sulphur dioxide boils at about –10 °C.

(e) It turns moist blue litmus paper red.

Chemical properties

(a) *Reaction with water and acidic characteristics*: Sulphur dioxide is an acidic gas which readily dissolves in water to form an acidic solution commonly known as sulphurous acid.

$$SO_2(g) + H_2O(l) \longrightarrow H_2SO_3(aq)$$



Activity 1.14

Aim: To demonstrate the acidity of sulphur dioxide

Requirements: Round-bottomed flask, thistle funnel with a tap, conical flask, retort stand and clamp, Bunsen burner, delivery tubes, gas jar with a lid, spatula, rubber bungs, 5-cm^3 measuring cylinder, sodium sulphite, dilute and concentrated sulphuric acid, distilled water, red litmus paper, and blue litmus paper

Procedure

1. Prepare a gas jar filled with sulphur dioxide by following the procedure in Activity 1.13.
2. Put 2 cm^3 of distilled water into the gas jar containing sulphur dioxide and shake well.
3. Drop a piece of red litmus paper and blue litmus paper into the gas jar containing the solution. Record the observations.

Questions

1. What was the colour of the solution formed in Step 2?
2. Explain the observations when pieces of blue litmus paper and red litmus paper were dropped into the solution formed in Step 2.

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(b) *Reaction with oxygen:* Sulphur dioxide combines with oxygen in the presence of a catalyst to give sulphur trioxide.

$$2SO_2(g) + O_2(g) \xrightarrow{\text{catalyst}} 2SO_3(g)$$

Mix the gas prepared in Activity 1.13 with dry oxygen gas under a catalyst (vanadium pentoxide) to produce sulphur trioxide gas. The set-up of the experiment is shown in Figure 1.19.

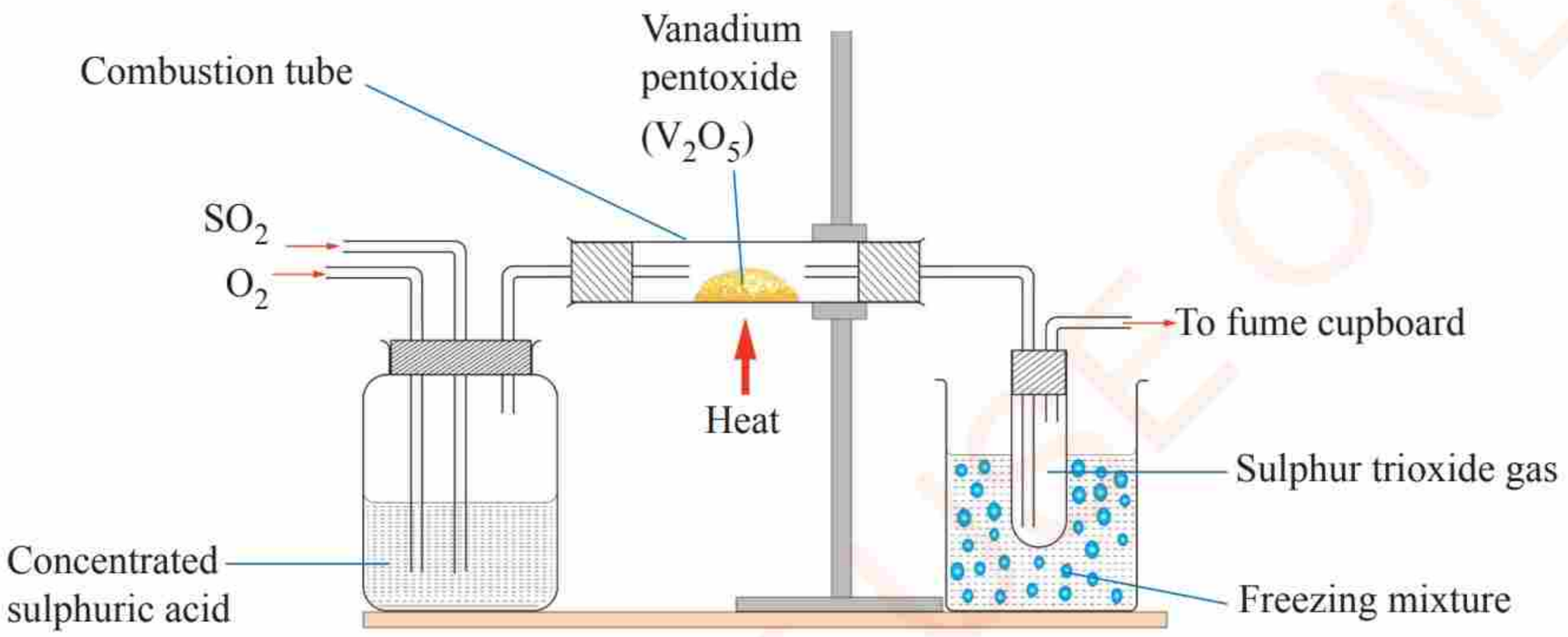


Figure 1.19: *Set-up for the preparation of sulphur trioxide*

The combustion tube and the test tube for collecting sulphur trioxide should be dried. Otherwise, the sulphur trioxide would dissolve in the moisture that would result in less gas being collected. Thick white fumes of sulphur trioxide are formed which condense in the test tube in the form of silky white needles.

(c) *Reducing property*: Sulphur dioxide is a strong reducing agent. It reduces potassium permanganate and potassium dichromate solutions to manganese(II) sulphate, and chromium(III) sulphate, respectively. Sulphur dioxide decolourises purple potassium permanganate solution. Sulphur dioxide is first converted to a sulphite (SO_3^{2-}) after reacting with water and then oxidised to a sulphate (SO_4^{2-}) by the permanganate.

$$2KMnO_4(aq) + 2H_2O(l) + 5SO_2(g) \longrightarrow K_2SO_4(aq) + 2MnSO_4(aq) + 2H_2SO_4(aq)$$

Purple — Colourless

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The ionic equation of the reaction is:

$$2MnO_4^-(aq) + 2H_2O(l) + 5SO_2(g) \longrightarrow 2Mn^{2+}(aq) + 5SO_4^{2-}(aq) + 4H^+(aq)$$

Purple → Colourless

In this reaction, manganese is reduced as its oxidation state changes from +7 to +2.



Activity 1.15

Aim: To investigate the reduction of acidified potassium permanganate solution by sulphur dioxide

Requirements: Gas jars containing sulphur dioxide, potassium permanganate solution, dilute sulphuric acid, and sulphur dioxide gas

Procedure

1. Mix 2 cm^3 of potassium permanganate solution with 3 cm^3 of dilute sulphuric acid.
2. Pour 1 cm^3 of the acidified potassium permanganate solution into a gas jar full of sulphur dioxide. Shake the mixture and record the observations.

Questions

1. What was observed on the colour of the potassium permanganate solution when the solution was poured into the gas jar containing sulphur dioxide? Explain.
2. Write an equation for the reaction that occurred in Step 2.
3. Name the type of reaction that occurred in the experiment and explain your answer.

When sulphur dioxide is mixed with potassium dichromate solution in the presence of sulphuric acid, the orange colour of the potassium dichromate changes to green. The dichromate(VI) is reduced to chromate(III) which is green in aqueous state.

$$K_2Cr_2O_7(aq) + H_2SO_4(aq) + 3SO_2(aq) \longrightarrow K_2SO_4(aq) + Cr_2(SO_4)_3(aq) + H_2O(l)$$

Orange → Green

The ionic equation is as follows:

$$Cr_2O_7^{2-}(aq) + 2H^+(aq) + 3SO_2(g) \longrightarrow 2Cr^{3+}(aq) + 3SO_4^{2-}(aq) + H_2O(l)$$

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The oxidation state of chromium changes from +6 in potassium dichromate to +3 in chromic sulphate. On the other hand, sulphur dioxide is oxidised by the dichromate(VI) to sulphate (SO_4^{2-}).



Activity 1.16

Aim: To investigate the reduction of acidified potassium dichromate solution by sulphur dioxide

Requirements: Gas jars containing sulphur dioxide, and acidified potassium dichromate solution

Procedure

1. Pour 1 cm^3 of acidified potassium dichromate solution into a gas jar filled with sulphur dioxide gas.
2. Shake the mixture and record the observations.

Questions

1. Explain the change in colour when sulphur dioxide gas was mixed with acidified potassium dichromate solution.
2. Write the balanced chemical equation for the reaction that occurred in the experiment.

Sulphur dioxide also reduces a solution of iron(III) to iron(II).

$$Fe_2(SO_4)_3(aq) + 2H_2O(l) + SO_2(g) \longrightarrow 2FeSO_4(aq) + 2H_2SO_4(aq)$$

Yellow — Pale green

The ionic equation showing the reduction of iron(III) to iron(II) is:

$$2Fe^{3+}(aq) + 2H_2O(l) + SO_2(g) \longrightarrow 2Fe^{2+}(aq) + 4H^+(aq) + SO_4^{2-}(aq)$$

Yellow — Green

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Sulphur dioxide reduces chlorine, bromine and iodine to their hydrogen halides in the presence of water.

$$Cl_2(g) + 2H_2O(l) + SO_2(g) \longrightarrow H_2SO_4(aq) + 2HCl(aq)$$

$$Br_2(l) + 2H_2O(l) + SO_2(g) \longrightarrow H_2SO_4(aq) + 2HBr(aq)$$

$$I_2(s) + 2H_2O(l) + SO_2(g) \longrightarrow H_2SO_4(aq) + 2HI(aq)$$

(d) *Oxidising property*: Sulphur dioxide is an oxidising agent. The oxidising property of sulphur dioxide can be tested using hydrogen sulphide gas produced from the reaction of iron(II) sulphide with hydrochloric acid.

$$FeS(s) + 2HCl(aq) \longrightarrow H_2S(g) + FeCl_2(aq)$$

Hydrogen sulphide gas has a rotten egg smell and is oxidised by sulphur dioxide to sulphur. The sulphur produced is a yellow residue. The reaction takes place in the presence of moisture which acts as a catalyst. In the laboratory experiment to investigate the oxidation of hydrogen sulphide by sulphur dioxide, water (a catalyst) is added in the jar containing sulphur dioxide.

$$2H_2S(g) + SO_2(g) \longrightarrow 3S(s) + 2H_2O(l)$$



Activity 1.17

Aim: To investigate the oxidation of hydrogen sulphide by sulphur dioxide

Requirements: Thistle funnel (with a tap), a rubber bung, stand and clamp, delivery tube, spatula, conical flask, gas jar with sulphur dioxide gas, iron(II) sulphide, dilute hydrochloric acid, and distilled water

Caution: This experiment should be carried out in a fume chamber or using full-face respirator because hydrogen sulphide gas is poisonous and has a bad smell.

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Procedure

1. Put one spatulaful of iron(II) sulphide into a conical flask. Set up the apparatus as shown in Figure 1.20.

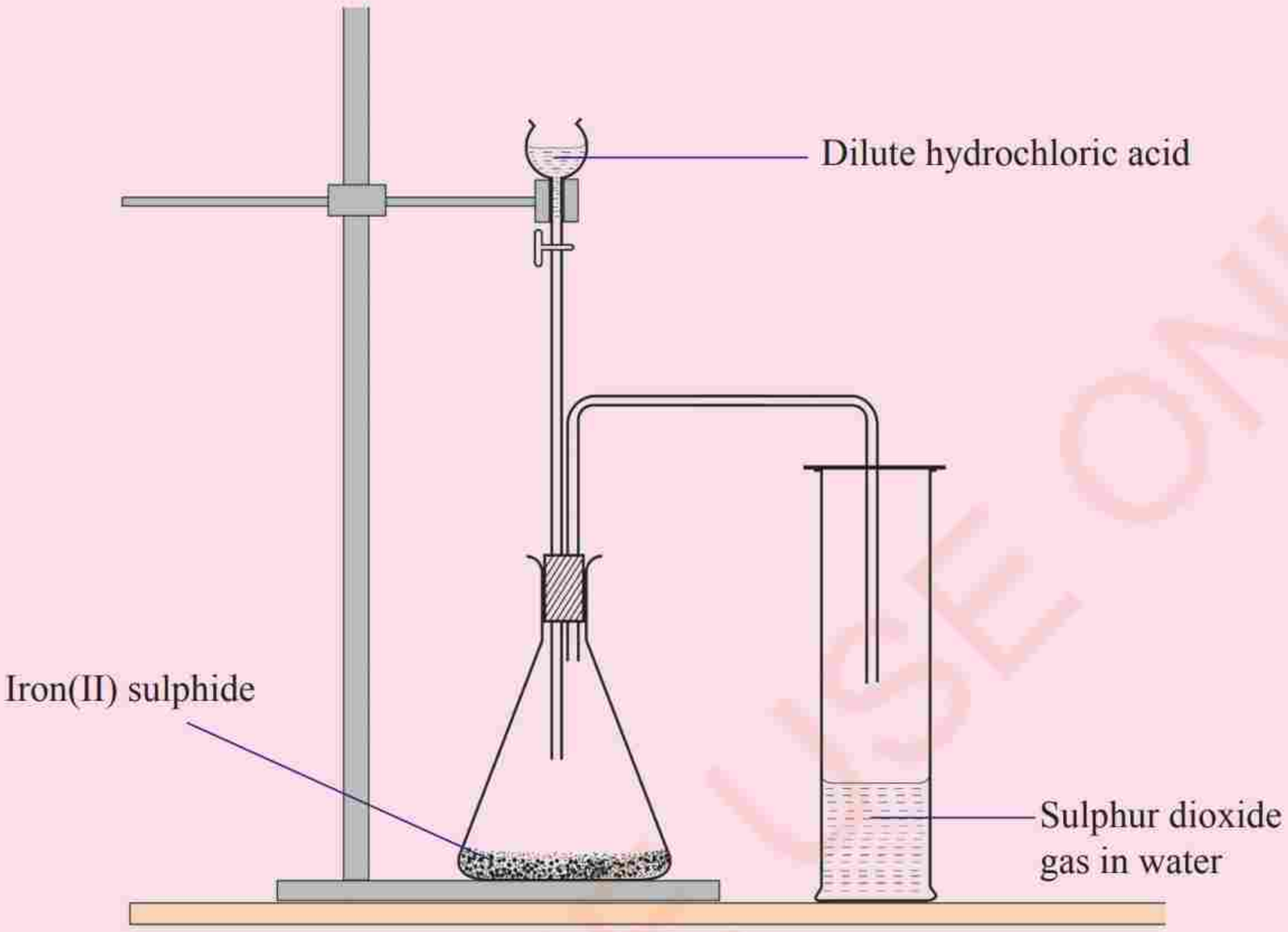


Figure 1.20: *Set-up for oxidation of hydrogen sulphide by sulphur dioxide*

2. Add dilute hydrochloric acid dropwise into the iron(II) sulphide by opening the tap of the thistle funnel.
3. Pass the gas produced in Step 2 through a gas jar of sulphur dioxide dissolved in water. Record the observations.

Note: If the experimental set-up does not produce enough hydrogen sulphide gas, replace with Kipp's apparatus.

Questions

1. Explain the importance of dissolving sulphur dioxide gas in water before passing hydrogen sulphide gas into it.
2. Write an equation for the reaction that took place in Step 3.

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(e) *As a bleaching agent*: In moist conditions, sulphur dioxide is a bleaching agent. The gas reduces a dye by removing oxygen from it to form a colourless product. Sulphur dioxide is used to bleach wool and silk.

$$SO_2(g) + H_2O(l) \longrightarrow H_2SO_3(aq)$$

$$H_2SO_3(aq) + \underset{\text{(Coloured)}}{\text{dye}} \longrightarrow H_2SO_4(aq) + \underset{\text{(Colourless)}}{\text{dye – deoxygenated complex compound}}$$



Activity 1.18

Aim: To investigate the bleaching power of sulphur dioxide

Requirements: Coloured paper or petals of a coloured flower, gas jars containing sulphur dioxide gas

Procedure

1. To one of the jars, drop a wet piece of coloured paper or wet petals of a coloured flower.
2. To the other gas jar, drop a dry piece of coloured paper or dry petals of a coloured flower. Observe and record the observations.

Questions

1. What happened to the colour of the paper or petals in the gas jars?
2. Write an equation for the reaction that took place in the two gas jars.

Test for sulphur dioxide

The presence of sulphur dioxide can be tested using acidified potassium dichromate. If sulphur dioxide is present, the colour changes from orange to green due to reduction of chromium(VI) to chromium(III). Sulphur dioxide also decolourises acidified potassium permanganate solution.

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Hazards of sulphur dioxide

Sulphur dioxide is a major air pollutant. The major sources of sulphur dioxide in the air are power plants that use fossil fuels such as coal and diesel, industrial boilers, and exhaust emissions from motor vehicles. Exposure to high levels of sulphur dioxide can cause impairment of respiratory function and heart diseases. Sulphur dioxide affects the respiratory system, particularly the lung functions. It irritates the respiratory tract and increases the risks of tract infections. It causes coughing, mucus secretions and aggravates conditions such as asthma and chronic bronchitis. It also irritates the eyes. Sulphur dioxide causes acid rain. Acid rain occurs when the gas comes in contact with moisture, causing it to be converted to acids such as sulphuric acid (H_2SO_4) and sulphurous acid (H_2SO_3). Acid rain damages the leaves and barks of plants, making them more vulnerable to diseases, weather, and insects. When acid rain reaches water bodies such as lakes, rivers, and ponds, the receiving water bodies can become acidic. Even low levels of acid in the water can have harmful health effects to fish and other organisms in the aquatic environment. Acid rain also damages structures, especially those that are built out of limestone. Acid rain reacts with limestone, reducing it to a powdery substance and thus weakening the buildings. The world's ancient buildings are most vulnerable for damage by acid rain since most of them were built using metal carbonates.

Uses of sulphur dioxide

Sulphur dioxide has various uses. The following are some of its uses:

1. The main use of sulphur dioxide is in the manufacture of sulphuric acid through the Contact process.
2. It is used as a bleaching agent for fibres such as wool, silk, straw, and sponges.
3. It is used in the manufacture of calcium hydrogensulphite and sodium hydrogensulphite. Calcium hydrogensulphite, $Ca(HSO_3)_2$, is used for bleaching wood-pulp in the manufacture of paper and artificial silk. Sodium hydrogensulphite, $NaHSO_3$, is used as food additive and preservative, and in the treatment of wastewater and drinking water.
4. It is used for fumigating houses and clothing to kill microorganisms. It is also used to kill insects such as white ants because it is poisonous.

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5. Sulphur dioxide is used in small doses as a preservative of some liquids such as lemon and orange juices. This is because a small concentration of the gas prevents fermentation of the liquids as it reacts with oxygen. This prevents oxidation of the liquids.

6. Liquid sulphur dioxide is used in refrigerators as a refrigerant because it liquefies at 3 atmospheres at room temperature.

Exercise 1.5

1. Write **TRUE** for a correct statement and **FALSE** for an incorrect statement. For the false statement(s) write its corresponding correct statement(s).
   (a) During the preparation of sulphur dioxide gas, it is impossible to identify the gas because it is colourless.
   (b) Sulphur dioxide is easily liquefied at ordinary pressure.
   (c) A moist blue litmus paper turns red in sulphur dioxide just like phenolphthalein will turn red in the gas.
   (d) The correct way to prepare a solution of sulphur dioxide is by inserting a delivery tube from the gas generator into a beaker with water.
   (e) Sulphur dioxide acts as a reducing agent when reacts with potassium dichromate and as an oxidising agent when reacts with potassium manganate(VII).
   (f) Sulphur dioxide gas is lighter than air.

2. Explain the observations when a solution of acidified potassium manganate(VII) is put into a gas jar containing sulphur dioxide.

3. Why is nitric acid not used to acidify potassium dichromate or potassium manganate(VII)?

4. (a) Explain the observations when a small amount of iron(III) sulphate solution is added into a gas jar containing sulphur dioxide.
   (b) Write the ionic equation for the reaction in 4(a).

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Sulphuric acid

Sulphuric acid, also known as *oil of vitriol*, is a mineral acid with the molecular formula H_2SO_4. It is a colourless, odourless, viscous liquid that is water miscible. It is produced in large scale using the Contact process.

Manufacture of sulphuric acid by Contact process

The *Contact process* involves four major stages as shown in Figure 1.21. These stages are production and purification of sulphur dioxide (SO_2), conversion of sulphur dioxide to sulphur trioxide (SO_3), formation of oleum ($H_2S_2O_7$), and conversion of oleum to sulphuric acid (H_2SO_4). The stages are described as follows:

Stage 1: Production and purification of sulphur dioxide

The sulphur dioxide used in the Contact process can be obtained from different sources as follows:

Burning sulphur in air.

$$S(s) + O_2(g) \longrightarrow SO_2(g)$$

This is the most convenient method of producing sulphur dioxide.

Burning sulphide ores such as iron pyrite (FeS_2), lead sulphide (PbS), and zinc blende (ZnS) in air.

$$4FeS_2(s) + 11O_2(g) \longrightarrow 2Fe_2O_3(s) + 8SO_2(g)$$

$$2ZnS(s) + 3O_2(g) \longrightarrow 2ZnO(s) + 2SO_2(g)$$

The produced mixture of the sulphur dioxide and air is passed through a purifier to remove particles of impurities such as dust and arsenic(III) oxide. These impurities would otherwise poison the catalyst used in the process rendering it ineffective. The purified mixture of air and sulphur dioxide is then passed through concentrated sulphuric acid for drying.

Stage 2: Conversion of sulphur dioxide to sulphur trioxide

The purified and dried mixture of sulphur dioxide and air is passed through the heat exchanger to acquire the necessary heat for its conversion to sulphur trioxide. The mixture is then taken to the conversion chamber which contains a catalyst.

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The catalyst used is vanadium pentoxide or platinum. Vanadium pentoxide is the preferred catalyst because it is cheaper and cannot be poisoned easily. Sulphur dioxide remains in contact with the catalyst during the conversion process, hence the name Contact process. The conversion process is exothermic, and is carried out at a temperature of 450 °C, and normal atmospheric pressure. This is because at these conditions the conversion of sulphur dioxide is both optimum and economical. The following reaction takes place during the conversion process.

$$2SO_2(g) + O_2(g) \underset{450\ ^{o}C,\ 2\text{-}3\ atm}{\overset{V_2O_5(s)}{\rightleftharpoons}} 2SO_3(g) + \text{heat}$$

Stage 3: Conversion of sulphur trioxide to oleum

The sulphur trioxide from the conversion chamber is passed through the heat exchanger to remove excess heat. It is then taken to an absorption tower where is dissolved in concentrated sulphuric acid to form oleum or fuming sulphuric acid.

$$SO_3(g) + H_2SO_4(l) \longrightarrow \underset{\text{Oleum}}{H_2S_2O_7(l)}$$

Sulphur trioxide cannot be dissolved directly in water to form sulphuric acid. This is because the reaction is highly exothermic and the heat produced vaporises the sulphuric acid formed. This makes it difficult to collect the acid.

Stage 4: Conversion of oleum to sulphuric acid

The oleum formed is then dissolved in water to give concentrated sulphuric acid.

$$H_2S_2O_7(l) + H_2O(l) \longrightarrow 2H_2SO_4(aq)$$

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A summary of the stages of the Contact process is shown in Figure 1.21.

Stage 1: Production and purification of SO_2

$$S(s) + O_2(g) \longrightarrow SO_2(g)$$

or

$$2PbS(s) + 3O_2(g) \longrightarrow 2PbO(s) + SO_2(g)$$

or

$$2ZnS(s) + 3O_2(g) \longrightarrow 2ZnO(s) + 2SO_2(g)$$

Stage 2: Conversion to SO_3

$$2SO_2(g) + O_2(g) \underset{450\ ^oC,\ 2\text{-}3\ atm}{\overset{V_2O_5(s)}{\rightleftharpoons}} 2SO_3(g)$$

Stage 3: Conversion to $H_2S_2O_7(l)$

$$SO_3(g) + H_2SO_4(l) \longrightarrow H_2S_2O_7(l)$$

Stage 4: Conversion to H_2SO_4

$$H_2S_2O_7(l) + H_2O(l) \longrightarrow 2H_2SO_4(aq)$$

Figure 1.21: *Summarised stages of the Contact process*

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Properties of sulphuric acid

The following are some of the physical and chemical properties of sulphuric acid:

Physical properties

(a) It is a dense oily liquid.

(b) It is colourless with a specific gravity of 1.84 g cm^{-3}.

(c) It has a boiling point of 337 °C. It decomposes at this temperature to give sulphur trioxide gas and water.

$$H_2SO_4(l) \xrightarrow{337\ ^oC} SO_3(g) + H_2O(g)$$

Chemical properties

Sulphuric acid is a strong acid which takes part in different chemical reactions to form various compounds.

(a) *Reactions with metals*: Dilute sulphuric acid reacts with metals such as magnesium, zinc and iron to form metal sulphates and hydrogen gas. For example, dilute sulphuric acid reacts with magnesium to give magnesium sulphate and hydrogen gas.

$$Mg(s) + H_2SO_4(aq) \longrightarrow MgSO_4(aq) + H_2(g)$$

Zinc and iron react in a similar way to form zinc sulphate and iron(II) sulphate, respectively. Hydrogen gas is evolved in both cases.

$$Zn(s) + H_2SO_4(aq) \longrightarrow ZnSO_4(aq) + H_2(g)$$

$$Fe(s) + H_2SO_4(aq) \longrightarrow FeSO_4(aq) + H_2(g)$$

(b) *Reactions with metal oxides*: Metal oxides react with dilute sulphuric acid to form metal sulphates and water. For example, copper(II) oxide reacts with dilute sulphuric acid to form copper(II) sulphate and water. Magnesium oxide reacts with the acid to form magnesium sulphate and water.

$$CuO(s) + H_2SO_4(aq) \longrightarrow CuSO_4(aq) + H_2O(l)$$

$$MgO(s) + H_2SO_4(aq) \longrightarrow MgSO_4(aq) + H_2O(l)$$

(c) *Reactions with metal hydroxides*: Metal hydroxides react with dilute sulphuric acid to form metal sulphates and water. For example, sodium hydroxide reacts with dilute sulphuric acid to form sodium sulphate and water as shown in the following equation:

$$2NaOH(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$$

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(d) *Reactions with metal carbonates*: Dilute sulphuric acid reacts with metal carbonates to give a metal sulphate, carbon dioxide, and water. For example, dilute sulphuric acid reacts with sodium carbonate and lead carbonate as shown in the following equations:

$$Na_2CO_3(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + CO_2(g) + H_2O(l)$$

$$PbCO_3(s) + H_2SO_4(aq) \longrightarrow PbSO_4(s) + CO_2(g) + H_2O(l)$$

(e) *As a dehydrating agent*: Concentrated sulphuric acid removes water from different substances.

(i) *Dehydration of sugar*: When concentrated sulphuric acid is added to sugar, a vigorous reaction takes place, causing the reaction mixture to rise. The colour of the sugar changes to brown and finally black. Concentrated sulphuric acid dehydrates sugar by taking away the water from the sugar, leaving carbon as a black mass. The reaction is highly exothermic. The heat produced evaporates the water from the reaction.

$$C_{12}H_{22}O_{11}(s) \xrightarrow{\text{concentrated } H_2SO_4} 12C(s) + 11H_2O(g)$$

Sugar



Activity 1.19

Aim: To investigate the dehydration of sugar by concentrated sulphuric acid

Requirements: Spatula, 250-cm^3 beaker, sugar, and concentrated sulphuric acid

Procedure

1. Put two teaspoonful of sugar into a 250-cm^3 beaker.
2. Slowly, add concentrated sulphuric acid until the acid covers the sugar.
3. Allow the reaction to proceed for about 10 minutes, and then record the observations.

Questions

1. Explain the observations when concentrated sulphuric acid was added to sugar.
2. Describe the appearance of the reaction mixture after 10 minutes.

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(ii) *Dehydration of copper(II) sulphate crystals*: When concentrated sulphuric acid is added to hydrated copper(II) sulphate crystals, the colour changes from blue to white. The concentrated sulphuric acid dehydrates the hydrated copper(II) sulphate to anhydrous copper(II) sulphate.

$$\underset{\text{Blue}}{CuSO_4 \cdot 5H_2O(s)} \xrightarrow{\text{concentrated } H_2SO_4} \underset{\text{White}}{CuSO_4(s)} + 5H_2O(l)$$



Activity 1.20

Aim: To investigate the dehydration of copper(II) sulphate crystals by concentrated sulphuric acid

Requirements: Test tube, spatula, dropper, concentrated sulphuric acid, and hydrated copper(II) sulphate crystals

Procedure

1. Put 2 spatulaful of hydrated copper(II) sulphate crystals in a clean test tube.
2. Add slowly about 2 cm^3 of concentrated sulphuric acid into the test tube containing copper(II) sulphate crystals. Record the observations.

Question

What was observed when concentrated sulphuric acid was added into the test tube containing copper(II) sulphate crystals?

(f) *Sulphuric acid as a drying agent*: Concentrated sulphuric acid absorbs water from substances. It is used as a drying agent during the laboratory preparation of different gases.

(g) *Sulphuric acid as an oxidising agent*: Hot concentrated sulphuric acid is a strong oxidising agent. It oxidises both metals and non-metals while itself is reduced to sulphur dioxide. For example, concentrated sulphuric acid oxidises carbon to carbon dioxide and sulphur to sulphur dioxide as shown in the following equations:

$$C(s) + 2H_2SO_4(l) \longrightarrow CO_2(g) + 2SO_2(g) + 2H_2O(l)$$

$$S(s) + 2H_2SO_4(l) \longrightarrow 3SO_2(g) + 2H_2O(l)$$

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Activity 1.21

Aim: To investigate the oxidation of carbon and sulphur by concentrated sulphuric acid

Requirements: Boiling tube, spatula, test tube holder, source of heat, small beaker, dropper, rubber bung fitted with a delivery tube, retort stand and clamp, concentrated sulphuric acid, powdered charcoal, limewater, dichromate indicator paper, and sulphur

Procedure

1. Put one spatulaful of powdered charcoal into a boiling tube.
2. Carefully, add about 2 cm^3 of concentrated sulphuric acid using a dropper to just cover the charcoal powder.
3. Place a dichromate indicator paper at the mouth of the boiling tube and gently heat the mixture.
4. Cork the boiling tube with the rubber bung that is fitted with a delivery tube. Direct the gas produced into the limewater as shown in Figure 1.22.
5. Repeat steps 1 to 4 using sulphur in the place of charcoal.

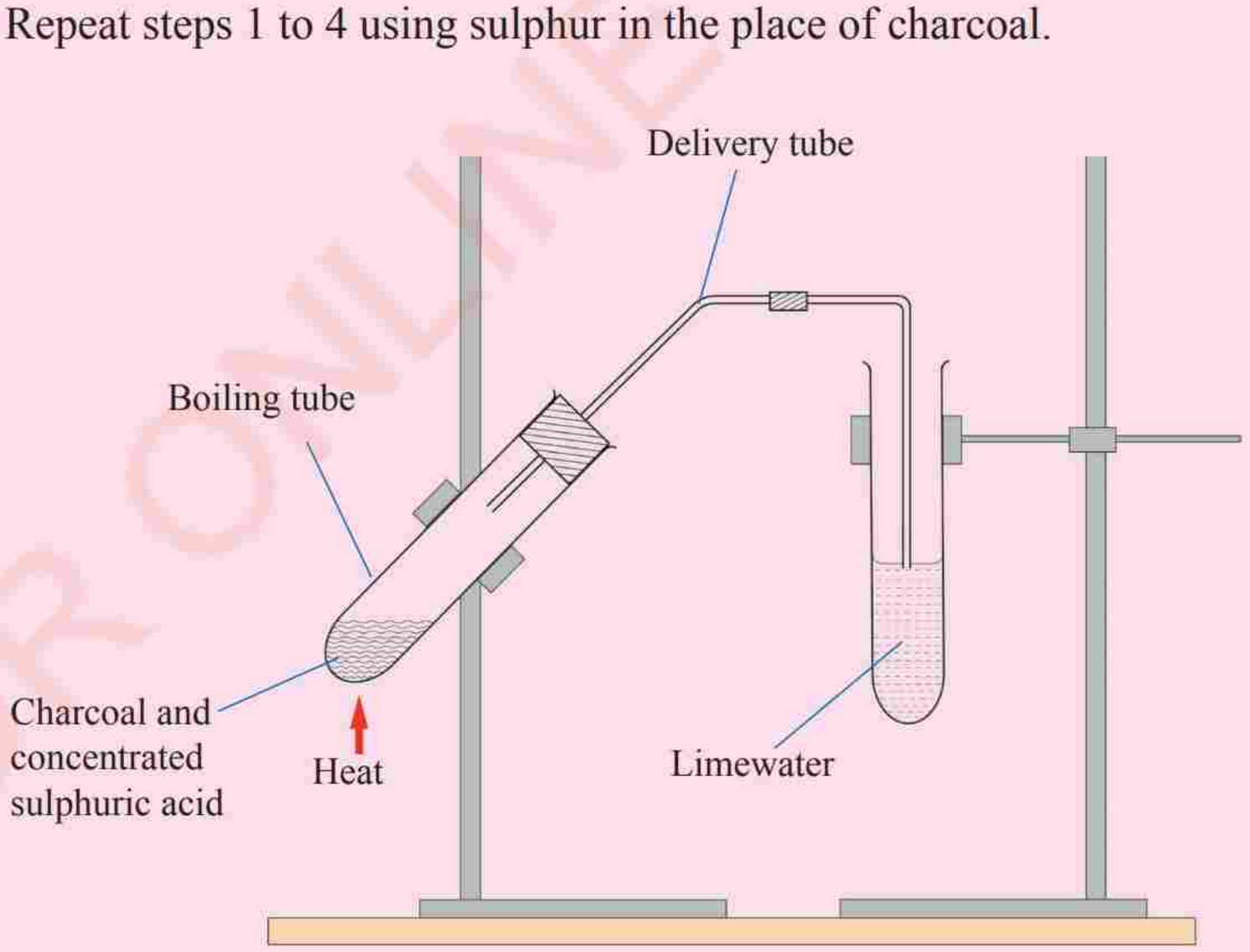


Figure 1.22: *Set-up for the oxidation of carbon by concentrated sulphuric acid*

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Questions

1. Explain the observations on dichromate(VI) paper when the mixture was heated.
2. Write an equation for the reaction between the charcoal and concentrated sulphuric acid.

Uses of sulphuric acid

Sulphuric acid has many uses. Some of them are as follows:

Extraction of metals: Sulphuric acid is used for extracting metals such as zinc, and copper from different mineral species (ores).

Cleaning and processing of metals: Sulphuric acid is used in large quantities in the iron and steel-making industry to remove rust and scale from rolled iron sheets.

Manufacture of fertilisers: Ammonium sulphate, an important nitrogenous fertiliser is commonly produced as a by-product in the production of coke from coal. The ammonia produced in the thermal decomposition of coal is reacted with waste sulphuric acid to produce ammonium sulphate.

Manufacture of aluminium sulphate: Sulphuric acid is used in the manufacture of aluminium sulphate which is used in water treatment plants to filter impurities and to improve the taste of the water. Aluminium sulphate is made by reacting bauxite (Al_2O_3) with sulphuric acid.

Refining crude oil: A large quantity of sulphuric acid is used in refining petroleum. The acid is used as a catalyst for the reaction of isobutane with isobutylene to give isooctane, a compound that raises the octane rating of petrol.

Other uses:

Sulphuric acid is also used in;

(i) lead-acid batteries, as an electrolyte.

(ii) the manufacture of a wide range of pigments.

(iii) the manufacture of variety of organic compounds such as drugs, detergents, explosives, alkenes, and alcohols.

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Exercise 1.6

1. Write **TRUE** for a correct statement and **FALSE** for an incorrect statement. For the false statement(s) write its corresponding correct statement(s).
   (a) Oleum does not show any acidic properties.
   (b) Copper is oxidised to Cu^{2+} by hot and concentrated sulphuric acid.
   (c) Dilute sulphuric acid gives copper(II) sulphate when reacted with copper(II) oxide.
   (d) Dilute sulphuric acid gives salt and water only when it reacts with a metal hydroxide.

2. Why is concentrated sulphuric acid a weaker electrolyte than dilute sulphuric acid?

3. Using chemical equations, explain the observations when concentrated sulphuric acid is added to the following:
   (a) Copper(II) sulphate pentahydrate
   (b) Sugar

Nitrogen

Nitrogen exists in gaseous state as a diatomic molecule (N_2). It is a Group V and Period 2 element of the Periodic Table. Its atomic number is 7 and it has the electronic configuration of 2:5. This arrangement shows that it has a valency of 3 because it requires three electrons to fill up its outermost shell. However, it is important to note that nitrogen can also have oxidation states of 2 and 4. Nitrogen gas occupies about 78% by volume of all the gases in the atmosphere. Nitrogen also occurs in combined states in the form of nitrates and oxides. It is also found in plants and animals as a constituent of proteins.

Laboratory preparation of nitrogen gas

Nitrogen gas can be prepared in the laboratory by isolating it from atmospheric air. In this process, air is first passed through sodium hydroxide to remove carbon dioxide and then passed over a heated copper metal to remove oxygen. When air is passed through a solution of sodium hydroxide or potassium hydroxide, carbon dioxide from the air dissolves in the alkali.

$$NaOH(aq) + CO_2(g) \longrightarrow NaHCO_3(aq)$$

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In the combustion tube, the hot copper turnings react with oxygen to form copper(II) oxide. In the process, oxygen is removed from the air.

$$2Cu(s) + O_2(g) \longrightarrow 2CuO(s)$$

The brown colour of copper changes to black which is the colour of copper(II) oxide. This reaction leaves nitrogen gas as the major component of the air at the end of the process. However, the presence of inert gases such as neon and argon still makes the gas impure. Dry nitrogen gas can be obtained by passing it through concentrated sulphuric acid instead of collecting it over water. The initial bubbles of the gas are not collected to avoid collecting air that was in the apparatus.



Activity 1.22

Aim: To prepare nitrogen gas from the air

Requirements: Bicycle pump, two retort stands with clamps, conical flask fitted with a two holed rubber stopper, combustion tube with a one-holed stopper at each end, delivery tubes, trough, gas jar, beehive shelf, 2 M potassium hydroxide solution or sodium hydroxide solution, and copper turnings.

Procedure

1. Put some potassium hydroxide or sodium hydroxide solution in the conical flask.
2. Put some copper turnings into the combustion tube.
3. Set up the apparatus as shown in Figure 1.23.

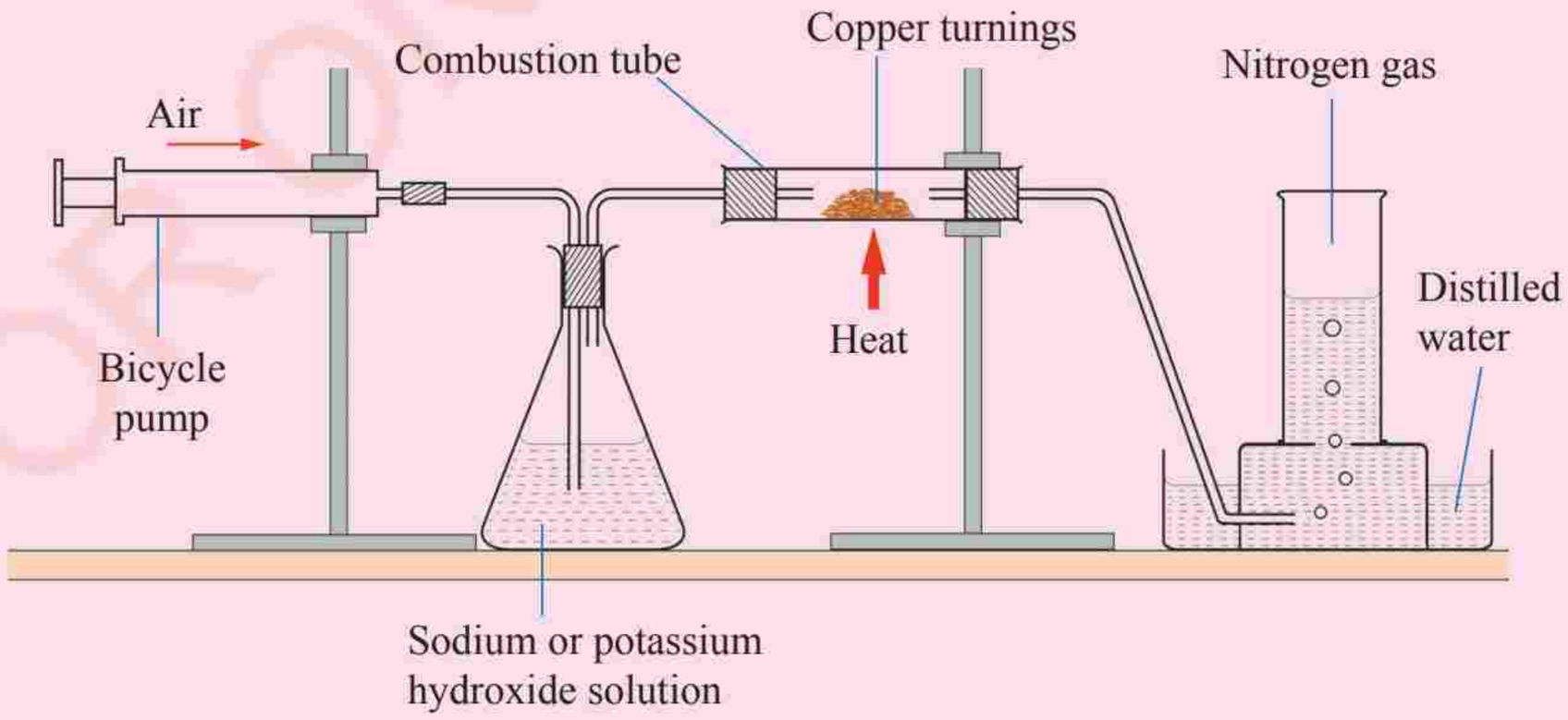


Figure 1.23: *Set-up for the preparation of nitrogen gas from air*

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4. Pump air in potassium hydroxide or sodium hydroxide solution using the bicycle pump.
5. Allow the initial bubbles of air to escape and then collect the gas over water.
6. Hold a magnesium ribbon with a pair of tongs then light it using a safety match.
7. Insert the burning ribbon into a gas jar of nitrogen gas and observe what happens.

Questions

1. Write an equation for the reaction in the conical flask after passing air.
2. Explain the colour changes observed for the reaction in the combustion tube.
3. Write an equation for the reaction in the combustion tube.
4. With the aid of an equation, explain the observations in Step 7.

Properties of nitrogen gas

The following are some of the physical and chemical properties of nitrogen gas:

Physical properties

(a) Nitrogen is a colourless, odourless, and tasteless gas.
(b) It is insoluble in water, and therefore conveniently collected over water.
(c) It has a boiling point of −196 °C.
(d) It can be liquefied to form liquid nitrogen.
(e) It is less denser than air.

Chemical properties

(a) *Nitrogen is relatively unreactive*: Nitrogen gas is stable and therefore takes part in reactions at very high temperatures. Nitrogen neither reacts with oxygen (does not burn) at room temperature nor does it support combustion. When heated, the gas combines with oxygen to form nitrogen monoxide gas.

$$N_2(g) + O_2(g) \xrightarrow{\text{heat}} 2NO(g)$$

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(b) *Reactions with hydrogen*: Nitrogen reacts with hydrogen when heated to form ammonia.

$$N_2(g) + 3H_2(g) \xrightarrow{\text{heat}} 2NH_3(g)$$

(c) *Reactions with metals*: When heated together with metals, nitrogen forms metal nitrides. For example when heated together with magnesium, nitrogen forms magnesium nitride that is accompanied with a bright flame.

$$3Mg(s) + N_2(g) \xrightarrow{\text{heat}} Mg_3N_2(g)$$

Uses of nitrogen gas

The following are some of the uses of nitrogen gas:

Manufacture of fertilisers: Nitrogen is used to manufacture nitrogenous fertilisers. These include diammonium phosphate (DAP), calcium ammonium nitrate (CAN), ammonium superphosphate (ASP), ammonium nitrate (AN), ammonium phosphate sulphate (APS), urea, ammonium sulphate nitrate (ASN), and sulphate of ammonia (SA).

Refrigeration: Nitrogen gas is used as a refrigerant because of its low boiling point (–196 °C).

Processing reactive substances: Due to its low reactivity, nitrogen is used to provide an inert atmosphere in some reactions and for storing and processing reactive substances.

Fibres industries: Nitrogen is used in the manufacture of synthetic fibres such as polyamides. Polyamides are commonly known as *nylons*. Nylons are chemically inert and are stronger than natural fibres. They are used in making items like fishing nets and clothes.

Manufacture of ammonia: Nitrogen is used in the manufacture of ammonia through the Haber process. In the Haber process, ammonia is manufactured by direct combination of nitrogen and hydrogen gases in the ratio of 1:3. The gases are reacted at a temperature of about 450 °C and a pressure of about 200 atmospheres in the presence of finely divided iron catalyst. The gases are cooled while still under pressure and ammonia is removed as a liquid.

$$N_2(g) + 3H_2(g) \underset{}{\overset{\text{catalyst}}{\rightleftharpoons}} 2NH_3(g)$$

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Manufacture of nitric acid: The ammonia gas manufactured from nitrogen in the Haber process is used in the manufacture of nitric acid by catalytic oxidation. This process involves three main stages which are catalytic oxidation of ammonia, oxidation of nitrogen monoxide to nitrogen dioxide, and the reaction of nitrogen dioxide with water to form nitric acid.

In the catalytic oxidation of ammonia, the ammonia from the Haber process and air are passed over heated platinum gauze at 700 °C. In this process, ammonia is oxidised to nitrogen monoxide.

$$4NH_3(g) + 5O_2(g) \xrightarrow{\text{catalyst}} 4NO(g) + 6H_2O(g)$$

The nitrogen monoxide is oxidised to nitrogen dioxide by passing it through a cooling chamber at about 30 °C where it combines with more oxygen from the air to form nitrogen dioxide.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$$

Nitrogen dioxide is then mixed with excess air and passed through an absorption tower which is lined with quartz. The quartz provides a large surface area for the absorption of the gas and slows down the flow of water. The following reaction takes place in the absorption tower:

$$4NO_2(g) + 2H_2O(l) + O_2(g) \longrightarrow 4HNO_3(aq)$$

Preservation of food: Nitrogen gas is used for generating an altered or man-made atmosphere condition where it is applied with carbon dioxide to help aid in the preservation of packaged or bulk foods. It helps in food preservation by safeguarding against oxidative damage, which causes the decay and breakdown leading to food spoilage.

Medicine and pharmaceuticals: Nitrogen can be found in some drugs due to its ability to form hydrogen bonding with biological targets. Nitrogen gas can also be used to preserve sperms, eggs, nerves, blood, stem cells, and various other biological specimens.

Mining: In the mining industries, nitrogen gas is used for quick extinguishing of fires by eliminating the oxygen from the air.

Pollution control: Nitrogen gas is used to remove the volatile organic compounds in liquids before they are discarded.

Soldering in electronics: When electronics are being assembled, nitrogen gas is used for soldering. Using nitrogen gas provides a cleaner breakaway from the solder site.

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Light bulb production: Nitrogen is often used in light bulbs as a cheaper alternative to argon.

Prevention of explosions: Nitrogen gas is used to displace oxygen and prevent explosions in areas such as chemical industries and manufacturing industries.

Inflating tires: Nitrogen is used to fill or inflate tires, and it offers benefits including giving tires a long life by reducing oxidation. It also improves tire pressure retention to give drivers better gas mileage.

Exercise 1.7

1. Describe the position of nitrogen in the Periodic Table using its electronic configuration.
2. How is dry nitrogen obtained from air?
3. Give the uses of nitrogen gas that corresponds with the following properties:
   (a) inert nature. (b) low boiling point.

Ammonia

Ammonia is a compound of hydrogen and nitrogen with the molecular formula NH_3. It is found in large amount in nitrogenous organic materials such as faeces and urine of animals. It can also be found in small amount in the hoofs and horns of animals.

Preparation of ammonia

Ammonia can be prepared in the laboratory by heating ammonium salt together with an alkali. The most commonly used alkalis are potassium hydroxide and calcium hydroxide. For example, calcium hydroxide reacts with ammonium chloride to produce ammonia gas, calcium chloride, and water.

$$2NH_4Cl(s) + Ca(OH)_2(s) \xrightarrow{\text{heat}} CaCl_2(aq) + 2H_2O(l) + 2NH_3(g)$$

In the experimental set up (Figure 1.24), the round-bottomed flask is tilted to prevent any condensed water from running back into the hot flask, which would crack the flask. Ammonia gas is dried by passing it over calcium oxide (quicklime). The common drying agents such as concentrated sulphuric acid and calcium chloride are not used because they react with the gas as follows:

$$2NH_3(g) + H_2SO_4(l) \rightleftharpoons (NH_4)_2SO_4(l)$$

$$8NH_3(g) + CaCl_2(s) \rightleftharpoons CaCl_2 \cdot 8NH_3(s)$$

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Ammonia is collected by upward delivery (downward displacement of air). This is because it is less dense than air. Ammonia is an alkaline gas and turns moist red litmus paper blue. When sodium hydroxide or potassium hydroxide are used, their solution forms are preferred because they are more reactive than their solid forms.



Activity 1.23

Aim: To prepare a dry sample of ammonia gas

Requirements: Round-bottomed flask, gas jars, drying tower, Bunsen burner, wire gauze, two retort stands with clamps, delivery tube, watch glass, rubber stoppers, ammonium chloride, calcium hydroxide, and calcium oxide (Quicklime)

Procedure

1. Mix equal amounts of calcium hydroxide and ammonium chloride in a watch glass.
2. Transfer the mixture into a round-bottomed flask.
3. Set up the apparatus as shown in Figure 1.24.

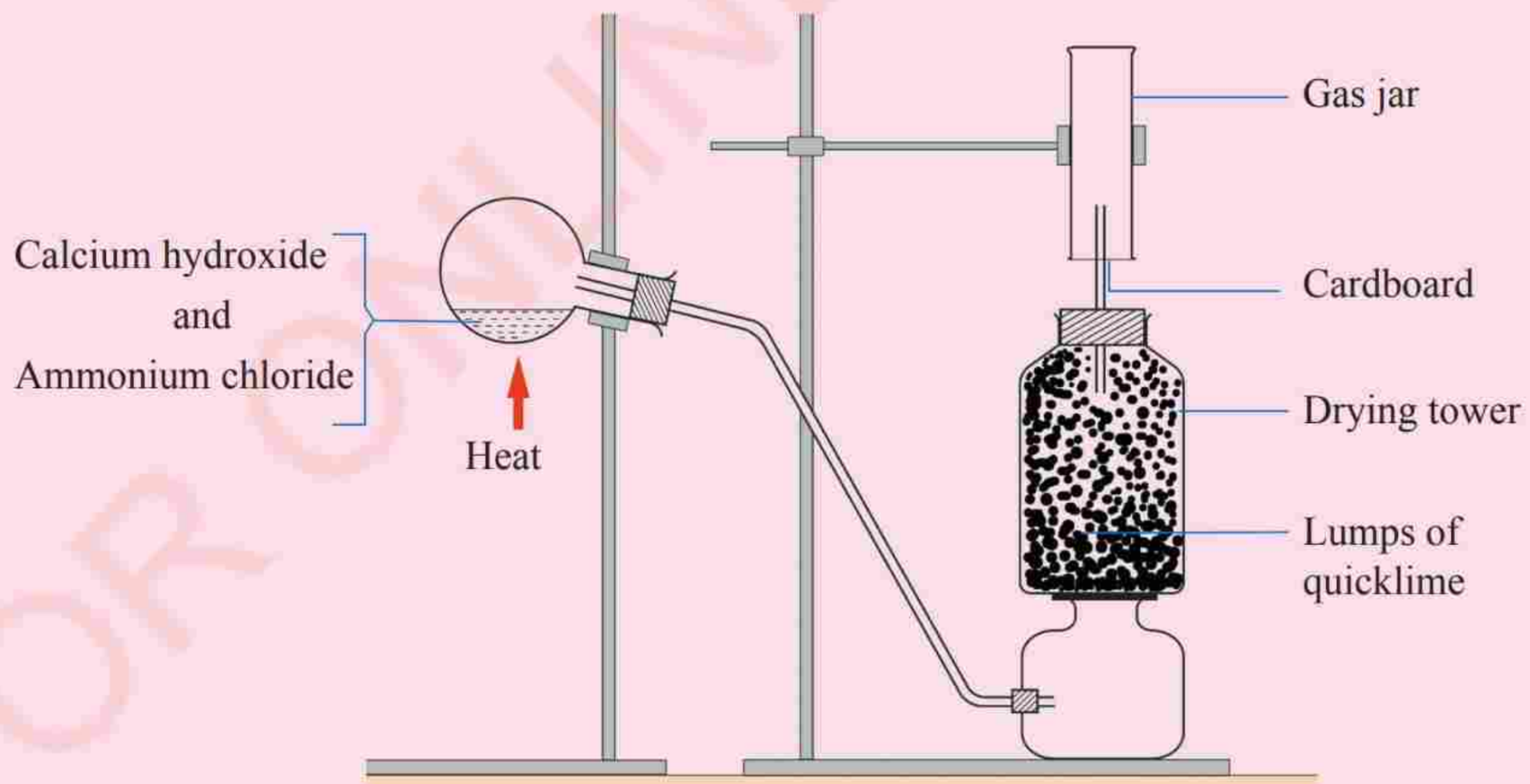


Figure 1.24: *Set-up for the preparation of ammonia gas*

4. Heat the mixture gently.
5. Test the gas produced using a moist red litmus paper.

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Questions

1. Why is the round-bottomed flask set in a tilting position?
2. What is the purpose of quicklime in this experiment?
3. Concentrated sulphuric acid and calcium chloride cannot be used as drying agents for ammonia. Explain.
4. Why was ammonia collected using the method shown in Figure 1.24?
5. What was the effect of the gas on the moist red litmus paper? Explain.
6. Write an equation for the reaction in the round-bottomed flask.

Properties of ammonia gas

The following are some of the physical and chemical properties of ammonia gas:

Physical properties

(a) Ammonia is a colourless gas with a pungent choking smell.

(b) It is less dense than air.

(c) Ammonia is highly soluble in water. This can be illustrated using the *fountain experiment.*

In the fountain experiment (Figure 1.25), when a drop of water is released into a boiling tube containing ammonia, the water dissolves some of the ammonia gas, thus leaving a partial vacuum. This lowers the pressure inside the boiling tube. The rubber remains pressed inside because of atmospheric pressure.

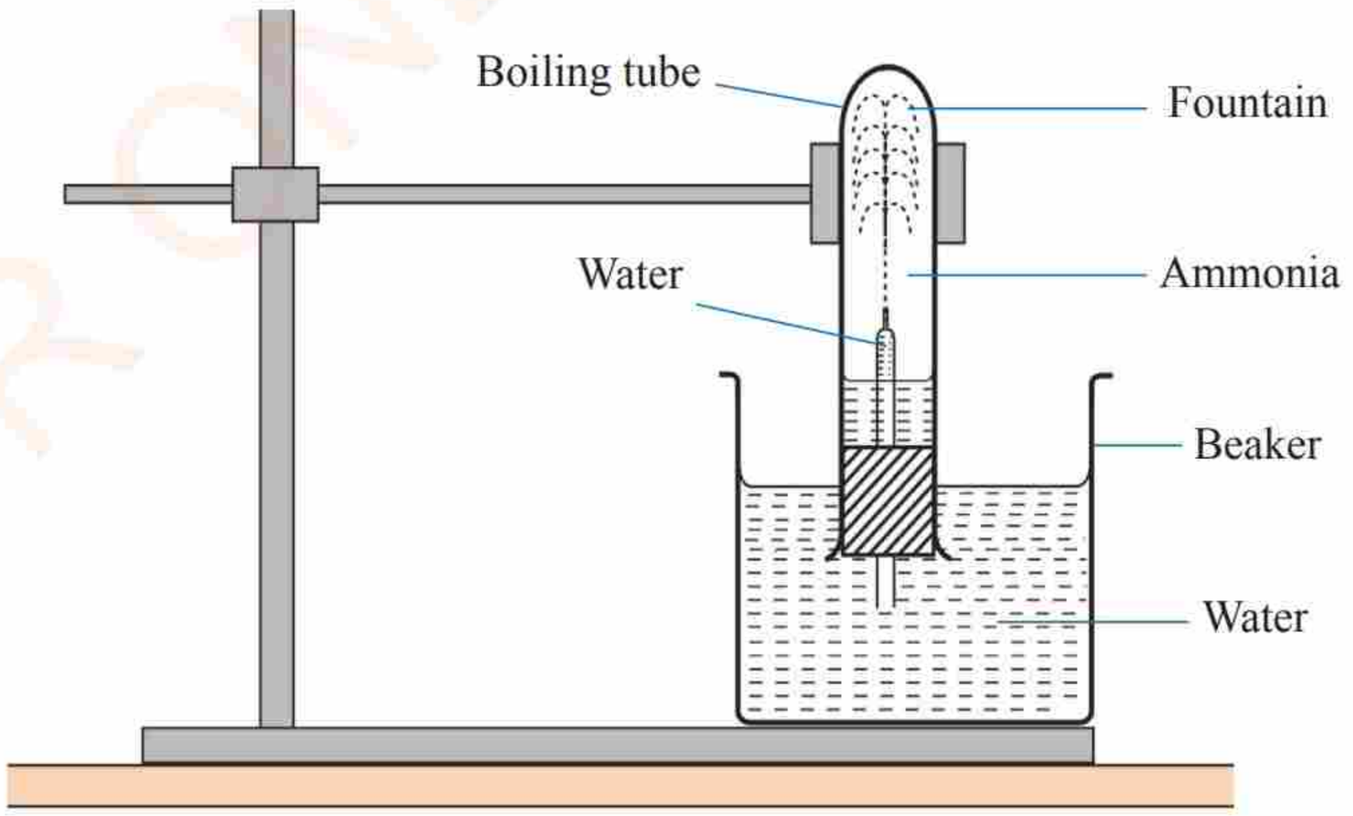


Figure 1.25: *Set-up of a fountain experiment*

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When the teat is removed from the pipette, the water in the beaker rushes into the boiling tube, thus dissolving the remaining ammonia gas. The water forms a *fountain,* hence the name of the experiment. The solution obtained is normally referred to as *aqueous ammonia.* When the solution is tested with the phenolphthalein indicator, the colour changes from colourless to pink indicating that the solution is alkaline. In aqueous ammonia, the molecules of ammonia continuously interact with water molecules to produce ammonium ions (NH_4^+) and hydroxyl ions (OH^-).

$$NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

Ammonium hydroxide does not exist as a molecule; instead, it exists as NH_4^+ and OH^- ions. The presence of the hydroxyl ions, OH^-, makes the solution alkaline.



Activity 1.24

Aim: To investigate the solubility of ammonia using the fountain experiment

Requirements: Teat pipette, a rubber bung, beaker, boiling tube with ammonia gas, a stand with a clamp, water, and litmus paper or phenolphthalein indicator

Procedure

1. Suck some drops of water into a teat pipette and fix a rubber bung to a boiling tube filled with ammonia gas as shown in Figure 1.26.

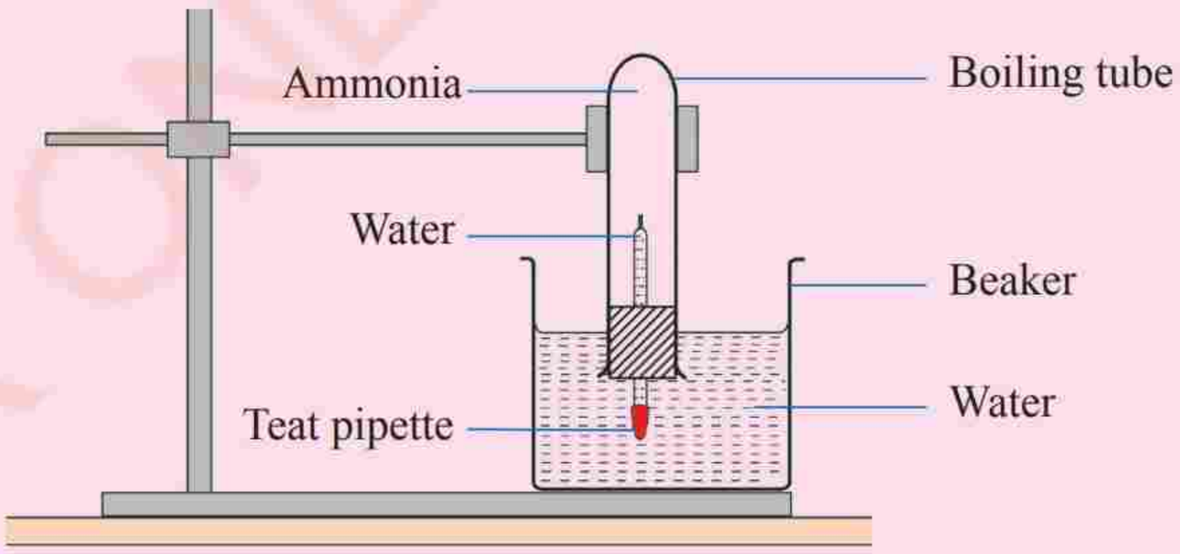


Figure 1.26: *Set-up for the fountain experiment*

2. Release one drop of water from the teat pipette.
3. Remove the teat from the pipette and observe what happens.
4. Test the solution in the boiling tube after the experiment with phenolphthalein indicator.

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Questions

1. Explain what happened when the teat was pressed to release water into the boiling tube containing ammonia gas.
2. What was observed when the teat was removed while the pipette was still in water?

Chemical properties

The following are chemical properties of ammonia:

(a) *Reaction with concentrated hydrochloric acid*: When a glass rod dipped in concentrated hydrochloric acid is placed at the mouth of a gas jar containing ammonia, dense white fumes of ammonium chloride are formed. Hydrogen chloride fumes from concentrated hydrochloric acid react with ammonia gas to form ammonium chloride. This is used as a test for ammonia gas.

$$NH_3(g) + HCl(g) \longrightarrow NH_4Cl(s)$$

(b) *Oxidation of ammonia*: Ammonia gas is oxidised to nitrogen by the oxidising agents such as copper(II) oxide. When ammonia gas is passed over heated copper(II) oxide, the gas is oxidised to nitrogen, while copper(II) oxide is reduced to copper.

$$3CuO(s) + 2NH_3(g) \longrightarrow 3Cu(s) + 3H_2O(l) + N_2(g)$$



Activity 1.25

Aim: To investigate oxidation of ammonia gas by copper(II) oxide

Requirements: Combustion tube, retort stand, beaker, test tube, water trough, gas jar, delivery tubes, three rubber stoppers, Bunsen burner, beehive shelf, copper(II) oxide, sources of ammonia gas, cobalt(II) chloride paper or anhydrous copper(II) sulphate, and ice-cold water

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Procedure

1. Place some copper(II) oxide in a combustion tube.
2. Set up the apparatus as shown in Figure 1.27.

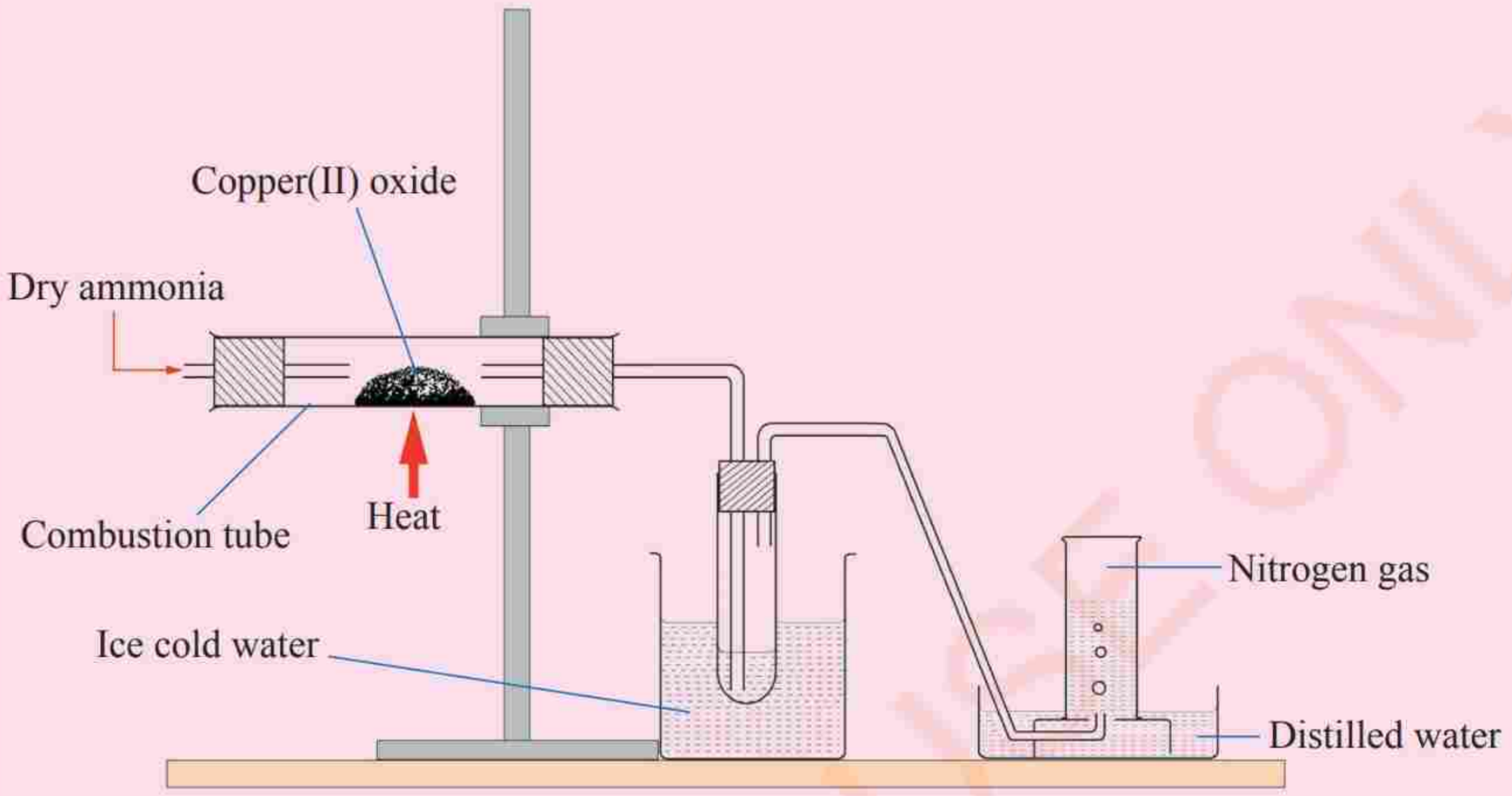


Figure 1.27: *Set-up for the oxidation of ammonia gas by copper(II) oxide*

3. Heat the copper(II) oxide in the combustion tube and slowly pass the ammonia gas.
4. Allow the initial bubbles of air to escape before placing the gas jar in the position shown.
5. Collect the liquid formed in the test tube dipped in ice-cold water.
6. Dip cobalt(II) chloride paper inside the liquid collected in the test tube in Step 5. Record the observations.

Questions

1. Explain the observations when ammonia gas was passed on copper(II) oxide.
2. What was observed when cobalt(II) chloride paper was dipped in the liquid collected in the test tube? Explain.
3. What was the purpose of using the ice-cold water?

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Uses of ammonia

The following are some of the uses of ammonia:

Manufacture of fertilisers: Ammonia is used in the manufacture of nitrogenous fertilisers such as ammonium sulphate nitrate (ASN), sulphate of ammonia (SA), di-ammonium phosphate (DAP), calcium ammonium nitrate (CAN), ammonium nitrate (AN), and urea.

Cleaning: Ammonia softens water and neutralises acid stains on cloth caused by perspiration, thus making washing easier.

Refrigeration: Liquid ammonia can be used as a refrigerant because it is highly volatile.

Manufacture of nitric acid: Nitric acid is manufactured by the catalytic oxidation of ammonia.

Water treatment: Ammonia is used in wastewater treatment and purification of water supplies.

Manufacture of various organic substances: Ammonia is used in the manufacture of a number of organic substances including plastics, explosives, textiles, and dyes.

Exercise 1.8

1. Ammonia gas is prepared by heating a mixture of ammonium chloride and calcium hydroxide. The gas is then passed through quicklime and collected by downward displacement of air.
   (a) Write an equation for the reaction between ammonium chloride and calcium hydroxide.
   (b) Explain the role of quicklime in the preparation of ammonia gas.
   (c) Why is the gas collected by downward displacement of air?

2. Ammonia can be manufactured by reacting hydrogen with nitrogen gas in the presence of iron catalyst.
   (a) Write an equation for the reaction.
   (b) Explain the conditions necessary for optimum yield of ammonia.

3. How is ammonia gas tested in the laboratory?

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Carbon

Carbon is a Group IV and Period 2 element. It has an atomic number of 6 and an electronic configuration of 2:4. It exhibits a valency of 4 and usually forms covalent bonds when combining with other elements. Carbon is found in a variety of natural substances which include shells, coal, petroleum, natural gas, proteins, carbohydrates, fats, diamond, and graphite. It is also found in the compounds of carbonates such as chalk ($CaCO_3$). Carbon is also found in many synthetic organic substances such as drugs, textiles, and plastics. Carbon is the major component of all organic compounds.

Allotropes of carbon

Carbon exists in several allotropic forms. The main allotropes of carbon are *graphite*, *diamond*, and *amorphous carbon*. Graphite and diamond are the common crystalline allotropes of carbon. The crystalline allotropes of carbon have definite crystalline structures but they have distinctive structural differences. The differences are mainly due to the way their atoms are packed.

Graphite: In graphite, each carbon atom is bonded to three other carbon atoms resulting to a trigonal structure. Three out of the four valence electrons of each carbon atom are used in bond formation. The fourth electron is referred to as a *delocalised electron*, and it is free to move in the graphite structure. The trigonal units come together to form hexagonal rings (Figure 1.28). These rings form flat parallel layers, one over the other. The formed layers can slide over one another hence making graphite soft and slippery.

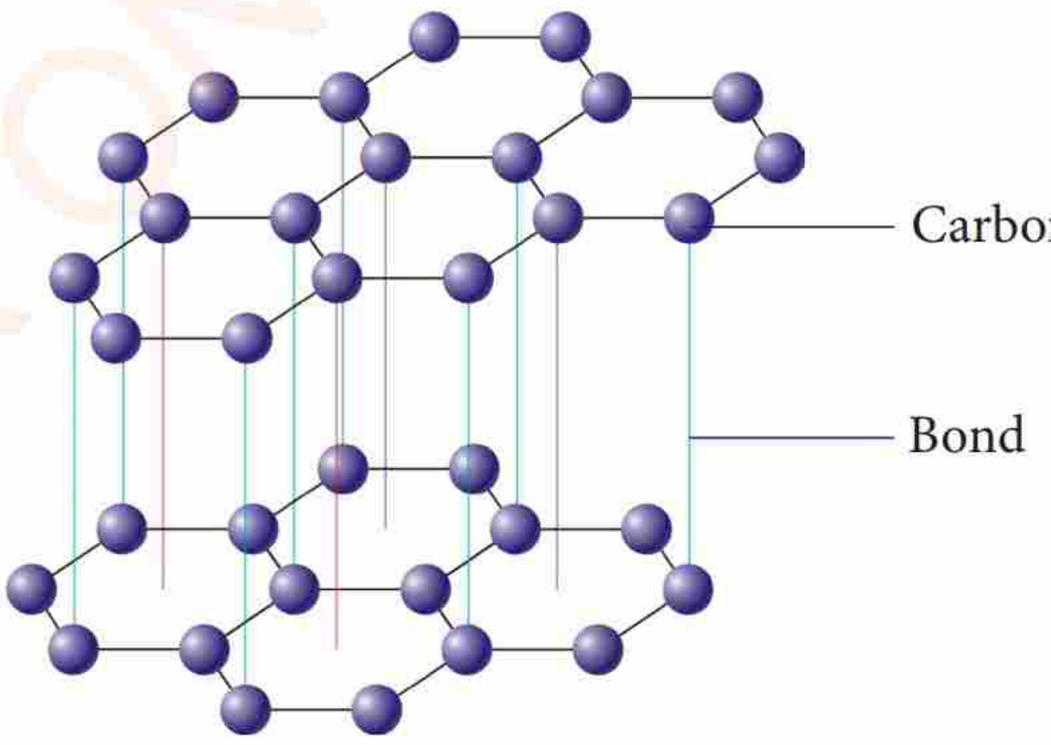


Figure 1.28: *Structure of graphite*

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The following are some of the physical properties of graphite:

(a) It has a density of about 2.26 g/cm^3.

(b) It is soft and slippery or greasy.

(c) It is a good conductor of electricity and heat due to delocalisation of electrons.

(d) It has a melting point of around 3600 °C and a boiling point of 4827 °C.

Uses of graphite

(i) It is used as one of the main ingredients in high temperature processes because of its slippery nature and high boiling point.

(ii) It is used to make electrodes in cells and batteries due to its good electrical conductivity.

(iii) It is mixed with clay to make the lead in pencils.

(iv) It is used in the manufacture of steel, glass, and electronics such as smartphones. Graphite is a common refractory material because it withstands high temperatures without changing chemically. It is also a substitute of asbestos in automobile brake linings.

(v) Powdered graphite is mixed in paints to create authentic protection for walls.

Diamond: In diamond, all the four valence electrons of a carbon atom are used in bonding, forming four strong covalent bonds. Therefore, each carbon atom is bonded to four other carbon atoms resulting to a tetrahedral structure (Figure 1.29).

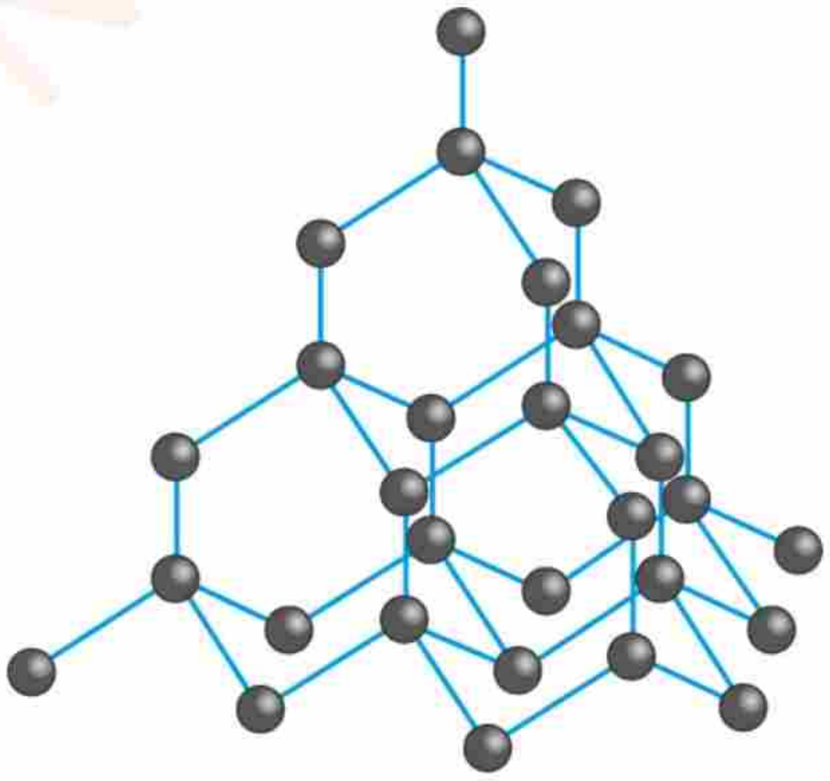


Figure 1.29: *Structure of diamond*

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The following are some of the physical properties of diamond:

(a) It has a higher density (3.53 g/cm^3) compared to graphite.

(b) It is the hardest natural substance known.

(c) It is a bad conductor of electricity and heat.

(d) The melting point of diamond is about 4027 °C and the boiling point is about 4830 °C.

(e) It has a high refractive index of 2.45. The high refractive index results in high dispersion of light, making it suitable for use in jewellery.

Uses of diamond

(i) It is used in making jewellery.

(ii) It is used to make glass cutters and rock borers because of its hardness.

Amorphous carbon: Amorphous carbon is the carbon that does not have any clear shape, form or crystalline structure. Amorphous carbon is made up of tiny bits of graphite with varying amounts of other elements considered as impurities. It is formed when a material containing carbon is burned in limited supply of oxygen, resulting in incomplete combustion. Amorphous carbon includes coal, sugar charcoal (made by dehydrating sugar), and wood charcoal (made by burning wood in a limited supply of air, in a process known as *destructive distillation).* Other forms of amorphous carbon are animal charcoal, coke, soot, activated carbon, and carbon fibre. Animal charcoal is made by burning animal bones in a limited supply of air.

Uses of amorphous carbon

(i) It is used to make ink, paint, and rubber products.

(ii) It is pressed into shapes and used to form cores of dry batteries.

(iii) It is used in textiles, plastics, and healthcare industries as well as in the fields of gas, water filtering, electrical applications and food packaging.

Chemical properties

The following are some of the chemical properties of carbon:

(a) Carbon burns in excess oxygen to form carbon dioxide gas.

$$C(s) + O_2(g) \longrightarrow CO_2(g)$$

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(b) It burns in limited supply of oxygen to form carbon monoxide gas.

$$2C(s) + O_2(g) \longrightarrow 2CO(g)$$

(c) Carbon has a high affinity for oxygen and thus acts as a reducing agent. Carbon reduces oxides of less reactive metals to their respective metals as shown in the following equations:

$$ZnO(s) + C(s) \longrightarrow Zn(s) + CO(g)$$

$$PbO(s) + C(s) \longrightarrow Pb(s) + CO(g)$$

(d) Carbon reduces hot concentrated nitric acid as well as concentrated sulphuric acid as shown in the following equations:

$$4HNO_3(l) + C(s) \longrightarrow 4NO_2(g) + CO_2(g) + 2H_2O(l)$$

$$2H_2SO_4(l) + C(s) \longrightarrow 2SO_2(g) + CO_2(g) + 2H_2O(l)$$

Task 1.2

Design the destructive distillation process for wood using the methods common to your local environment.

Carbon dioxide

Carbon dioxide is one of the oxides of carbon. A molecule of carbon dioxide is made up of two oxygen atoms covalently bonded to a single carbon atom.

Preparation of carbon dioxide

Carbon dioxide is produced when an acid reacts with a carbonate. Calcium carbonate and hydrochloric acid are usually used because they are cheap and easy to obtain. The gas can therefore be prepared in the laboratory by the action of dilute hydrochloric acid on marble chips (calcium carbonate). Dilute hydrochloric acid reacts with marble chips to give calcium chloride, water, and carbon dioxide.

$$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

During laboratory preparation (Figure 1.30), potassium bicarbonate solution is used to absorb traces of hydrochloric acid from the carbon dioxide. The gas is then dried by passing it through anhydrous calcium chloride. Carbon dioxide is collected by downward delivery because it is denser than air. Other carbonates such as magnesium carbonate can also be used to prepare carbon dioxide gas.

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Activity 1.26

Aim: To prepare a dry sample of carbon dioxide

Requirements: Thistle funnel, flask, delivery tubes, gas jars, wash bottle, U-tube, retort stand and clamp, dilute hydrochloric acid, calcium carbonate (marble chips), potassium bicarbonate, and anhydrous calcium chloride

Procedure

1. Place some marble chips in a flask.
2. Put potassium bicarbonate solution in the wash bottle.
3. Place anhydrous calcium chloride in the U-tube.
4. Set up the apparatus as shown in Figure 1.30.

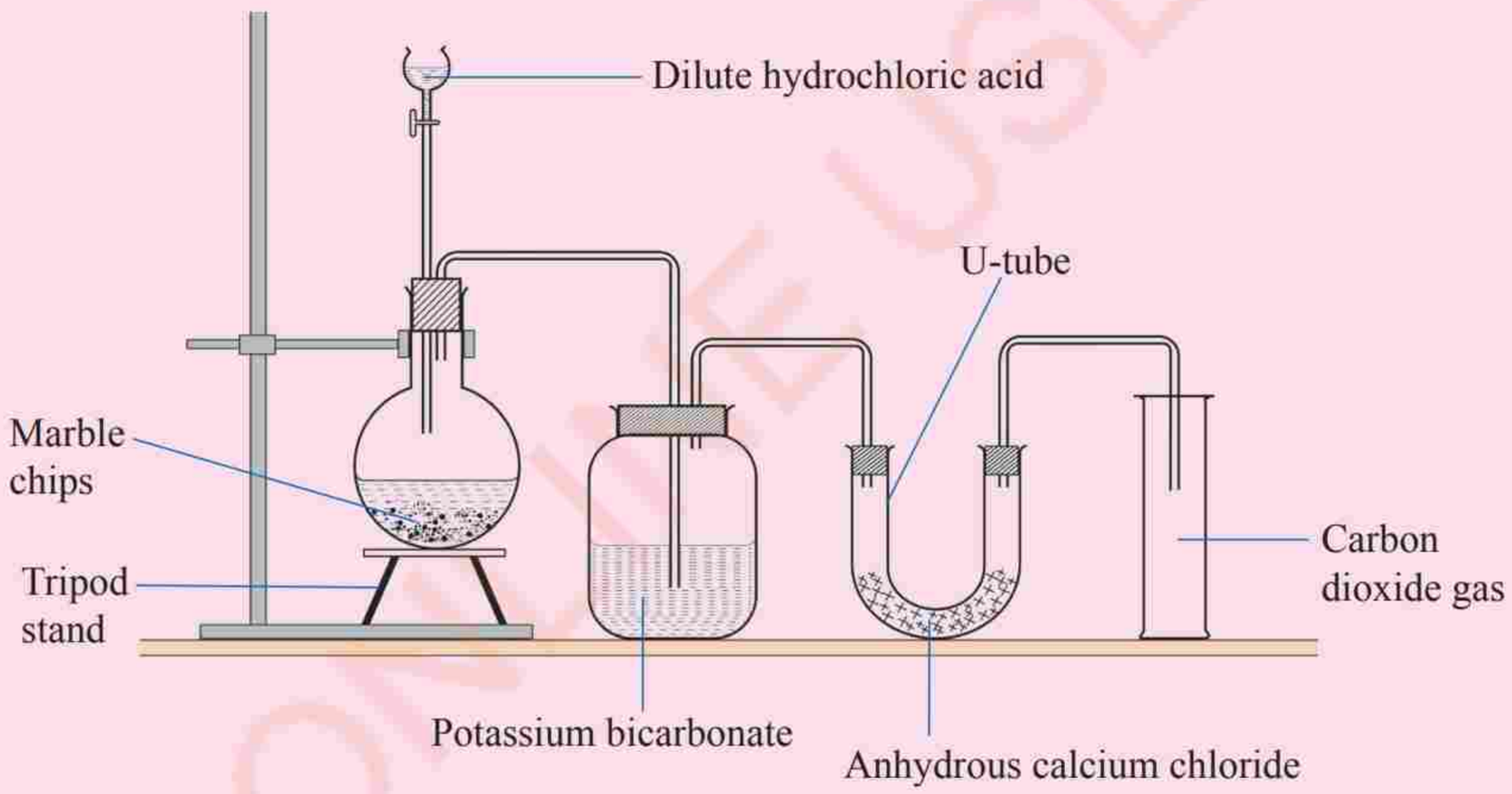


Figure 1.30: *Set-up for the preparation of carbon dioxide*

5. Add dilute hydrochloric acid dropwise into the flask containing the marble chips, until no more effervescence is observed.
6. Insert a burning wooden splint into the gas jar containing the gas collected.
7. Place a moist blue litmus paper on the mouth of the gas jar. Record the observations.

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Questions

1. What was observed when dilute hydrochloric acid was added into the flask containing the marble chips?
2. What is the use of potassium bicarbonate solution in this experiment?
3. From the observations, state whether the gas collected in the jar;
   (a) supports combustion.
   (b) is acidic or basic.

Properties of carbon dioxide gas

The following are some of the physical and chemical properties of carbon dioxide gas:

Physical properties

(a) It is a colourless and odourless gas.

(b) It has a melting point of –56.6 ºC and a boiling point of –78.5 ºC.

(c) It is denser than air.

(d) Solid carbon dioxide is referred to as *dry ice*. Dry ice sublimes, changing directly to gas at the atmospheric pressure.

(e) The gas is slightly acidic and therefore it may not have observable effect on a litmus paper.

Chemical properties

Carbon dioxide does not support combustion.

(a) *Tests for carbon dioxide*:

(i) Limewater (aqueous solution of calcium hydroxide) is used to test the presence of carbon dioxide. When a little carbon dioxide is bubbled into limewater, white precipitates of calcium carbonate are formed. This is a confirmatory test for the presence of carbon dioxide.

$$Ca(OH)_2(aq) + CO_2(g) \longrightarrow CaCO_3(s) + H_2O(l)$$

When excess carbon dioxide is bubbled into the limewater, the milky or white precipitate dissolves due to the formation of soluble calcium hydrogencarbonate.

$$CaCO_3(s) + H_2O(l) + CO_2(g) \longrightarrow Ca(HCO_3)_2(aq)$$

(ii) Barium hydroxide can also be used to test for carbon dioxide as it forms a precipitate of barium carbonate.

$$Ba(OH)_2(aq) + CO_2(g) \longrightarrow BaCO_3(s) + H_2O(l)$$

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(b) *Reaction of carbon dioxide with metals*: Generally, carbon dioxide does not react with metals except under specific conditions. For example, when a burning magnesium ribbon is lowered into a gas jar containing carbon dioxide, it continues to burn for a short time with a spluttering flame. A white ash of magnesium oxide and black specks of carbon are formed.

$$2Mg(s) + CO_{2(g)} \longrightarrow 2MgO(s) + C(s)$$

Magnesium is more reactive than carbon, therefore, it can displace the carbon in carbon dioxide to form magnesium oxide which is white in colour.



Activity 1.27

Aim: To investigate the reaction between magnesium and carbon dioxide

Requirements: Gas jar containing carbon dioxide gas, a pair of tongs, and magnesium ribbon

Caution: In the presence of carbon dioxide, magnesium ribbon burns with a very bright flame that can damage eyes. Do not look directly at a burning magnesium ribbon. Use safety goggles when performing this experiment.

Procedure

Lower a piece of burning magnesium into a gas jar containing carbon dioxide as shown in Figure 1.31. Record the observations.

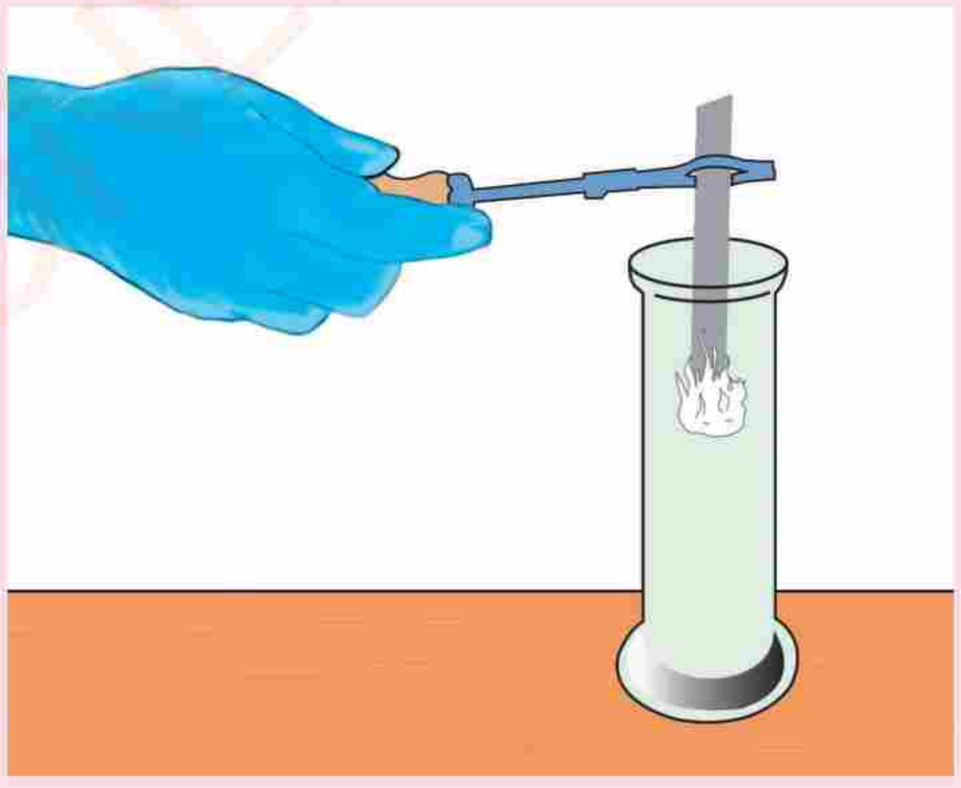


Figure 1.31: *Set-up for the reaction between burning magnesium and carbon dioxide*

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Questions

1. What was observed when the burning magnesium was lowered into a gas jar of carbon dioxide?
2. Carbon dioxide is a fire extinguisher, but when exposed to a burning magnesium metal, it supports the combustion of the metal. Explain.
3. Write an equation for the reaction that took place in the gas jar after lowering the burning magnesium.

(c) *Reaction with water*: When carbon dioxide is bubbled in water, it dissolves to form carbonic acid, which is a weak acid. The formed solution (carbonic acid) turns a blue litmus paper red. This indicates that the solution is acidic.

$$H_2O(l) + CO_2(g) \rightleftharpoons H_2CO_3(aq)$$



Activity 1.28

Aim: To investigate the reaction of carbon dioxide with water

Requirements: Two test tubes, test tube rack, delivery tube, source of carbon dioxide gas, distilled water, and red and blue litmus papers

Procedure

1. Put some water in a test tube.
2. Dip a blue litmus paper into the water. Record the observations.
3. Connect a delivery tube from the source of carbon dioxide gas into the water as shown in Figure 1.32.

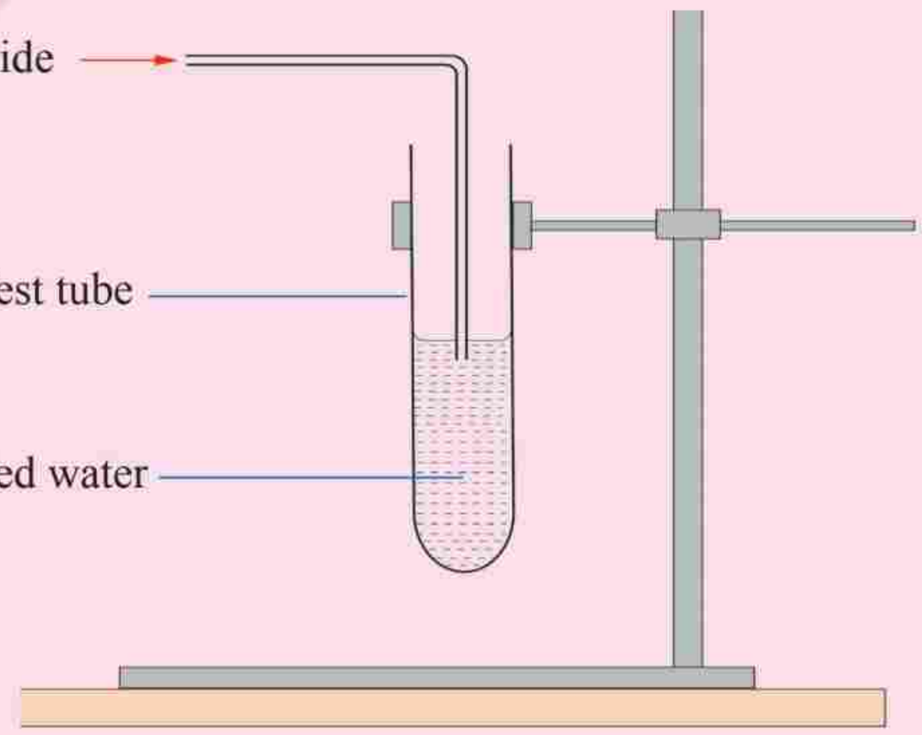


Figure 1.32: *Set-up for the reaction of carbon dioxide with water*

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4. Bubble some carbon dioxide into the water for about two minutes.
5. Dip a red litmus paper and a blue litmus paper into the mixture. Record the observations.

Question

Explain the observations when blue and red litmus papers were dipped into the mixture formed in Step 4.

Uses of carbon dioxide

The following are some of the uses of carbon dioxide:

Fire extinguisher: Carbon dioxide gas is used as a fire extinguisher because it does not support combustion and is denser than air. This means it displaces oxygen from the burning site, thus stopping the fire.

Manufacture of fizzy drinks: Carbon dioxide is used in making fizzy drinks and mineral salts. A solution of the gas in water has a pleasant taste. Carbon dioxide gas is also used to carbonate soft drinks, beer, and wine and to prevent fungal and bacterial growth.

Refrigeration: Carbon dioxide is used as a refrigerant. The gas solidifies at –78 °C to form dry ice. Dry ice is a good refrigerant because it leaves no residue after sublimation.

Manufacture of sodium carbonate: Carbon dioxide is used in the manufacture of anhydrous sodium carbonate in the *Solvay process*. Solvay process is an industrial method of making sodium carbonate from calcium carbonate and sodium chloride. The sodium carbonate formed is used in the manufacture of glass.

As a solvent: Liquid carbon dioxide is a good solvent for many organic compounds. For example, carbon dioxide is used by the producers of flavours and fragrances to separate and purify volatile flavour and fragrance concentrates.

Chemicals, pharmaceuticals, and petroleum industries: Large quantities of carbon dioxide are used as a raw material in the chemical process industries especially for methane and urea production. Pharmaceuticals and fuels can be produced using carbon dioxide as the starting materials.

Manufacture of baking soda: Carbon dioxide is used in making baking soda (sodium hydrogencarbonate). Baking soda is prepared by passing carbon dioxide into cold concentrated sodium carbonate and water vapour at temperatures between 60 ºC and 80 ºC.

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Manufacture of food in plants: Plants make use of carbon dioxide to manufacture food through the process of photosynthesis. Carbon dioxide is also used in promoting the growth of plants in greenhouses.

Cloud seeding: Carbon dioxide is used in the cloud seeding. Cloud seeding is a method of increasing the amount of rainfall received in an area by dispersing substances that help in cloud formation into the air.

Environmental uses and water treatment: Carbon dioxide is used to neutralise alkaline water.

Exercise 1.9

1. Write **TRUE** for a correct statement and **FALSE** for an incorrect statement. For the false statement, write its corresponding correct statement(s).
   (a) Both diamond and graphite conduct electricity.
   (b) Carbon atoms in diamond are covalently bonded.
   (c) Diamond has a low melting point as compared to graphite.
   (d) Diamond is soluble in water.
   (e) Graphite readily dissolves in water.
   (f) Each carbon atom in graphite is bonded to three other carbon atoms.

2. Which of the following combinations of reagents can be used to prepare carbon dioxide in the laboratory?
   (a) Marble chips and sodium hydroxide.
   (b) Copper metal and dilute hydrochloric acid.
   (c) Marble chips and dilute hydrochloric acid.
   (d) Magnesium metal and dilute sulphuric acid.

3. Write the balanced chemical equation for the answer in Question 2.

4. What will happen if a re-lighted splint is lowered into a gas jar containing carbon dioxide?

5. What is the observation when carbon dioxide is passed through limewater?

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6. A piece of burning magnesium ribbon is lowered into a gas jar containing carbon dioxide.
   (a) State the observations.
   (b) Write an equation for the reaction.

7. (a) Describe three allotropes of carbon.
   (b) Which of the allotropes of carbon conducts electricity? Explain.

Project 1.1

Using the chemicals available in your school laboratory, prepare a water disinfectant. Also obtain some commercial disinfectants from local shops in your area, and design an experiment to study the efficacy of each disinfectant against microorganisms such as bacteria and fungi. Compare the results of the disinfectants and propose the way forward.

Chapter summary

1. Chlorine is a yellowish-green gas which is denser than air.
2. Chlorine is a strong oxidising agent. It is the second strongest oxidising agent among halogens, after fluorine.
3. Chlorine water is a solution of chlorine gas in water.
4. Chlorine is used to manufacture various substances including bleaches, solvents, hydrochloric acid, and plastics.
5. Hydrogen chloride gas is a binary compound of chlorine and hydrogen.
6. Hydrogen chloride gas is very soluble in water and results into formation of hydrochloric acid.
7. Sulphur is a yellow crystalline solid. It is extracted from sulphur deposits deep in the Earth by the Frasch process.
8. The allotropes of sulphur are monoclinic sulphur, rhombic sulphur, plastic sulphur, milk of sulphur, and colloidal sulphur. The allotropes are categorised mainly into crystalline and amorphous.

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9. In chemical reactions, sulphur can act as a reducing or an oxidising agent.

10. Sulphur dioxide is a binary compound of sulphur and oxygen.

11. Sulphuric acid is a compound of sulphur that can be manufactured by the Contact process.

12. Sulphuric acid is an important reagent for many industrial processes.

13. Nitrogen exists in the gaseous state as a diatomic molecule (N_2). It is odourless and colourless.

14. Nitrogen can be prepared in the laboratory by isolation from air. Nitrogen is relatively unreactive.

15. Nitrogen has various uses including the manufacture of useful substances such as ammonia, nitric acid, pharmaceuticals, and medicines.

16. Ammonia is a compound of nitrogen and hydrogen. It can be prepared in the laboratory by heating ammonium salt together with an alkali.

17. Ammonia is manufactured commercially in large scale using the Haber process.

18. Carbon is one of the non-metals that exist as a solid at room temperature and pressure.

19. The allotropes of carbon include graphite, diamond, and amorphous carbon.

20. Carbon dioxide is one of the oxides of carbon. It is a colourless and odourless gas.

21. Carbon dioxide is used in fire extinguishers, in fizzy drinks, as a refrigerant, as a solvent, in chemicals, pharmaceuticals, and petroleum industries for manufacture of various chemicals such as baking soda, methanol, urea, sodium carbonate, and fuel.

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Revision exercise 1

Choose the correct answer in items 1 – 6.

1. When chlorine gas is bubbled through distilled water; the distilled water turn pale yellow. Which of the following equations represents the reaction?

   (a) $Cl_2(g) + H_2O(l) \longrightarrow Cl_2 \cdot H_2O(aq)$

   (b) $Cl_2(g) + H_2O(l) \rightleftharpoons HCl(aq) + HOCl(aq)$

   (c) $2Cl_2(g) + 2H_2O(l) \rightleftharpoons 4Cl(aq) + 2H_2O(aq)$

   (d) $Cl_2(g) + 2H_2O(l) \rightleftharpoons 2HOCl(aq) + H_2(g)$

2. Which of the following statements is incorrect?
   (a) Sulphur is soluble in carbon disulphide.
   (b) Monoclinic sulphur is stable above 96 °C.
   (c) Flowers of sulphur are a fine powder of pure sulphur.
   (d) Rhombic sulphur has needle shaped crystals.

3. Which among the following statements is true?
   (a) Ammonia gas can be prepared by the reaction of ammonium salt with an alkali.
   (b) Concentrated sulphuric acid is used to dry ammonia gas.
   (c) Ammonia is an acidic gas.
   (d) Ammonia gas is slightly soluble in water.

4. Which gas is produced when dilute nitric acid reacts with magnesium metal?
   (a) Nitrogen (b) Hydrogen
   (c) Oxygen (d) Nitrogen dioxide

5. The catalyst used in the industrial manufacture of nitric acid is
   (a) finely divided iron. (b) vanadium pentoxide.
   (c) platinum. (d) platinum-rodium.

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6. Which of the following statements is true?
   (a) Carbon dioxide is very acidic.
   (b) Solid carbon dioxide (dry ice) undergoes sublimation.
   (c) Carbon dioxide has an irritating smell.
   (d) Carbon dioxide is less dense than air.

7. Answer the following questions related to nitrogen and ammonia:
   (a) Explain the role of copper(II) oxide when it reacts with ammonia.
   (b) Ammonia gas is collected by downward displacement of air. Explain.
   (c) Describe the role of nitrogen in the manufacture of fertilisers.

8. The following equation shows the reaction between fluorine gas and sodium chloride solution. What type of reaction is this? Explain.

$$F_2(g) + 2NaCl(aq) \longrightarrow 2NaF(aq) + Cl_2(g)$$

9. Write an equation to show the reaction between chlorine gas and potassium bromide.

10. Explain any four uses of chlorine.

11. The following are properties of some allotropes of carbon. Identify the type of the allotrope described by the respective property.
   (a) It is a good conductor of electricity.
   (b) It is the hardest natural substance known.
   (c) It is used in making jewellery.
   (d) It is used to make electrodes.
   (e) It is soft and slippery.
   (f) Electrons are arranged in a tetrahedral shape.

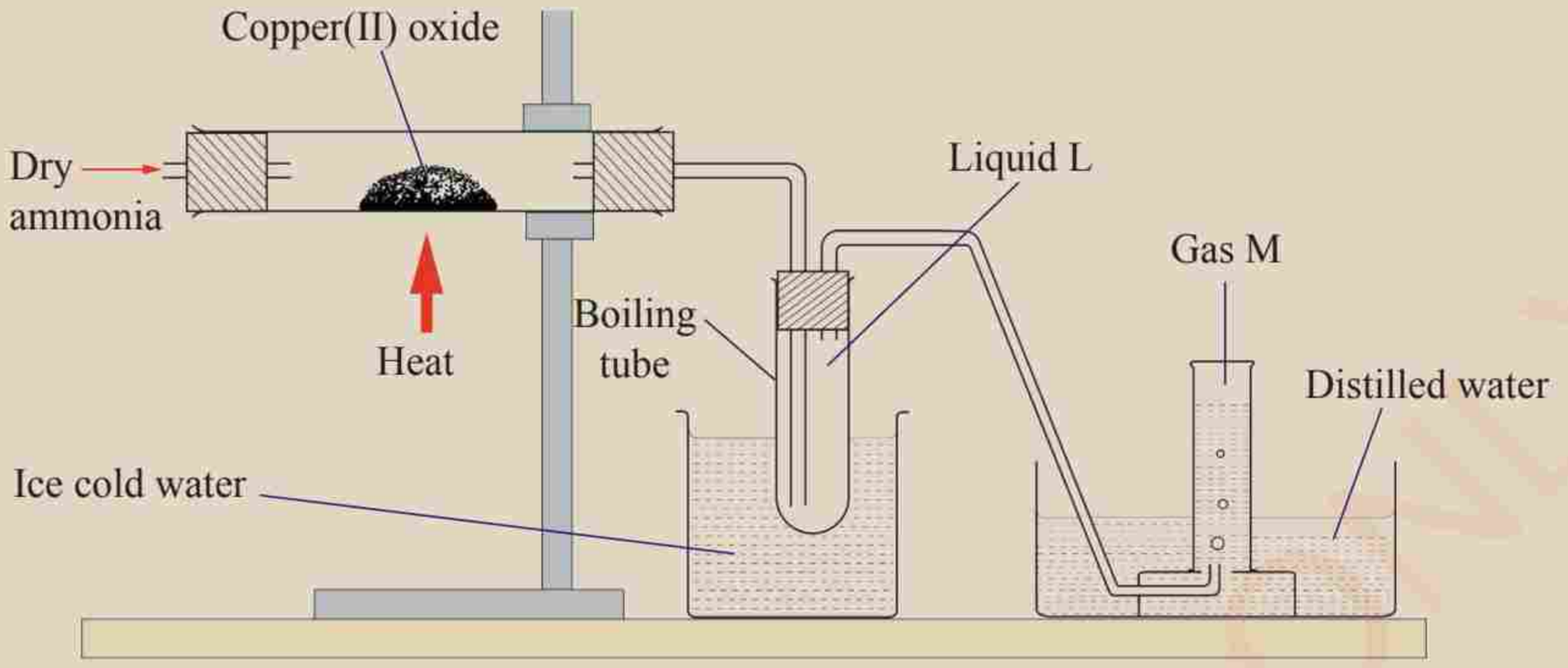
12. Write an equation to show how chlorine reacts with the following metals:
   (a) Iron. (b) Aluminium.
   (c) Sodium. (d) Potassium.

13. With the aid of an equation, describe the chemical test for carbon dioxide gas.

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14. Study the following figure and answer the questions that follow:



(a) Identify the liquid L and the gas M.

(b) With the aid of an equation, explain the reaction that takes place in the combustion tube.

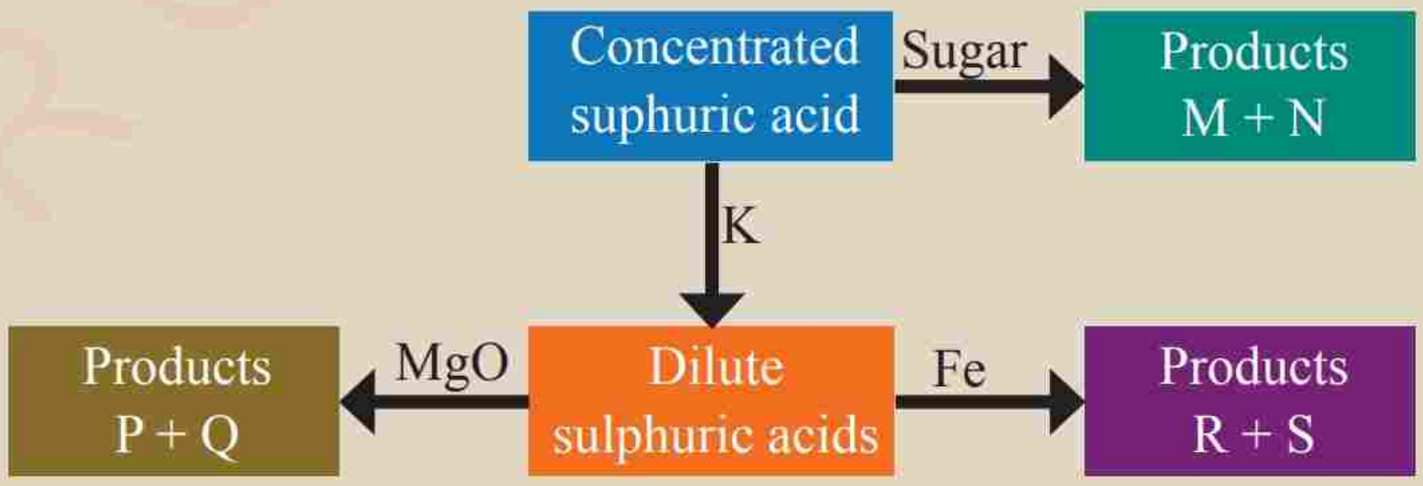
(c) Describe a chemical test that can be used to confirm the identity of liquid L.

15. A mixture of iron and sulphur was gently heated until it started to glow. The mixture continued to glow for some time even after heating had been stopped.

(a) Write an equation for the reaction between sulphur and iron.

(b) Why did the mixture continue glowing even after heating was stopped?

16. Use the following illustration to answer the questions that follow:



(a) What do the letters M, N, P, Q, R, and S represent?

(b) Write the chemical equations to show the formation of the products M, N, P, Q, R, and S.

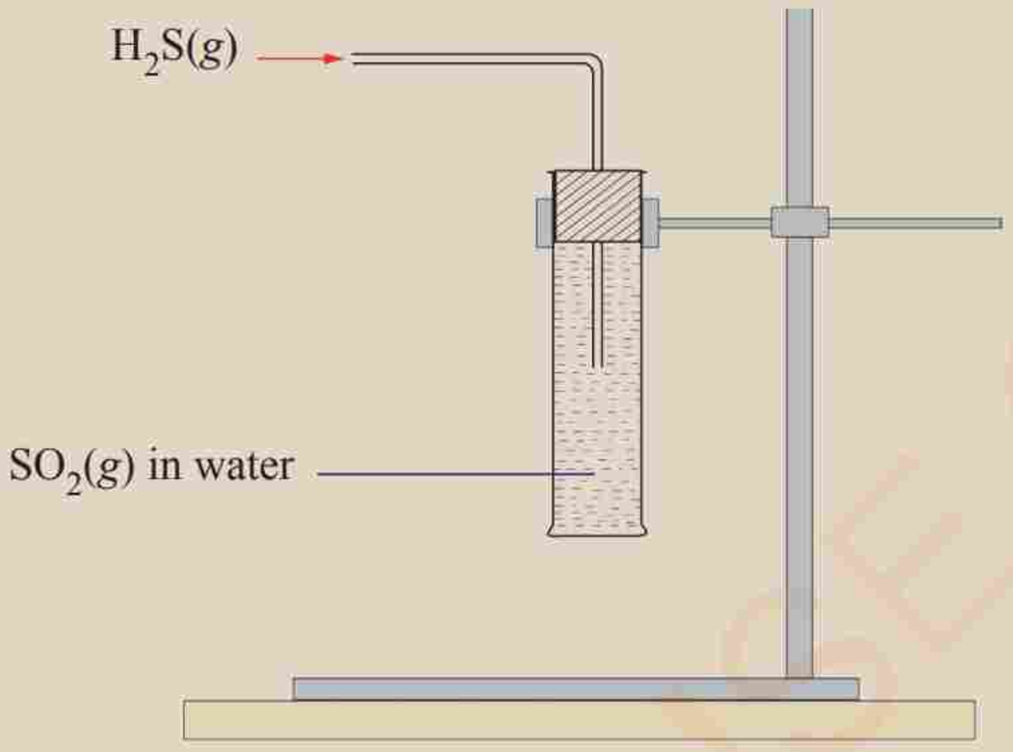
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(c) State the type of reaction that forms products M and N.

(d) How does process K take place in the laboratory? Explain.

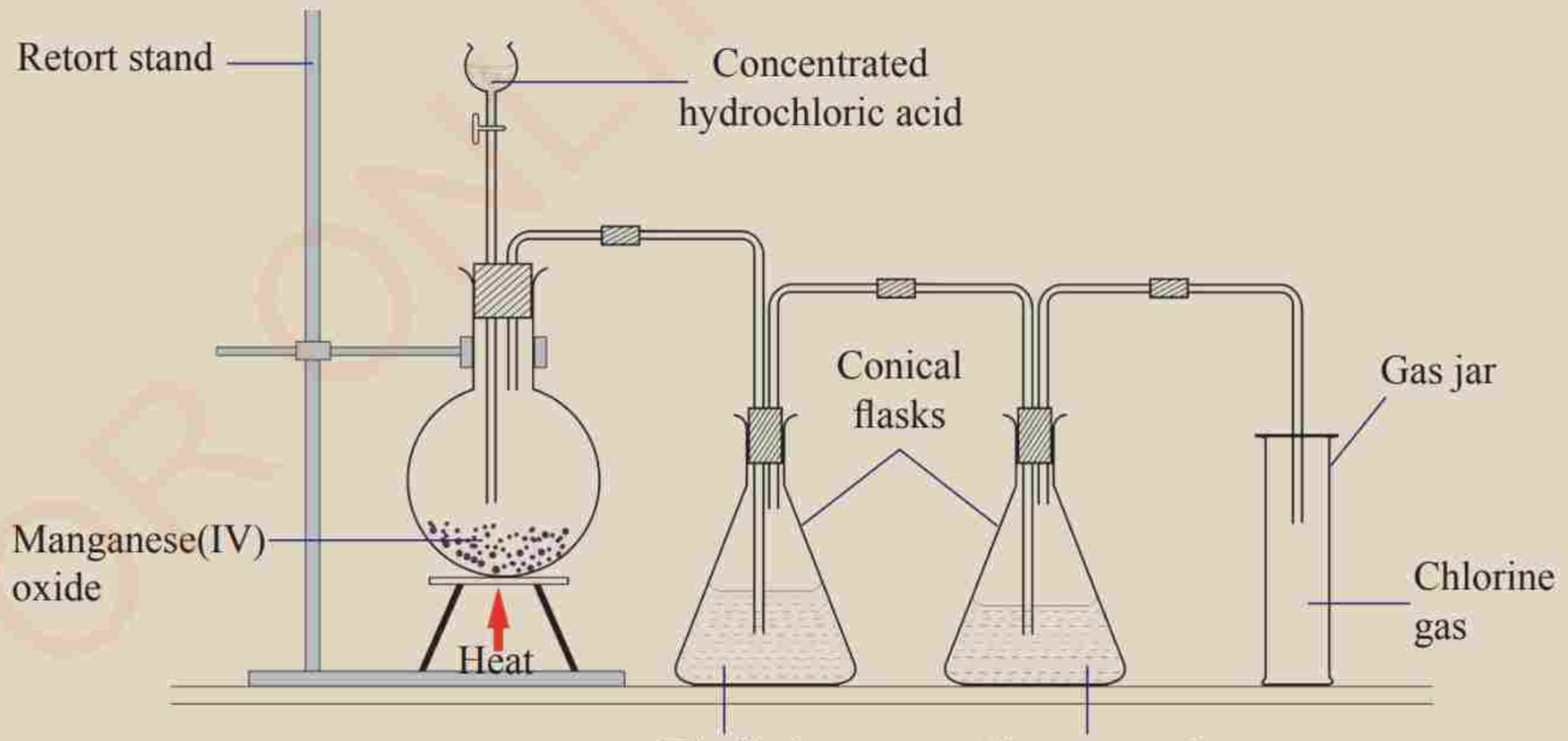
17. The set-up shown in the following figure was used to investigate a certain property of sulphur dioxide gas. Study it and answer the questions that follow:



(a) Write an equation for the reaction in the gas jar.

(b) What property of sulphur dioxide was being investigated?

18. The following figure shows how chlorine gas is prepared in the laboratory:



(a) Write an equation for the reaction between manganese(IV) oxide and concentrated hydrochloric acid.

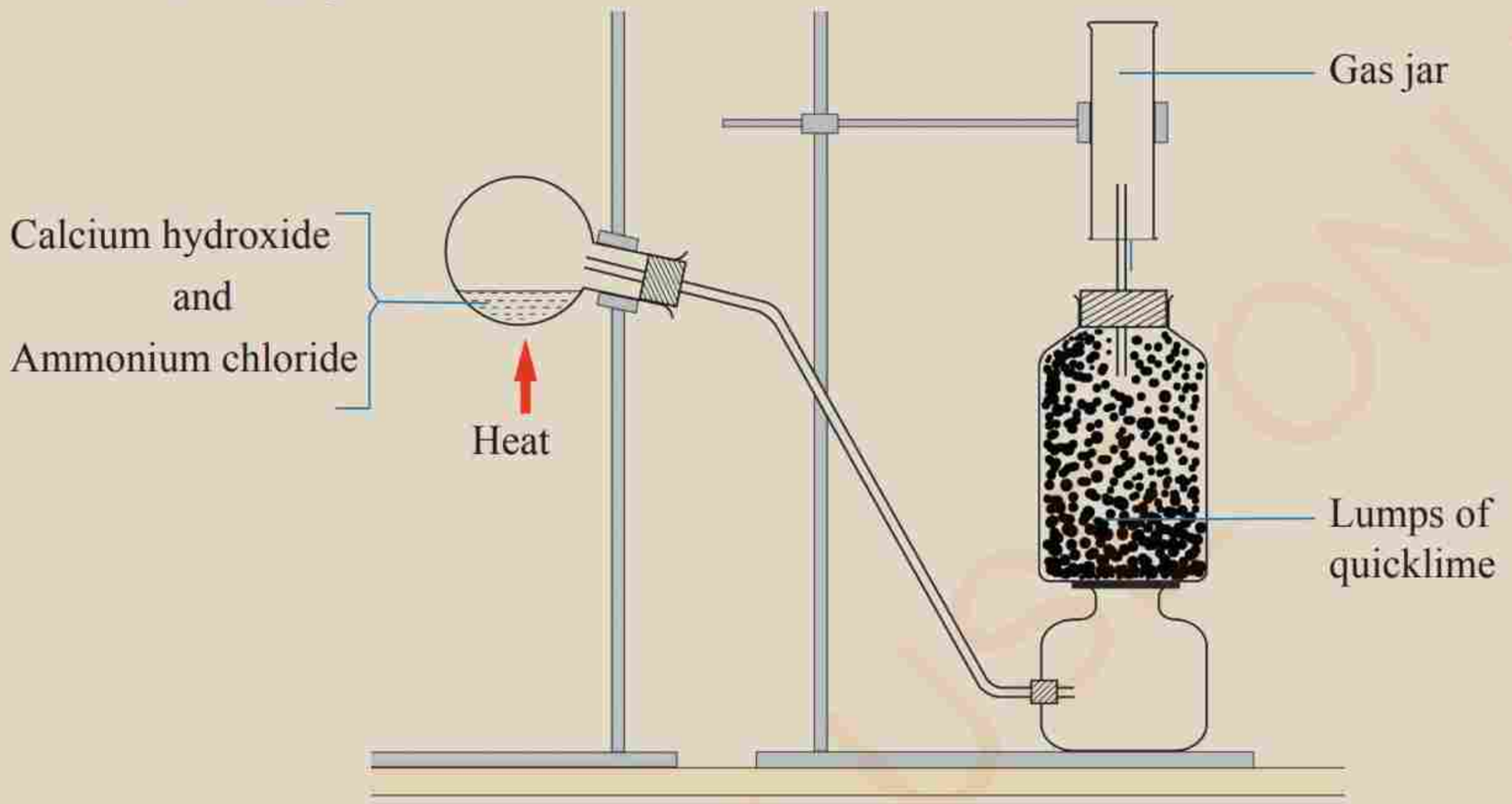
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(b) What are the uses of water and concentrated sulphuric acid in the reaction?

(c) Explain the method used to collect the gas.

19. The following figure shows a set-up that can be used to prepare a gas X in the laboratory:



(a) Identify gas X.

(b) Write an equation to show the formation of the gas.

(c) Why is the gas not collected over water? Explain.

(d) Describe a chemical test that can be used to confirm gas X.

(e) With the aid of an equation, explain what would happen if a dry sample of gas X is passed over heated copper(II) oxide.

20. Non-metals and their compounds contribute a lot to different domestic and industrial processes. Identify the element(s) or compound(s) with respect to their roles or effects in the following aspects:

(a) Manufacturing of food in plants
(b) Cleaning of glasses
(c) Industrial and home sources of heat
(d) Water treatment
(e) Manufacturing of fertilisers
(f) Forming acid rain
(g) Manufacturing of acids
(h) Manufacturing of car batteries
(i) Manufacturing of lubricants

21. Explain the fact that graphite has less electric conductivity than both copper and aluminium.

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Chapter

Two

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Introduction to organic chemistry

Introduction

The environment consist of several substances which are made from organic compounds. Plants, animals, plastics, textiles, and drugs are examples of substances made from organic compounds. The knowledge of organic chemistry helps to understand how these substances are made. The major constituent elements of organic compounds are carbon and hydrogen. Other important elements commonly found in organic compounds include oxygen, nitrogen, sulphur, phosphorus, halogens, and few metals such as magnesium and lithium. It should be noted that not all carbon containing compounds are organic; some compounds such as carbon dioxide, carbides, hydrogen carbonates, and carbonates are inorganic. In this chapter, you will learn about the concept of organic chemistry, and basic descriptions of hydrocarbons, alcohols, and carboxylic acids. The competencies developed will enable you to identify and use various organic compounds in different life activities.

Concept of organic chemistry

Many organic compounds are found in the environment where they were formed as a result of various chemical reactions. The study of organic chemistry involves preparation methods, structures, properties, composition, and reactions of organic compounds. More than three quarters of the global compounds contain carbon. Carbon is unique in its chemical properties as it can form many compounds due to its ability to catenate and forms multiple bonds which are single, double, and triple bonds. *Catenation* is the bonding of atoms of the same element to form a chain. Carbon forms stable bonds with itself and other elements. It can make straight chains and branched chains. Carbon can form simple and complex molecules that contain many numbers of carbon atoms.

Substances made from organic compounds

Organic compounds include different types of substances such as oils, dyes, pharmaceuticals, papers, inks, paints, plastics, fuels, rubbers, and textiles. These substances can be grouped into different categories based on their sources as follows:

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(a) those derived from fossil fuels such as petroleum, coal and natural gas.

(b) those derived from plants such as carbohydrates, oils, vitamins, textiles, and rubbers.

(c) those derived from animals such as proteins and fats.

Organic compounds can also be categorised as natural and synthetic compounds. Natural organic compounds are those which occur naturally, such as carbohydrates, essential oils, and coal. Synthetic organic compounds are man made compounds such as plastics and dyes.

Differences between organic chemistry and inorganic chemistry

Organic compounds differ from inorganic compounds in many different ways as presented in Table 2.1.

Table 2.1: *Differences between organic compounds and inorganic compounds*

Organic compounds	**Inorganic compounds**
Most organic compounds contain carbon-hydrogen bond(s) with the exception of some compounds such as carbon tetrachloride, CCl_4, and urea, $CO(NH_2)_2$.	Inorganic compounds include compounds that lack carbon-hydrogen bond(s) such as carbonates, sulphates, oxides, hydroxides, and chlorides.
Most of the organic compounds are covalent in nature.	They can be covalent or ionic in nature.
Have low melting and boiling points.	Most have high melting and boiling points except gases.
There are many classes based on functional groups such as alkanes, alkenes, alkynes, and alcohols.	They exist in few classes only as salts, acids or bases.
They are soluble in organic solvents such as benzene, cyclohexane, alcohol, and ethers.	They are mostly soluble in water and other inorganic solvents such as ammonia, sulphuric acid, and nitric acid.
They are poor conductors of heat and electricity.	Most of them are good conductors of heat and electricity.
Reactions of most organic compounds generally proceed slowly.	Reactions of most inorganic compounds are generally fast.

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Importance of organic chemistry

Organic chemistry is important both in life and in industrial processes. The following are some areas where organic chemistry is applied.

Body anatomy, functioning, and physiology: All organisms are made of millions of organic compounds categorised as carbohydrates, lipids, proteins, nucleic acids, enzymes, and hormones. Body tissues such as muscles and blood, are made up of the combinations of these groups. For example, carbohydrates are a class of important organic molecules that provide the body with energy and structure. Enzymes and hormones control the body chemical reactions, and nucleic acids (deoxyribonucleic acid or DNA and ribonucleic acid or RNA) are for storage and transferring genetic information.

Medicines and drugs: Several careers (engineers, dentists, pharmacologists, and chemists) apply the knowledge of organic chemistry in their technical innovations. Dentists use potassium citrate to combat sensitive toothache. Doctors use the knowledge of organic processes in the body to treat illnesses. The study of drugs (pharmacology) relies on organic chemistry synthetic pathways. These drugs are used for treating various illnesses. For example, artemisinin is for treatment of malaria, streptomycin is an antibiotic for tuberculosis (TB), clotrimazole is for treatment of fungal infections, and paracetamol is an analgesic (painkiller). Figure 2.1 shows some drugs manufactured by using organic compounds.



Figure 2.1: *Drugs made from organic compounds*

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Textile industries: Clothes are made from fibrous organic compounds which are either natural or synthetic. Natural fibres include wool, cotton, and silk, while synthetic fibres include polyesters and nylons. Synthetic fibres are increasingly becoming essential for the textile industry. Organic dyes are important in colouring clothes and other textile materials. Examples of clothes made from organic compounds are shown in Figure 2.2.



Figure 2.2: *Clothes made from organic compounds*

Energy: Fossil fuels such as coal, petroleum, and natural gas are all made from organic compounds derived from remains of dead organisms. These fuels provide energy for industrial and domestic uses. Examples of organic fuels are diesel, petrol, kerosene, and cooking gas such as liquefied natural gas (LNG), and liquefied petroleum gas (LPG).

Polymers: The common polymers encountered everyday include cellulose and plastic products such as nylons, polyvinyl chloride (PVC), polypropylene, and polyethylene. These polymers are used to manufacture a broad range of items such as containers, shoes, building materials, glasses, motor vehicle parts, electrical components, aircraft parts, and water conducting pipes (Figure 2.3).



Figure 2.3: *Variety of items made from polymers*

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Agricultural activities: Organic substances such as fertilisers are important materials used to supply plants with essential nutrients for their growth. For example, urea contains high nitrogen content (46%) and is easily converted to nitrates in the soil for the plants to absorb. Other useful chemicals in agriculture are pesticides such as cypermethrin, and 2, 4 -Dichlorophenoxyacetic acid (2,4-D), for controlling pests such as insects and weeds (Figure 2.4).



Figure 2.4: *Examples of pesticides used for controlling pests*

Other uses

Organic compounds are also useful in the manufacture of cosmetics like body creams, lipsticks, eye makeups, body lotions, hair dyes, and shampoos. They are also used as food additives such as vitamins, and chemical warfare agents such as nerve agents (sarin), blistering agents (mustards), and choking agents or lung toxicants such as vinylchloride and phosgene. In addition, there are organic compounds such as trinitrotoluene (TNT) which are used for making explosives.

It is worth noting that some organic compounds have harmful effects as follows:

(i) Insecticides are intended to harm insects but they can cause health problems such as cancer, respiratory diseases, and even death to humans and other organisms.

(ii) Chlorofluorocarbons (CFCs) contribute to ozone layer depletion and global warming.

(iii) Plastic materials such as polyethylene, PVC, and polypropylene do not decompose easily and contribute to pollution when released into the environment as shown in Figure 2.5.

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Figure 2.5: *Plastics and other wastes at a waste disposal site.*

Origin of organic compounds

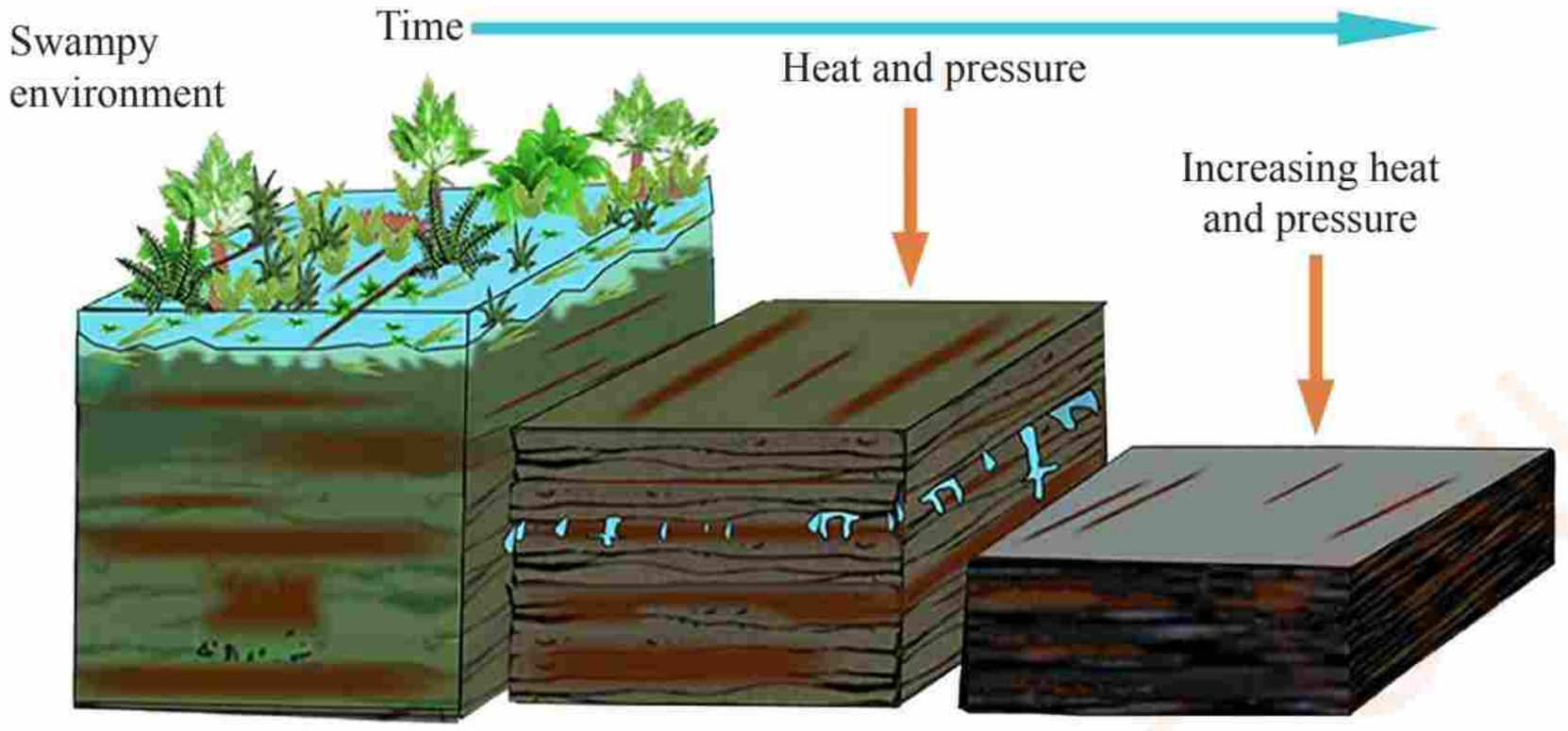
Organic compounds are derived from three major sources which are prehistoric, organisms, and synthetic compounds.

Prehistoric sources

Prehistoric sources of organic compounds are derived from the decomposition of dead organisms acted upon by extreme heat and pressure over many years. They include coal, petroleum and natural gas. Coal is a combustible black or brownish sedimentary rock, mainly made from organic compounds. The process of coal formation takes many years and it starts with the accumulation of dead plant matter in swampy areas. The accumulation continues, forming layers of dead plant materials mixed with soil, debris, and water. The heat and pressure from the top layers compress and turn the plant matter in the underlying layers into coal as shown in Figure 2.6. The quality of coal depends on the differences in the kinds of plant materials, degree of coalification (coal rank), and the range of impurities (coal grade). Coal can be classified into four main types which are anthracite, bituminous, subbituminous, and lignite coal.

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(a) The process of coal formation starts with the accumulation of dead plant matter in swampy areas.

(b) The accumulation forms layers of dead plant material, mixed with soil and water.

(c) The heat and pressure from top layers turn the underlying layers into coal.

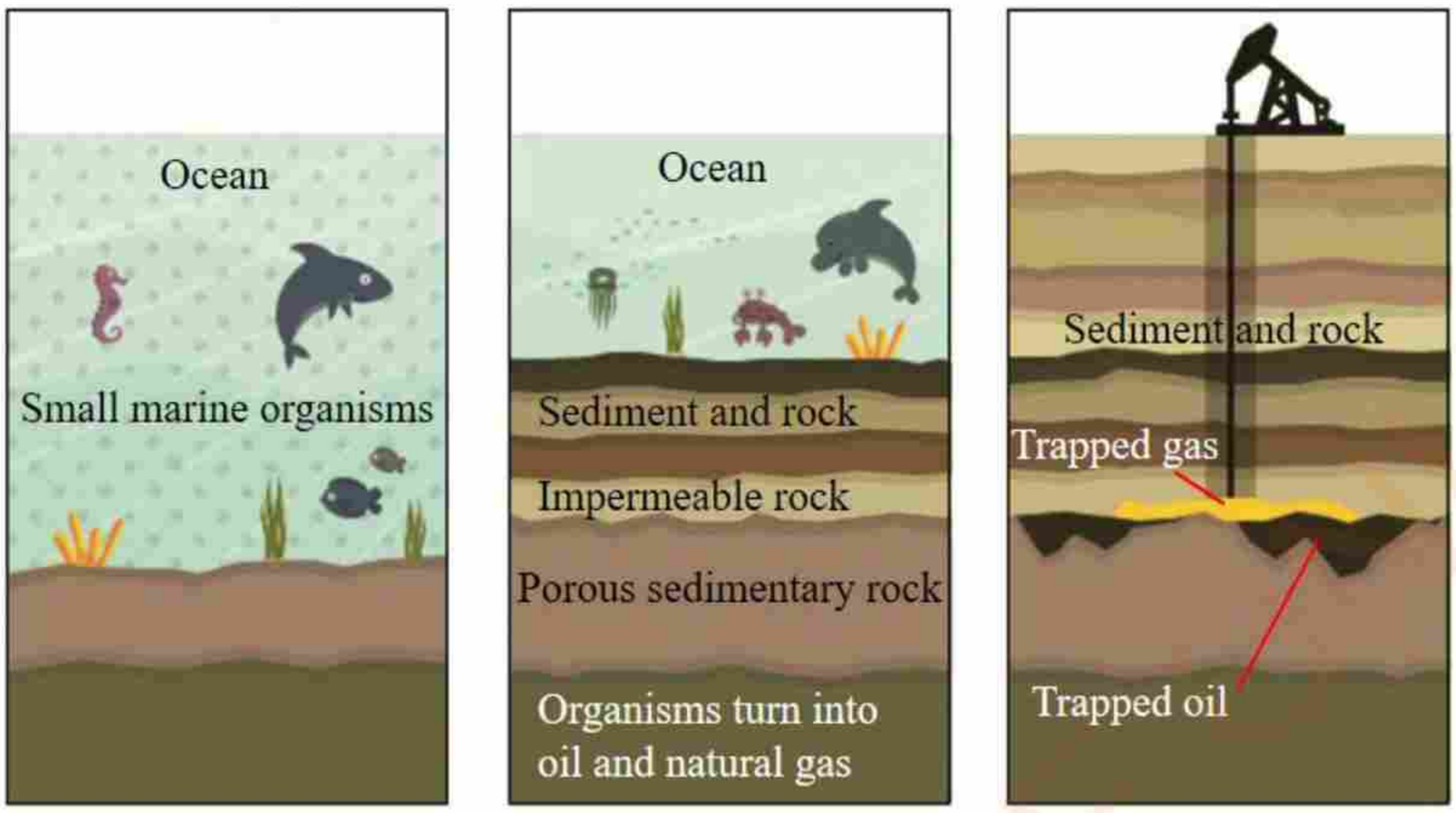
Figure 2.6: *Process of coal formation*

Petroleum is formed from the remains of marine organisms that sank at the bottom of the sea many years ago. The dead organisms mixed with mud were buried under heavy layers of sediment. The pressure and heat exerted by the overlying sediments caused the organic matter to change into liquid (petroleum) or gas (natural gas) as described in Figure 2.7.

Petroleum is a liquid mixture of hydrocarbons that can be extracted and refined to produce fuels such as paraffin, petrol, and diesel. Petroleum fuels are lighter than water and occasionally move upwards through the permeable rock layers until they reach the surface. Sometimes these hydrocarbons are trapped in porous rocks called *reservoirs* which are beneath impermeable rocks. Limestone is the major oil reservoir from which petroleum can be extracted by drilling and pumping. The area of land or sea producing petroleum or gas is known as an *oil field*. The petroleum from the oil fields is referred to as *crude oil*.

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(a) Dead organisms were buried on the ocean floor. Over time, they were covered by layers of silt and sand.

(b) Over millions of years, the remains were buried deeper and deeper. The enormous heat and pressure turned them into oil and gas.

(c) Today, we drill down through layers of sand, silt and rock to reach the rock formations that contain oil and gas deposits.

Figure 2.7: *Processes of petroleum and natural gas formation, and drilling*

Organisms

These include plants, animals, fungi, and algae that can be seen with naked eyes, and other tiny creatures such as protozoa, bacteria, and viruses that can be seen only with the aid of a microscope. Plants are primary producers and are able to manufacture complex organic compounds such as starch and glucose from simple inorganic substances (carbon dioxide and water) in the presence of sunlight energy and chlorophyll. This process by which plants manufacture complex organic compounds is called *photosynthesis*. Some of the organic compounds found in animals include carbohydrates, fats, and proteins.

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Synthetic compounds

Synthetic organic compounds are man-made substances prepared through various processes and that are not naturally occurring. Synthetic organic compounds are gradually replacing the natural organic compounds in different areas. Table 2.2 shows some synthetic organic substances which are widely used in place of natural organic compounds.

Table 2.2: *Synthetic organic substances*

Synthetic organic substances	**Uses**
Polyester	Making cloth items
Polyvinyl cyanide	Making cloth items and carpets
Perspex	Used as a substitute for glass in furniture design, signal displays, and lighting
Polyethene	Making packaging materials, baskets, cups, bowls, and a wide range of kitchenware
Polychloroethene (polyvinyl chloride, PVC)	Used to make water pipes, crates, electrical appliances, and as a substitute for leather
Polystyrene	Used in electrical and thermal insulators
Neoprene	Used as a substitute for natural rubber

Fractional distillation of crude oil

Crude oil is a naturally occurring viscous black oil drilled from the oil fields and contains a mixture of different types of organic compounds. Fractional distillation is used in oil refineries to separate the various hydrocarbons in the crude oil to produce different petroleum products. The individual components of crude oil are known as fractions and each has a different boiling point. Before crude oil undergoes fractional distillation, different solids and gases mixed with it are first removed. In a refinery, crude oil is heated to a high temperature of about 400 °C and passing the resulting vapour up a fractionating tower which is also known as the *fractional distillation column*. The vapour condenses at the cooler upper part into various fractions according to the molecular sizes of the components in the crude oil (Figure 2.8). Each component is collected within a given range of temperature.

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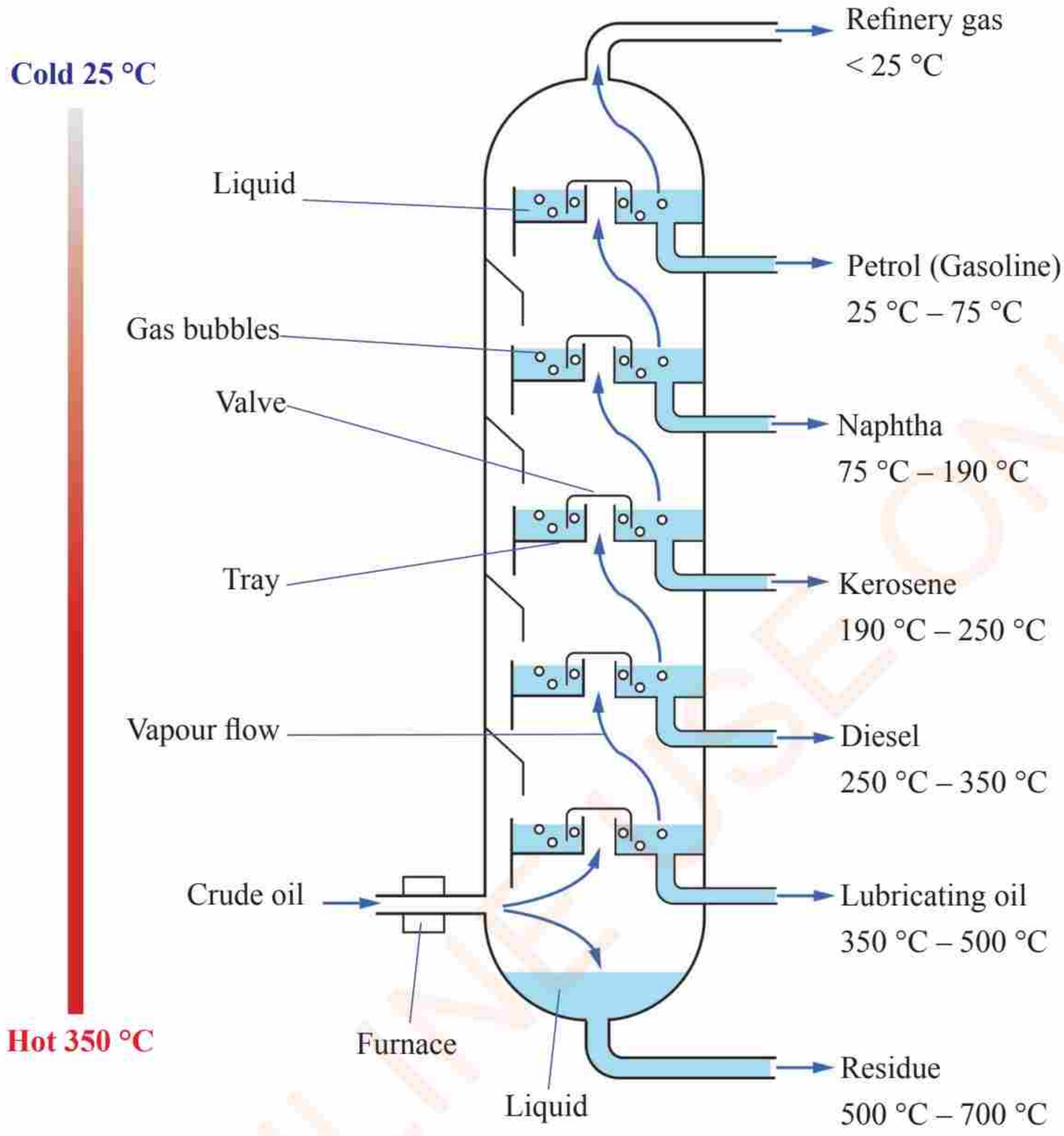


Figure 2.8: *Fractional distillation of crude oil*

The fractionating tower is fitted with a series of bubble cups where vapour passes and cools as it rises further up the column. The 'heavy' fractions are collected at the bottom and the 'light' ones are collected at the top of the fractionating tower. Each of these fractions is a mixture of different hydrocarbons and has specific uses (Table 2.3). In order to accommodate this large range of condensation zones, fractionating columns range from 0.5 to 6.0 metres in diameter and 6.0 to 60.0 metres tall, depending on the refinery plant.

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Table 2.3: *Uses of various fractions of the crude oil*

Fraction	Number of carbon atoms	Boiling point (°C)	Uses
Petroleum gas	1 – 4	< 25	• For domestic cooking and heating
Petrol (Gasoline)	5 – 7	25 – 75	• Motor car fuel • Manufacture of petrochemicals
Naphtha	6 – 10	75 – 190	• As a solvent • Manufacture of petrochemicals
Paraffin (kerosene)	10 – 16	190 – 250	• Jet fuel • Domestic heating • Can be cracked to produce petrol
Diesel oil	16 – 20	250 – 350	• Fuel in diesel engines • Heating industrial boilers • Can be cracked to produce petrol
Lubricating oil and heavy oil	21 – 30	350 – 500	• As lubricants • Fuels for power stations
Residuals	>30	500 – 700	• For making wax • To make bitumen (asphalt) for road surfacing, roofing and coatings

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Cracking

Some of the fractions obtained from the fractional distillation of the crude oil are converted into other products which are needed in the market. The conversion is mainly done by *cracking* of heavy fractions. Cracking is the breaking of larger hydrocarbon molecules into smaller hydrocarbon molecules. The two main methods used in cracking are *thermal cracking* and *catalytic cracking*. In thermal cracking, large hydrocarbons molecules are heated to a high temperature (450 °C to 700 °C) and high pressure (about 70 atm) until the molecules break into smaller useful compounds.

$$C_{14}H_{30} \xrightarrow[70\ atm]{700\ °C} 2C_2H_4 + C_3H_6 + C_7H_{16}$$

Catalytic cracking uses a catalyst at moderate low pressure to speed up the cracking process instead of relying on heating alone.

$$C_{10}H_{22} \xrightarrow[Zeolite\ (catalyst)]{500\ °C} C_2H_4 + C_3H_6 + C_5H_{12}$$

Cracking is important for two main reasons.

(a) It helps to increase the supply of fractions with demands in the market.

(b) It produces various alkene molecules which are useful raw materials for the petrochemical industry.

Terms commonly used in organic chemistry

The following terms are commonly used in organic chemistry:

Molecular formula

The molecular formula of a compound is a chemical formula indicating the total number of atoms of each element in a molecule. It does not show how the atoms are connected to each other, for example, C_2H_6.

Structural formula

A structural formula is a chemical formula that shows how the atoms are arranged in a molecule. The structural formula is actually the molecular formula expanded to show the arrangements of the atoms. The structural formula of a compound can be written by only showing the arrangements of atoms, or by showing the arrangements of atoms together with their bonds. The structural formula in which only atoms are shown is referred to as a *closed* or *condensed* structural formula,

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while the one in which the bonds are shown is referred to as an *open* structural formula as shown in Figure 2.9.

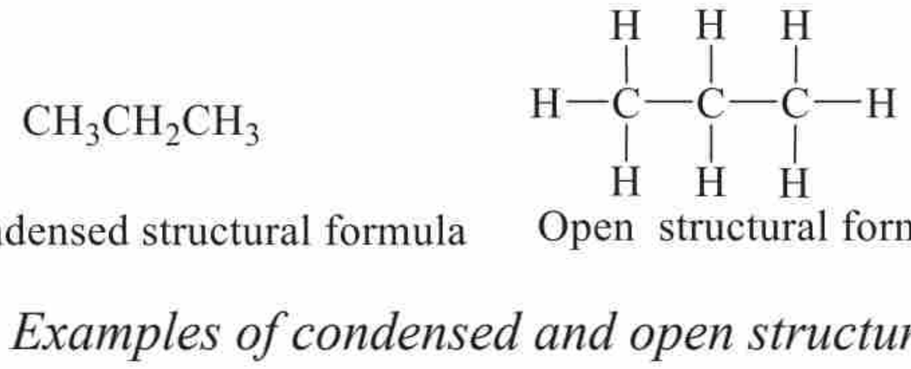


Figure 2.9: *Examples of condensed and open structural formulae*

General formula

A general formula is a general rule used to calculate the number of atoms of each element in a molecule. Each homologous series has a unique general formula. The following are examples of general formulae; C_nH_{2n+2} (for alkanes), C_nH_{2n} (for alkenes), C_nH_{2n-2} (for alkynes), $C_nH_{2n+1}OH$ (for alcohols), and $C_nH_{2n+1}COOH$ (for carboxylic acids) where n is the number of carbon atoms in a molecule.

Homologous series

A homologous series is a series of organic compounds with the same functional group and similar chemical properties, in which the members differ from each other by $-CH_2$ group. The following are some of the characteristics of homologous series:

1. All the members of a particular homologous series can be represented by the same general formula, e.g. C_nH_{2n+2} for alkanes.
2. The molecular formula of each member of a particular series differs from the member above or below it by one structural unit. A structural unit is made up of one carbon atom and two hydrogen atoms, that is, $-CH_2$. The molecular mass of two adjacent members therefore differs by 14, since the molecular mass of $-CH_2$ is $12 + (2 \times 1) = 14$.
3. All members of the homologous series can be prepared using the same general methods.
4. The physical properties such as melting points, boiling points, and density show a gradual change with the increase in their molecular masses.
5. Members of a given homologous series have similar chemical properties.

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Isomers

Isomers are compounds with the same molecular formula but different structural formulae. The occurrence of two or more compounds that have the same molecular formula but different structural formula is called *isomerism*. There are two main types of isomerism, namely *structural isomerism* and *stereoisomerism*. These two types of isomerism are further sub-divided as shown in Figure 2.10.

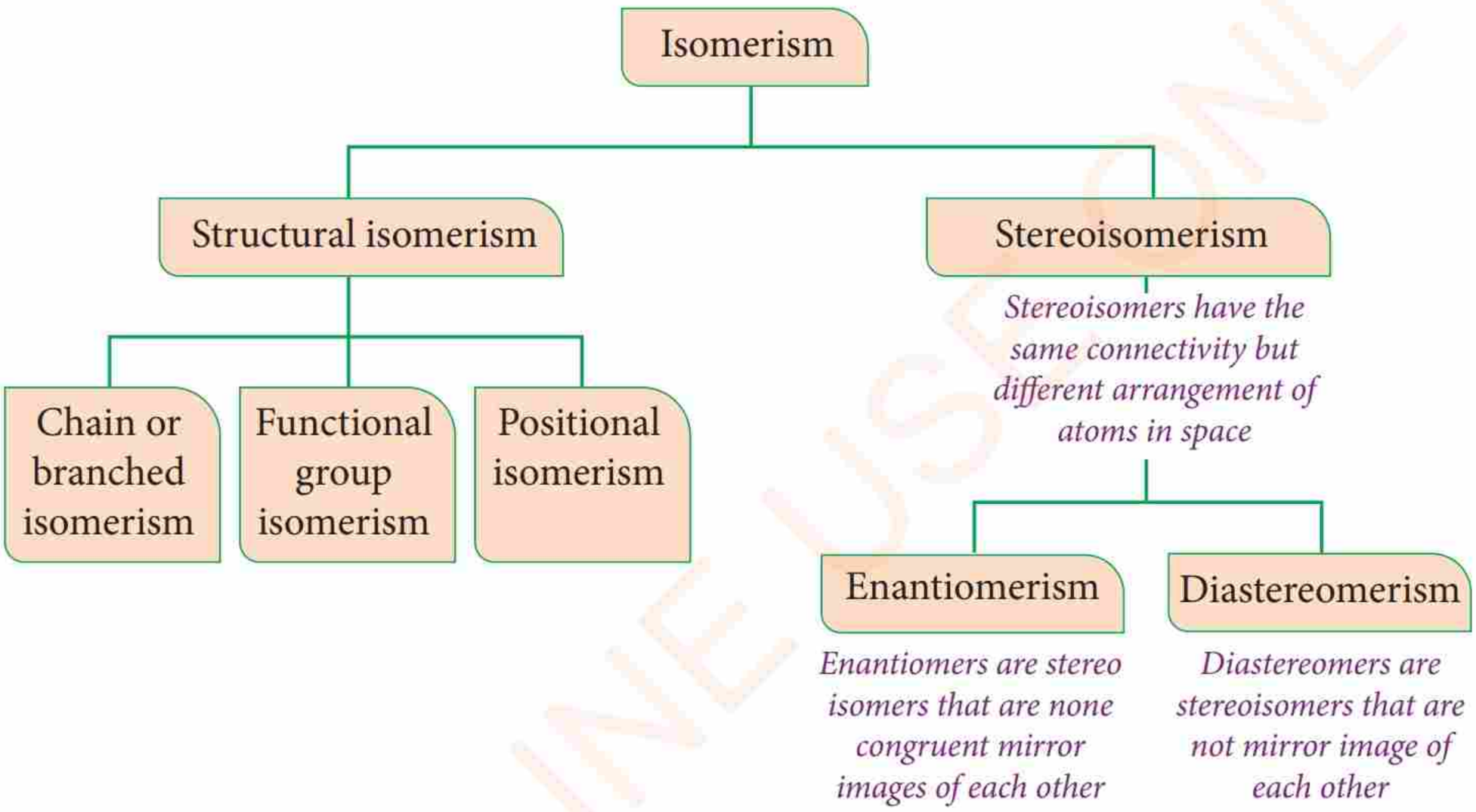


Figure 2.10: *Types of isomerism*

Functional group

A functional group is a group of atoms or bonds with a characteristic chemical reactivity. Hydrocarbons are considered as the parent of all the organic compounds and are characterised by their functional groups. Other organic compounds are derived by substituting one or more hydrogen atoms of the hydrocarbons with more reactive atoms or groups of atoms. Examples of functional groups include C=C, C≡C, –OH, and –COOH.

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Exercise 2.1

1. Identify the organic substances from the following substances:
   Table salt, plastics, baking powder, vitamin C, cooking oil, rubber, grease, carbides, sugar, and car tires.

2. Why does fractional distillation of crude oil give different products?

3. The equation below represents the industrial preparation of ethene from a higher alkane.

$$C_{13}H_{28}(l) \xrightarrow[70\ atm]{750\ ^oC} C_2H_4(g) + C_3H_6(g) + C_8H_{18}(l)$$

   (i) What name is given to this reaction?
   (ii) Suggest the uses of the products formed in the reaction.

4. Briefly explain any three (3) sources of organic compounds.

5. Giving example, describe the following:
   (a) Molecular formula
   (b) Homologous series
   (b) Isomers
   (c) Functional group

Hydrocarbons

Hydrocarbons are organic compounds composed of carbon and hydrogen only. They are grouped into two main types, which are *saturated hydrocarbons* and *unsaturated hydrocarbons*. Saturated hydrocarbons are made up of single bonds between carbon atoms (C−C) and are less reactive towards strong acids/bases and oxidising agents. Unsaturated hydrocarbons have a double bond (C=C) or a triple bond (C≡C) between any of the carbon atoms and are very reactive.

Families of hydrocarbons

There are three main families of hydrocarbons which differ in their physical and chemical properties. These families are alkanes, alkenes and alkynes.

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Naming of hydrocarbons

There are two ways of naming organic compounds. These are the International Union of Pure and Applied Chemistry (*IUPAC) nomenclature system* which gives systematic names, and the *common nomenclature system* which gives common or traditional names. The internationally accepted names are those of the IUPAC system which follow specific rules. The IUPAC names have clear advantages over the traditional or common names since they can give the information about the structure and functional group or family group of a compound.

The names given using this system have two parts; the *root (parent) name* and the *primary suffix*. A root word indicates the nature of the basic carbon chain making up the hydrocarbon. Chains with 1 to 4 carbon atoms are known by special root words. Chains with 5 or more carbon atoms are known by their respective Greek numbers. The Greek number indicates the number of carbon atoms in the chain. Table 2.4 shows the root names for hydrocarbon chains with up to 10 carbon atoms.

Table 2.4: *Root names of hydrocarbons*

Number of carbon atoms(n)	Root names
1	Meth-
2	Eth-
3	Prop-
4	But-
5	Pent-
6	Hex-
7	Hept-
8	Oct-
9	Non-
10	Dec-

Primary suffixes are added to the root name to show whether the hydrocarbon is saturated or not, and the degree of unsaturation. Table 2.5 shows the primary suffixes for the three main families of hydrocarbons.

Table 2.5: *Primary suffixes for hydrocarbons*

Family	Type of bond	Suffix
Alkanes	Single (C–C)	-ane
Alkenes	Double (C=C)	-ene
Alkynes	Triple (C≡C)	-yne

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Alkanes

Alkanes are described as saturated hydrocarbons because they have only single covalent bonds between the carbon atoms and contain the maximum possible number of hydrogens per carbon. Alkanes form a homologous series represented by a general formula C_nH_{2n+2}. Thus, if an alkane has six carbon atoms, the formula of the alkane will be $C_6H_{(2\times6)+2}$, this can be simplified to C_6H_{14}. This generalisation holds for all members of the alkane family. The structures of the first three members of alkanes are shown in Figure 2.11.

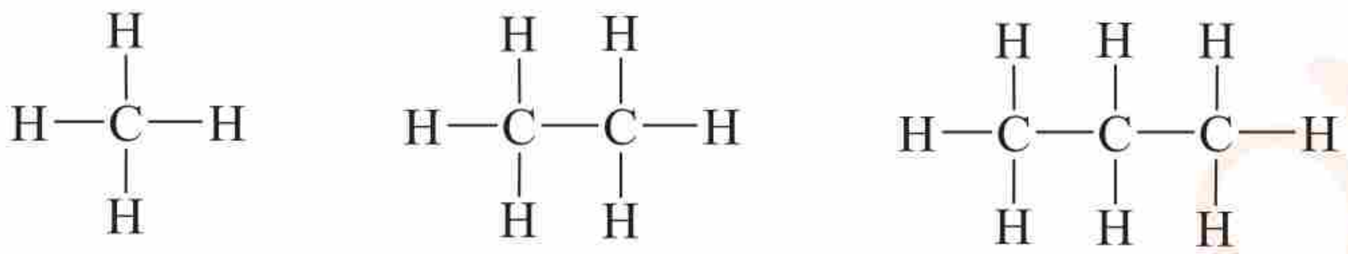


Figure 2.11: *Structures of the first three alkanes*

Naming of alkanes

The naming of alkanes use the same rules of naming hydrocarbons that have been discussed. The names of the first ten members of the alkane homologous series are shown in Table 2.6.

Table 2.6: *Homologous series of alkanes*

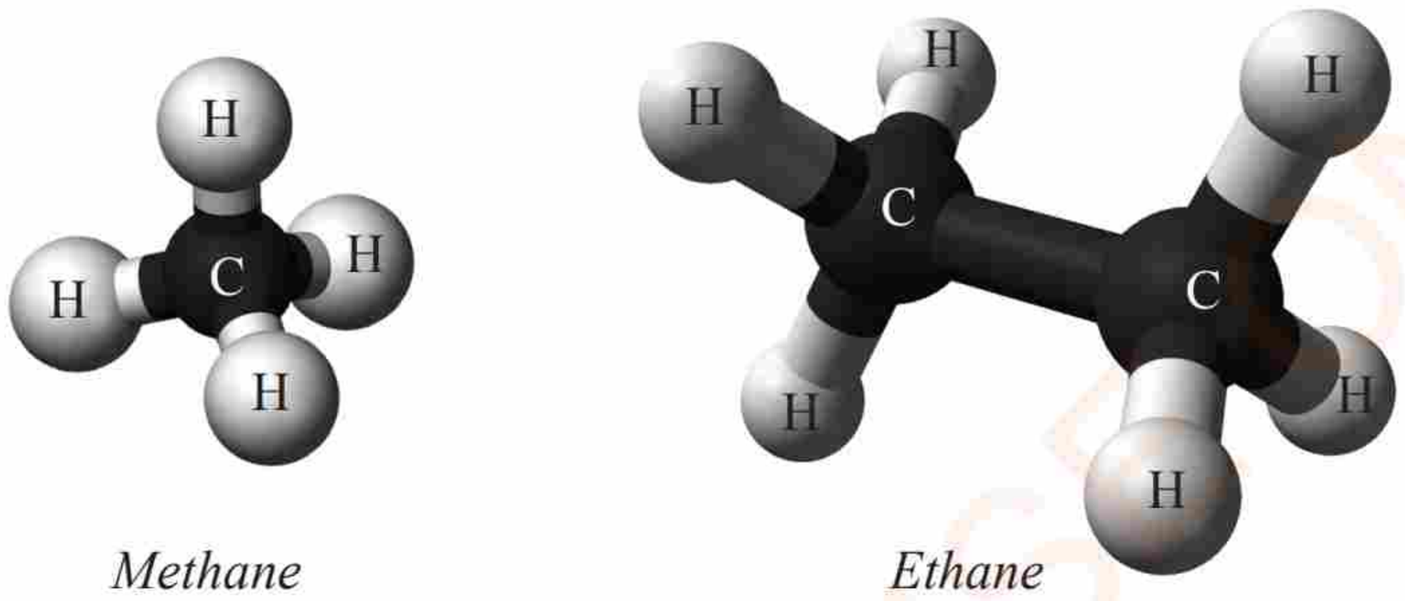
Number of carbon atoms (*n*)	Name	Molecular formula	Structural formula
1	Methane	CH_4	CH_4
2	Ethane	C_2H_6	CH_3CH_3
3	Propane	C_3H_8	$CH_3CH_2CH_3$
4	Butane	C_4H_{10}	$CH_3(CH_2)_2CH_3$
5	Pentane	C_5H_{12}	$CH_3(CH_2)_3CH_3$
6	Hexane	C_6H_{14}	$CH_3(CH_2)_4CH_3$
7	Heptane	C_7H_{16}	$CH_3(CH_2)_5CH_3$
8	Octane	C_8H_{18}	$CH_3(CH_2)_6CH_3$
9	Nonane	C_9H_{20}	$CH_3(CH_2)_7CH_3$
10	Decane	$C_{10}H_{22}$	$CH_3(CH_2)_8CH_3$

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Molecular formulae

Using the general formula C_nH_{2n+2}, the first member of the homologous series in alkane is methane, whose molecular formula is CH_4. Methane contains one carbon atom covalently bonded to four hydrogen atoms. The second member of the alkane series is ethane, whose molecular formula is C_2H_6. Ethane has two carbon atoms bonded together and each carbon is bonded to three hydrogen atoms. Figure 2.12 shows models of molecules of methane and ethane.



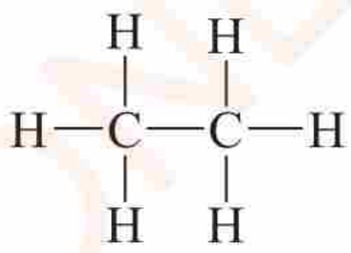
Methane *Ethane*

Figure 2.12: *Models of methane and ethane*

Structural formulae

The open and condensed structural formulae of ethane and butane, respectively are presented in Figure 2.13.

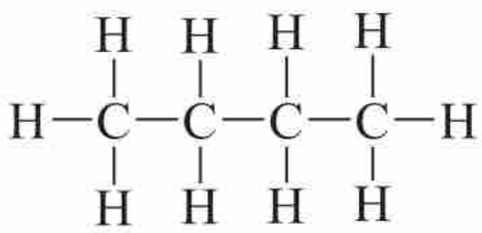
(a)Ethane



or

CH_3CH_3

(b)Butane



or

$CH_3CH_2CH_2CH_3$

Figure 2.13: *Structural formulae of ethane and butane*

The condensed structural formulae for butane can be simplified further as shown in Figure 2.13. The two ends of the molecule contain $-CH_3$ groups and between them there are two $-CH_2-$ structural units. The condensed structural formula for butane can therefore be expressed as $CH_3(CH_2)_2CH_3$.

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Branched-chain alkanes

The alkanes discussed so far are referred to as straight-chain alkanes. In the straight-chain alkanes, the carbon atoms are arranged in a straight continuous chain from the first to the last. In branched alkanes, some carbon atoms are attached as branches along the main continuous carbon chain. Figure 2.14 shows a straight-chain alkane and a branched-chain alkane.



Figure 2.14: *Straight and branched-chain alkanes*

The two molecules are isomers of butane because they have the same molecular formula (C_4H_{10}). Note that in a straight chain, the middle carbon atoms are joined to two other carbons only, while in a branched chain, there must be at least one carbon atom joined to more than two other carbon atoms. The name of the alkane is based on the longest continuous chain which is considered to be the parent chain. The branches or side groups are called *substituents*. A substituent in the structure of an organic molecule is any atom or group of atoms, except hydrogen, which is bonded to the longest continuous carbon chain. The most common substituents are *alkyl groups* which are derived from alkanes. An alkyl group has one hydrogen less than the corresponding alkane. They have a general formula of C_nH_{2n+1}. The name of the alkyl group is obtained by replacing the suffix *–ane* in a corresponding alkane with *–yl*. Table 2.7 shows the names and formulae of some alkyl substituents.

Table 2.7: *Names of some alkyl substituents*

Number of carbon atoms(n)	Name of substituent	Molecular formula
1	Methyl	$-CH_3$
2	Ethyl	$-C_2H_5$
3	Propyl	$-C_3H_7$
4	Butyl	$-C_4H_9$

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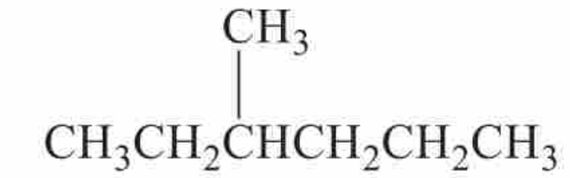
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Rules for naming branched alkanes

The following rules are followed when naming branched alkanes.

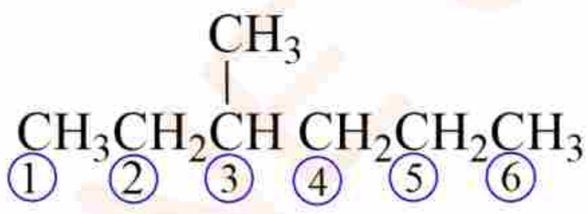
1. Identify the longest continuous carbon chain that becomes the parent chain.

   Consider the alkane shown below. The longest continuous carbon chain has six carbon atoms. Its parent name is hexane.



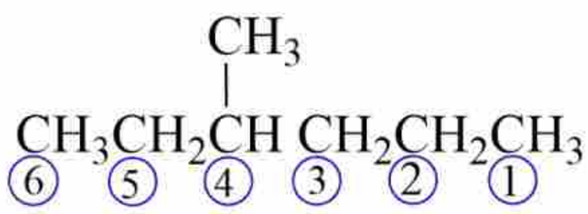
2. Identify the position and the name of the substituents attached to the longest continuous carbon chain. To get the position of the substituent, the longest continuous carbon chain is numbered starting from the end that gives the smallest possible number to the carbon atom to which the substituent is attached. It is important to note that numbering of carbon atoms in a chain with a substituent in the middle is done from either side. The number that gives the location of a substituent is known as a *locant*.

   Consider the alkane shown in step 1. The substituent is a methyl group. Starting from left to right, the methyl group is attached to the third carbon atom.



3-methylhexane

Starting from right to left, the methyl group is attached to the fourth carbon atom which is the higher number and is against the rule.



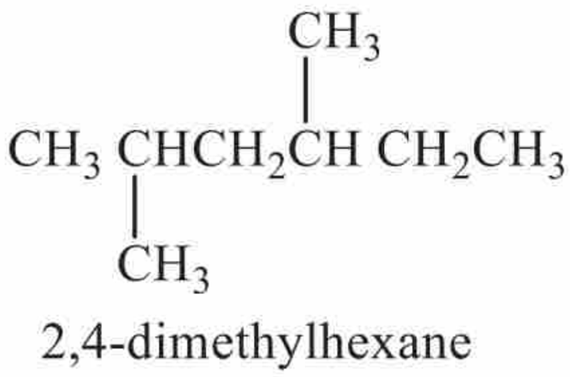
Therefore, left-to-right numbering gives the smallest possible number (3) of the locant.

3. Write down the name of the alkane, starting with the locant, followed by the name of the substituent and then the name of the parent chain. Use a hyphen (-) to separate the locant from the name of the substituent. The name of the alkane in step 2 is therefore 3-methylhexane. The name should be continuous with no spaces between. The name which follows after the locant should start with a small letter.

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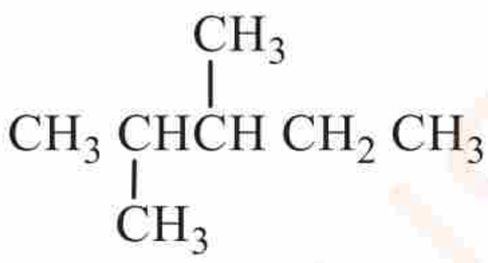
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4. When the same substituent is repeated in more than one carbon atoms in the parent chain, the numbers in the repeated carbons are separated by a comma. For example, the following compound has two CH_3 groups attached to the second and fourth carbon atoms in the chain.



2,4-dimethylhexane

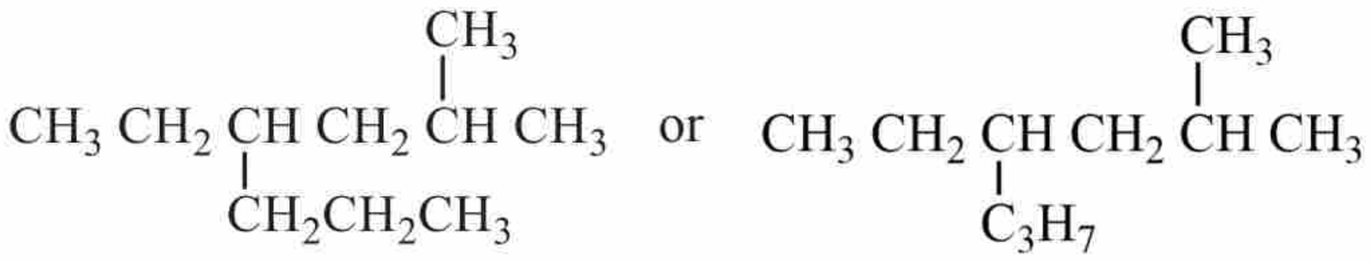
5. When more than one substituents are attached to the parent chain, the numbering is done in such a way that the sum of the locants is the lowest possible. Consider the alkane shown below.



2,3-dimethylpentane

The longest continuous chain has five carbon atoms. The parent chain is therefore pentane. There are two methyl substituents. Starting from left to right, the methyl substituents are on carbon atoms number 2 and 3. The sum of the two locants is 2 + 3 = 5. Starting from right to left, the methyl substituents are on carbon atoms number 3 and 4. The sum of the locants is 3 + 4 = 7. Since 5 is less than 7, the parent chain is numbered from left to right. The prefix *di*, meaning two, is used to indicate that there are two methyl substituents. A comma is used to separate the locants. The name of the alkane is 2,3-dimethylpentane.

6. When two or more different substituents are attached to the parent chain, the names of the substituents are written in an alphabetical order. Consider the alkane shown below.



4-ethyl-2-methylheptane

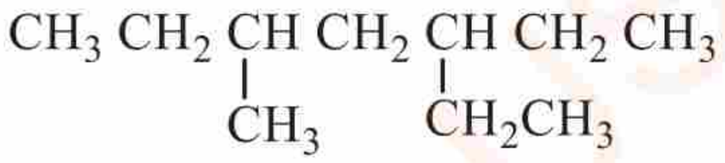
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Note that the formula of the propyl group can be abbreviated to $-C_3H_7$. Therefore, the longest continuous chain has seven carbon atoms.

The name of the parent chain is therefore heptane. Starting from left to right, there is an ethyl substituent on the fourth carbon atom and a methyl substituent on the sixth carbon atom. The sum of the locants is 4 + 6 = 10. Starting from right to left, the methyl substituent is on the second carbon atom, while the ethyl substituent is on the fourth carbon atom. The sum of the locants is 2 + 4 = 6. Because 6 is less than 10, the parent chain is numbered from right to left. Applying the sixth rule, 'e' (for ethyl) is before 'm' (for methyl) in the alphabet. The name of the alkane therefore is 4-ethyl-2-methylheptane.

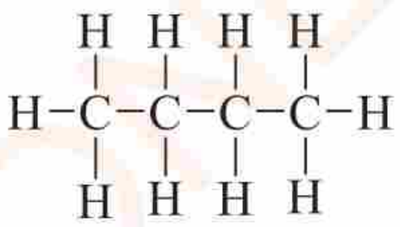
7. If all the attached substituents have equal distance from both ends of the molecule, the first cited group (alphabetically) receives the lowest number. For example,



3-ethyl-5-methylheptane

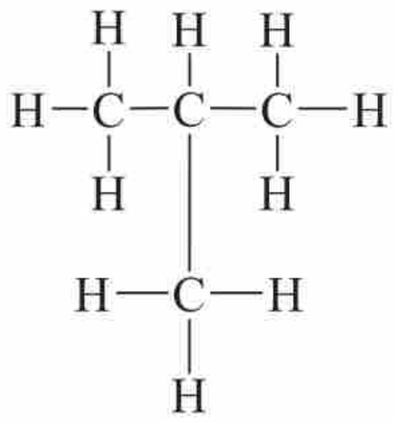
Alkanes exhibit isomerism except the first three members which are methane, ethane and propane. For example, butane has two isomers as shown in Figure 2.15.

(a) Butane



or $CH_3\,CH_2\,CH_2CH_3$

(b) 2-methylpropane



or $CH_3\,CH\,CH_3$ with CH_3 on CH

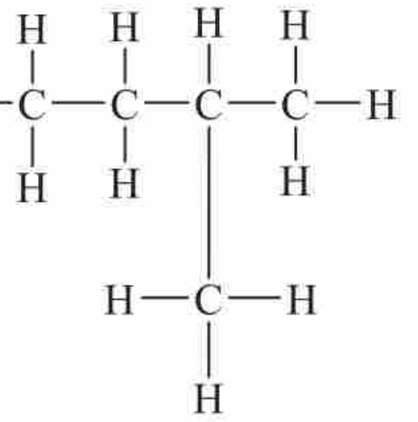
Figure 2.15: *Isomers of butane*

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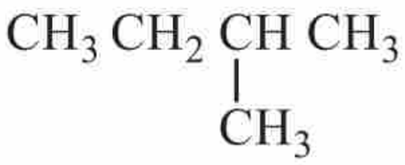
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As the number of carbon atoms increases, the number of possible isomers also increases. Pentane has more isomers than butane. Figure 2.16 shows three isomers of pentane.

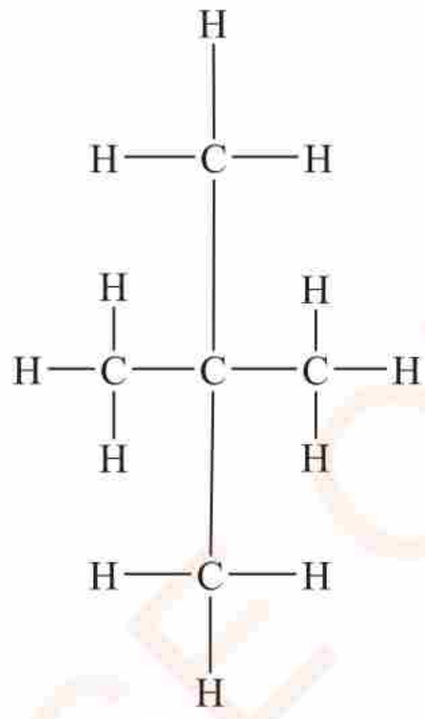
(a) 2-methylbutane



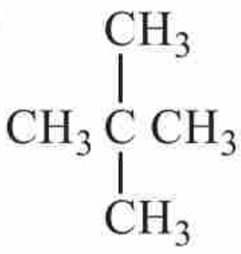
or



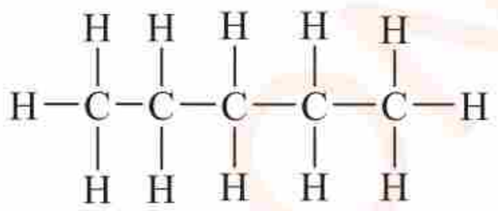
(b) 2,2-dimethylpropane



or



(c) Pentane



or

$CH_2CH_2CH_2CH_2CH_3$

Figure 2.16: *Isomers of pentane*

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Preparation of alkanes

A similar laboratory method can be used to prepare alkanes of different chain lengths. The following sections describe how to prepare methane and ethane from sodium ethanoate and propanoate, respectively with soda lime.

(a) *Preparation of methane*

Methane can be prepared in the laboratory by reacting sodium ethanoate with soda lime. Soda lime is a mixture of sodium hydroxide and calcium oxide. The sodium hydroxide in the mixture reacts with sodium ethanoate to produce methane gas. Methane gas is colourless, odourless and insoluble in water leading to its collection over water. Calcium oxide is used as a dehydrating agent since sodium hydroxide is a deliquescent solid.

$$CH_3COONa(s) + NaOH(s) \xrightarrow[\Delta]{CaO} CH_4(g) + Na_2CO_3(s)$$



Activity 2.1

Aim: To prepare methane

Requirements: Test tube, four gas jars with covers, water trough, beehive shelf, one-hole rubber stopper, delivery tube, rubber bung, retort stand and clamp, Bunsen burner, spatula, measuring cylinder, anhydrous sodium ethanoate, soda lime, and water

Procedure

1. Put a mixture of anhydrous sodium ethanoate and soda lime in equal proportions in a dry test tube.
2. Set the apparatus as shown in Figure 2.17

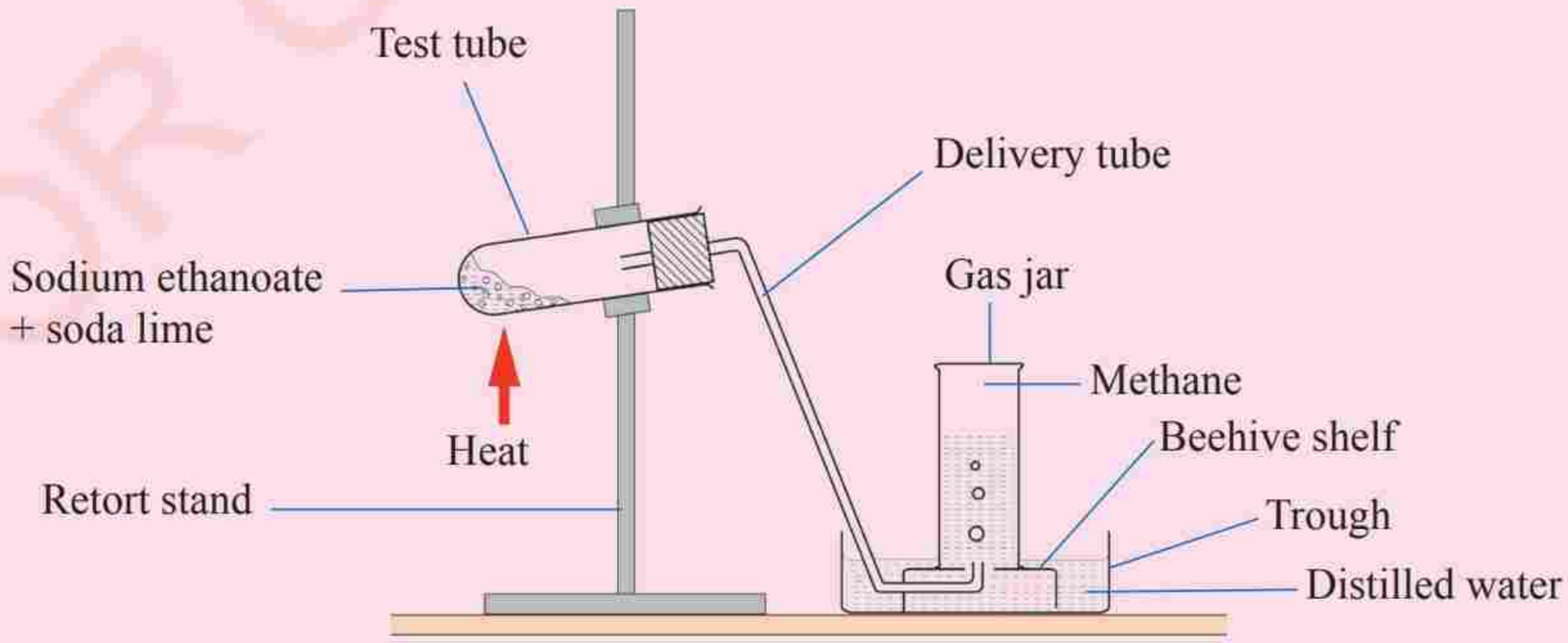


Figure 2.17: *Set-up for the preparation of methane*

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3. Heat the mixture gently using a non-luminous flame.
4. Collect the methane gas produced in the gas jars.
5. Note the colour and smell of the gas.

Questions

1. Why was the mixture of sodium ethanoate and soda lime heated during preparation of the gas?
2. Why was the gas collected over water?
3. What was the colour and smell of the gas?

(b) *Preparation of ethane*

Ethane gas can be prepared in the laboratory by reacting sodium propanoate with soda lime. Sodium propanoate reacts with sodium hydroxide in soda lime to give ethane. Ethane is a constituent of natural gas but it is of a lower percentage compared to methane. It is characterised by its colourless and odourless properties and it is insoluble in water thus should be collected over water.

$$CH_3CH_2COONa(s) + NaOH(s) \xrightarrow[\Delta]{CaO} C_2H_6(g) + Na_2CO_3(s)$$



Activity 2.2

Aim: To prepare ethane

Requirements: Test tube, four gas jars, gas jar covers made of glass, water trough, beehive shelf, delivery tube, rubber bung, retort stand and clamp, Bunsen burner, spatula, 5-cm^3 measuring cylinder, sodium propanoate, soda lime, water, limewater, bromine water or dilute potassium permanganate, and blue cobalt(II) chloride paper

Procedure

1. Put a mixture of sodium propanoate and soda lime in equal proportions in a dry test tube.
2. Set the apparatus as shown in Figure 2.18.

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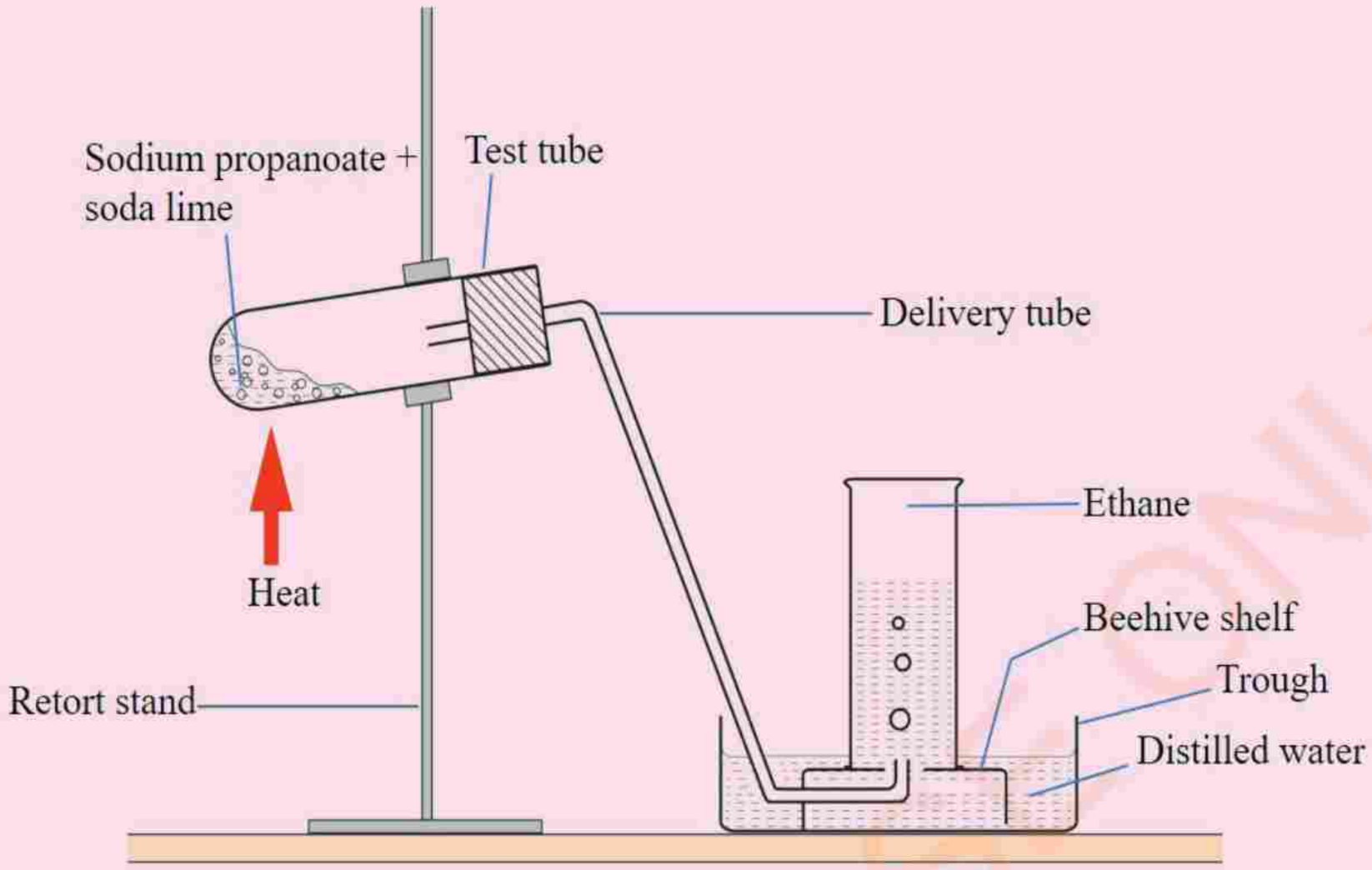


Figure 2.18: *Set-up for the preparation of ethane*

3. Heat the mixture gently using a non-luminous flame.
4. Collect four gas jars of ethane over water in a water trough.
5. Take note of the colour and smell of ethane.
6. To one of the gas jars containing ethane, add about 5 drops of limewater, and to another, add about 1 cm^3 of bromine water or dilute potassium permanganate. Replace the covers immediately, shake and make observations.
7. Expose the two gas jars to sunlight for some time then record the observations.
8. Measure about 1 cm^3 of bromine water or dilute potassium permanganate and put in a test tube containing ethane gas and cover it with an aluminium foil. Leave it for some time.
9. Ignite the gas in the third gas jar and after it has burned completely, replace the cover and allow it to cool. Add 5 drops of limewater into the gas jar.
10. Repeat step 9 using the fourth gas jar but instead of adding limewater, add a piece of blue cobalt(II) chloride paper.

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Questions

1. What is the colour and smell of ethane?
2. How does the collection method of ethane relate to its solubility in water?
3. What was observed when:
   (a) limewater was added to a gas jar containing ethane?
   (b) bromine water or dilute potassium permanganate was added to a gas jar containing ethane?
4. What was observed when ethane was ignited followed by addition of limewater?

Properties of alkanes

The following are some of the physical and chemical properties of alkanes:

Physical properties

The trend in physical properties of the straight-chain alkanes changes gradually from methane to decane. The change in the physical states is due to increase in their molecular masses which in turn increases their intermolecular attractions. The first four alkanes (methane, ethane, propane, and butane) are gases at room temperature and pressure. Alkanes with five to ten carbon atoms (pentane to decane) are liquids. The boiling points, melting points and density of alkanes increase with the increase of molecular masses. This is also due to increase in intermolecular forces of attraction between the molecules. The boiling points of isomeric alkanes also decrease with increase in branching. Table 2.8 outlines some of the physical properties of the first ten alkane series.

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Table 2.8: *Physical properties of the first ten alkanes*

Alkane	Boiling point (°C)	Melting point (°C)	Density (g/cm^3)
Methane	–162	–182	0.466
Ethane	–89	–183	0.572
Propane	– 42	–188	0.585
Butane	–1	–138	0.601
Pentane	36	–130	0.626
Hexane	69	–95	0.659
Heptane	98	–91	0.684
Octane	126	–57	0.703
Nonane	151	–51	0.718
Decane	174	–30	0.730

Chemical properties

The chemical properties of alkanes are described as follows:

(a) *Reactions with air*: Alkanes burn in good supply of air to give carbon dioxide and water vapour. Methane burns in air as shown in the following equation.

$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)$$

If the oxygen supply is less, incomplete combustion will occur and two reactions are possible. The by-products formed are carbon monoxide, carbon (soot) and less energy. In the motor engines, if less energy is produced the engine performance is inefficient.

$$2CH_4(g) + 3O_2(g) \longrightarrow 2CO(g) + 4H_2O(g)$$

$$CH_4(g) + O_2(g) \longrightarrow C(s) + 2H_2O(g)$$

The combustion of alkanes is an exothermic reaction, and the heat generated is used as a means for industrial and domestic heating. Most alkanes are actually used as fuels.

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(b) *Test for saturation (reactions with halogens)*: Alkanes are saturated hydrocarbons. They react with halogens in a *substitution reaction*. A substitution reaction is one in which an atom or a group of atoms is replaced by another atom or group of atoms. Substitution reactions of alkanes mainly involve halogens such as bromine and chlorine. Methane gas does not react with bromine water in the dark. It does not also decolourise potassium permanganate solution. The two reagents are used to test for saturation in hydrocarbons. However, bromine reacts with methane in the presence of ultraviolet light in a substitution reaction to form tetrabromoethane.

$$CH_4(g) + 4Br_2(g) \xrightarrow{\text{UV light}} CBr_4(g) + 4HBr(g)$$

Chlorine also reacts with methane in a similar way.

$$CH_4(g) + 4Cl_2(g) \xrightarrow{\text{UV light}} CCl_4(g) + 4HCl(g)$$

These substitution reactions take place in stages, with one hydrogen atom in methane being substituted at each stage. Substitution reactions are characteristic of saturated hydrocarbons. For example,

(i) $CH_4(g) + Cl_2(g) \xrightarrow{\text{UV light}} CH_3Cl(g) + HCl(g)$
(Chloromethane)

(ii) $CH_3Cl(g) + Cl_2(g) \xrightarrow{\text{UV light}} CH_2Cl_2(g) + HCl(g)$
(Dichloromethane)

(iii) $CH_2Cl_2(g) + Cl_2(g) \xrightarrow{\text{UV light}} CHCl_3(g) + HCl(g)$
(Trichloromethane)

(iv) $CHCl_3(g) + Cl_2(g) \xrightarrow{\text{UV light}} CCl_4(g) + HCl(g)$
(Tetrachloromethane)

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Activity 2.3

Aim: To taste for the saturated nature of alkanes

Requirements: Three gas jars, aluminium foil, 10-cm^3 measuring cylinder, methane gas source, bromine water, and acidified potassium permanganate

Procedure

1. Prepare three gas jars of methane using the procedure in Activity 2.1. Do not collect the first bubbles of the gas produced.
2. Wrap one of the gas jars with aluminium foil. Add about 5 cm^3 of bromine water into the gas jar and shake the mixture. Unwrap the gas jar and make observations.
3. To another gas jar, add 5 drops of bromine water. Shake the mixture and make observations.
4. To the third gas jar, add 5 drops of acidified potassium permanganate solution and make observations.

Questions

What was observed when;

(a) bromine water was added to the methane gas in the clear gas jar?

(b) bromine water was added to the methane gas in the gas jar covered with aluminium foil?

(c) potassium permanganate solution was added to methane gas?

Uses of Alkanes

Alkanes have various uses including the following:

1. The alkanes from pentane to octane are volatile liquids and good solvents for non-polar substances.
2. Alkanes are important raw materials of the chemical industry and the principal constituent of gasoline and lubricating oils.
3. Natural gas mainly contains methane and ethane and is used for heating and cooking purposes and for power utilities (gas turbines).

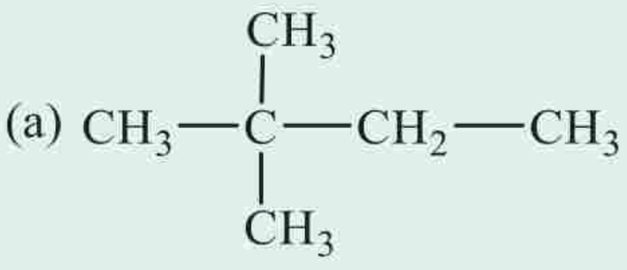
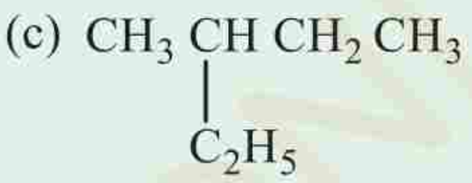
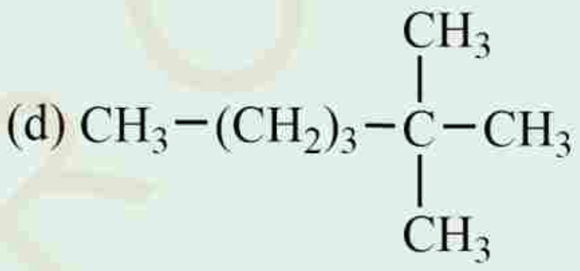
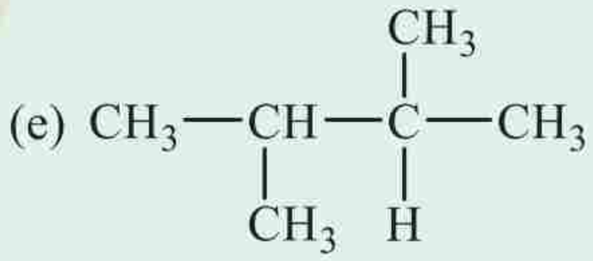
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Exercise 2.2

1. Draw the structural formulae of the following compounds:
   (a) 3-ethyl-4,4-dimethylheptane
   (b) 2,3-dichloropentane
   (c) 3-ethyl-4-methylnonane
   (d) 1-chloro-2-methylpentane

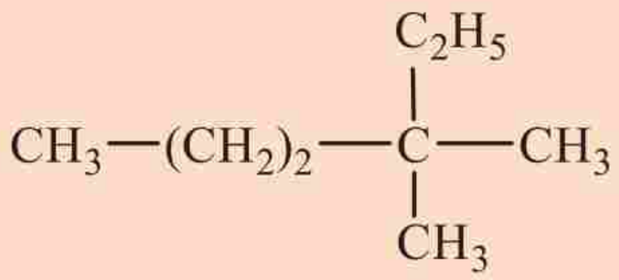
2. You are given two lists in Column A and Column B as shown in the table below. Match each of the items in Column A that corresponds with the item in Column B.

Column A	Column B
(a) 	(i) Propane
(b) $CH_3\ CH_2\ CH_3$	(ii) 2-ethylbutane
(c) 	(iii) 3-methylpentane
(d) 	(iv) 2,2-dimethylbutane
(e) 	(v) 2,3-dimethylbutane
	(vi) 2,2-dimethylhexane
	(vii) 2,2,2-trimethylbutane

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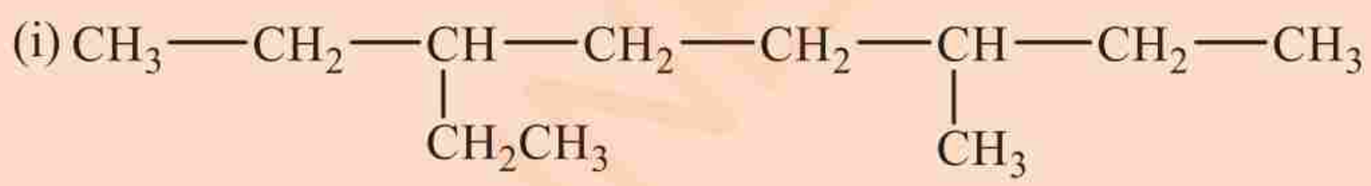
3. Use the given structure of the hydrocarbon to answer the questions that follow:

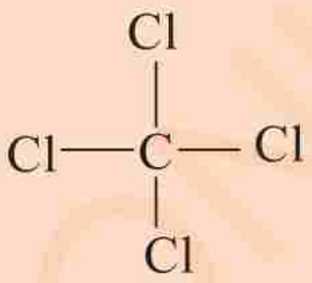


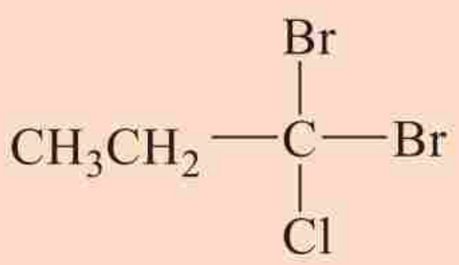
(a) Give the name of the longest continuous carbon chain.
(b) Write the names of the substituents present in the molecule.
(c) Write the open structures of the substituents given in (b).
(d) Identify the locants of the substituents.
(e) Write the systematic name of the compound.

4. Write all possible isomers of the compounds with the following molecular formulae:
(a) C_5H_{12} (b) C_4H_{10}

5. Name the following compounds:

(i) 

(ii) 

(iii) 

(iv) 

6. Explain whether the following organic compounds are correctly named, and give the correct names for the incorrect ones:
(a) 1-methylpentane (b) 2,3-dichloropentane
(c) 2-ethylbutane (d) 1,1,3-trimethylpropane
(e) 2-bromomethylpropane

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Alkenes

Alkenes are hydrocarbons which contain at least one double bond (–C=C–) between two carbon atoms. Alkenes contain two hydrogen atoms less than the corresponding alkanes. Alkenes with one double bond form a homologous series. Alkenes are very reactive compared to alkanes due to the presence of double bonds that have more electrons density.

General formula

All alkenes are represented by the general formula C_nH_{2n}. If an alkene has seven carbon atoms, the molecular formula of the alkene will be $C_7H_{(2\times7)}$ which is the same as C_7H_{14}.

Molecular formulae

Since there must be at least one double bond between two carbon atoms, the first member of the homologous series is ethene, which contains two carbon atoms with one double bond. The molecular formula of ethene is C_2H_4. Figure 2.19 shows a model of an ethene molecule.

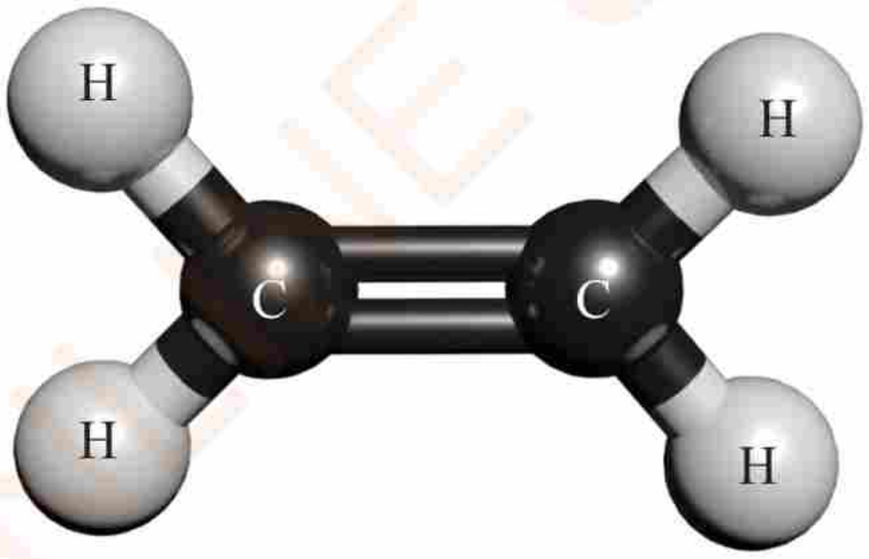


Figure 2.19: *Molecular model of ethene*

The second member of the homologous series is propene with a molecular formula of C_3H_6. The open structural formula of propene is shown in Figure 2.20. The first nine straight chain alkenes are summarised in Table 2.9

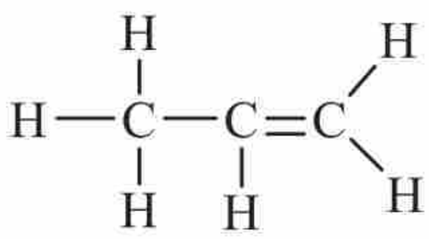


Figure 2.20: *Open structural formula of propene*

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Table 2.9: *First nine members of alkenes*

IUPAC name	Molecular formula	Structural formula
Ethene	C_2H_4	CH_2CH_2 or $CH_2=CH_2$
Propene	C_3H_6	CH_3CHCH_2 or $CH_3CH=CH_2$
But-1-ene	C_4H_8	$CH_3CH_2CHCH_2$ or $CH_3CH_2CH=CH_2$
Pent-1-ene	C_5H_{10}	$CH_3(CH_2)_2CHCH_2$ or $CH_3(CH_2)_2CH=CH_2$
Hex-1-ene	C_6H_{12}	$CH_3(CH_2)_3CHCH_2$ or $CH_3(CH_2)_3CH=CH_2$
Hept-1-ene	C_7H_{14}	$CH_3(CH_2)_4CHCH_2$ or $CH_3(CH_2)_4CH=CH_2$
Oct-1-ene	C_8H_{16}	$CH_3(CH_2)_5CHCH_2$ or $CH_3(CH_2)_5CH=CH_2$
Non-1-ene	C_9H_{18}	$CH_3(CH_2)_6CHCH_2$ or $CH_3(CH_2)_6CH=CH_2$
Dec-1-ene	$C_{10}H_{20}$	$CH_3(CH_2)_7CHCH_2$ or $CH_3(CH_2)_7CH=CH_2$

Naming of alkenes

The rules used in naming alkanes are also applied in naming alkenes. The root name of an alkene is the same as that of a corresponding alkane. A number that indicates the position of the double bond is added to the root word followed by the suffix *–ene*. A hyphen is inserted on either sides of the number showing the position of the double bond. The carbon chain is numbered in such a way that the carbon atom with the double bond is given the lowest possible number. Consider the alkene $CH_3CH_2CH=CH_2$;

Numbering the carbon atoms from left to right, the double bond is on the third carbon atom. Since there are four carbon atoms in the chain, the name of the alkene would be but-3-ene. On the other hand, starting from the right-hand side, the double bond is on the first carbon atom. The correct name of the alkene is therefore but-1-ene because the first carbon carrying the double bond has the lowest number.

For branched alkenes, the longest continuous carbon chain having the double bond is taken to be the parent chain. All the other rules used in naming branched alkanes also apply when naming alkenes. Table 2.10 shows examples of some alkenes and their IUPAC names.

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Table 2.10: *Names of some branched alkenes*

Structural formula	Name
$CH_3\ CH{=}CH\ CH_2CH_3$	Pent-2-ene or 2-pentene
$CH_3\ \underset{\displaystyle CH_3}{\underset{\vert}{CH}}\ CH{=}CH\ CH_3$	4-methylpent-2-ene or 4-methyl-2-pentene
$CH_3\ CH_2\ \underset{\displaystyle C_2H_5}{\underset{\vert}{CH}}\ \underset{\displaystyle CH_3}{\underset{\vert}{CH}}\ CH_2\ CH{=}CH_2$	5-ethyl-4-methylhept-1-ene or 5-ethyl-4-methyl-1-heptene
$CH_3\ \underset{\displaystyle C_2H_5}{\underset{\vert}{CH}}\ CH_2\ \underset{\displaystyle C_3H_7}{\underset{\vert}{CH}}\ CH{=}CH\ CH_3$	6-methyl-4-propyloct-2-ene or 6-methyl-4-propyl-2-octene

Isomerism in alkenes

Alkenes form different isomers due to changing positions of the double bond as well as the presence and positions of substituents. Ethene and propene do not have any isomers. Butene has the following isomers:

(a) $CH_3CH_2CH{=}CH_2$ (but-1-ene or 1-butene)

(b) $CH_3CH{=}CHCH_3$ (but-2-ene or 2-butene)

(c) $H_3C{-}\underset{\displaystyle CH_3}{\underset{\vert}{C}}{=}CH_2$ (2-methylprop-1-ene or 2-methyl-1-propene)

The above isomers have different structures. Isomers (a) and (b) are due to the position of the double bonds. They are usually referred to as *positional isomers*. Isomer (c) is due to the presence of a substituent, and is referred to as *branch isomer*.

Preparation of ethene

Ethene is a colourless gas with a faint sweet smell and slightly soluble in water. Ethene can be prepared in the laboratory by heating a mixture of ethanol and concentrated sulphuric acid. The concentrated sulphuric acid is added to dehydrate ethanol into ethene at a temperature range from 160 °C to 180 °C.

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Alkaline solution is added to remove traces of sulphur dioxide produced due to the slight decomposition of sulphuric acid.

$$CH_3CH_2OH(l) \xrightarrow[170\ ^\circ C]{H_2SO_4} CH_2{=}CH_2(g) + H_2O(l)$$

Ethene can also be prepared in the laboratory by dehydrating ethanol using aluminium oxide.

$$CH_3CH_2OH(l) \xrightarrow{Al_2O_3} CH_2{=}CH_2(g) + H_2O(l)$$



Activity 2.4

Aim: To prepare a sample of ethene gas

Requirements: Gas jars, conical flask, round-bottomed flask, beehive shelf, water trough, spatula, delivery tubes, sand bath, Bunsen burner, retort stand and clamp, thistle funnel with tap, 25-cm^3 measuring cylinder, 10-cm^3 measuring cylinder, tripod stand, wire gauze, concentrated sulphuric acid, ethanol, concentrated potassium hydroxide, and sand

Caution: Hot concentrated sulphuric acid is very corrosive.

Procedure

1. Put a clean and dried sand into the sand bath.
2. Add 20 cm^3 of concentrated sulphuric acid into the round-bottomed flask.
3. Add 5 cm^3 of ethanol to the mixture.
4. Set the apparatus as shown in Figure 2.21.
5. Heat the mixture and collect two gas jars. Record observations.

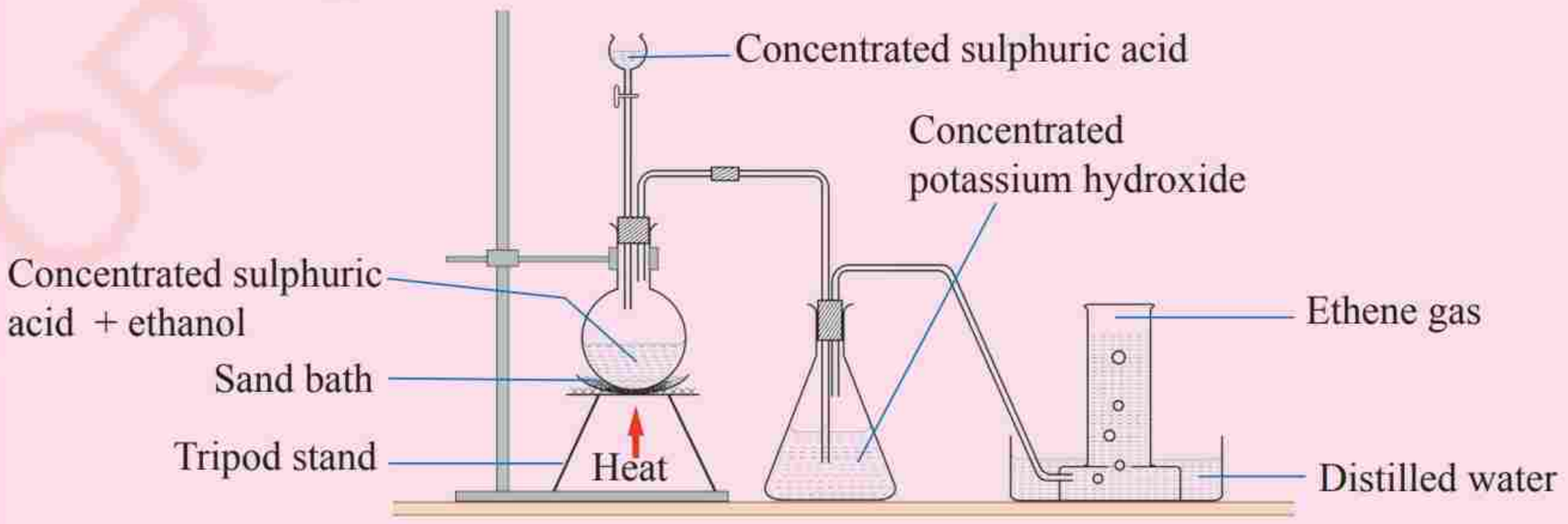


Figure 2.21: *Set-up for the preparation of ethene gas*

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Questions

1. What is the colour and smell of the gas produced?
2. Comment on the solubility of the gas in water.
3. Write an equation for the reaction that produced the gas.
4. What was the function of concentrated potassium hydroxide in this experiment?
5. Why was the flask heated over sand bath?

Properties of alkenes

Some of the physical and chemical properties of alkenes are described as follows:

Physical properties

The first three alkenes are gases at room temperature. Boiling points of alkenes depend on the strength of intermolecular forces which increase with the increase in chain length. All alkenes are insoluble in water but soluble in organic solvents like benzene or acetone. The trends in melting points and boiling points, and density of the first five alkenes are summarised in Table 2.11.

Table 2.11: *Trends in physical properties of the first five alkenes*

Name	Boiling point (°C)	Melting point (°C)	Density $\left(g\ cm^{-3}\right)$
Ethene	–104.0	–169.0	0.501
Propene	–47.0	–185.0	0.519
But-1-ene	–6.5	−185.0	0.595
Pent-1-ene	30.0	−165.0	0.641
Hex-1-ene	63.0	−140.0	0.673

Chemical properties

The main chemical reactions involving alkenes are *addition reactions*. An addition reaction is the one in which an atom or group of atoms are added to the molecule. The atoms are added across the carbon-carbon double bond.

(a) *Halogenation of ethene*: Halogenation of alkenes is the reaction through which halogens such as bromine and chlorine are added across the carbon-carbon double bond. The reaction between bromine and ethene is an addition reaction, in which the carbon-carbon double bond is broken

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and new carbon-bromide bonds are formed. In this reaction, bromine is immediately decolourised on addition of alkene.

$$CH_2{=}CH_2(g) + Br_2(g) \longrightarrow CH_2BrCH_2Br(g)$$

1,2-dibromoethane

Light is not necessary for the reaction between bromine and ethene, unlike that with ethane. Addition reactions are characteristic of unsaturated hydrocarbons and often bromine is used to test for unsaturation in hydrocarbons. Chlorine will react in a similar way with ethene in the presence of silica (SiO_2) to form 1, 2-dichloroethane.

$$CH_2{=}CH_2(g) + Cl_2(g) \xrightarrow{SiO_2} CH_2ClCH_2Cl(g)$$

1,2-dichloroethane

Potassium permanganate solution can also be used to test for unsaturation in hydrocarbons. Potassium permanganate solution is decolourised when shaken with alkenes.



Activity 2.5

Aim: To investigate the reaction of ethene with dilute potassium permanganate

Requirements: Source of ethene gas, two gas jars with covers, dilute potassium permanganate, and bromine water

Procedure

1. Add 50 cm^3 of dilute potassium permanganate into one gas jar.
2. Bubble ethene gas prepared from Activity 2.4 in the jar containing dilute potassium permanganate, shake the mixture and record the observations.

Alternatively, add 50 cm^3 of bromine water into another gas jar then bubble it with ethene gas collected from Activity 2.4 and shake the mixture. Record the observations.

Questions

1. Explain the observations made when ethene gas was bubbled in dilute potassium permanganate.
2. If a gas jar containing dilute potassium permanganate in step 1 was wrapped with aluminium foil, could the reaction occur? Explain.
3. Explain the observations made when ethene gas was bubbled in bromine water.

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(b) *Hydrogenation of alkenes*: Hydrogenation of alkenes is an addition reaction which involves the addition of hydrogen atoms across the double bond. The reaction takes place in the presence of a catalyst such as nickel. Ethene undergoes hydrogenation as shown in the following equation:

$$CH_2{=}CH_2(g) + H_2(g) \xrightarrow[130\ ^\circ C]{\text{nickel}} CH_3CH_3(g)$$

Hydrogenation is an important industrial process in the manufacture of margarine from vegetable oils such as corn oil and sunflower oil. These oils are unsaturated and contain one or more double bonds. Hydrogenation converts the oils into solid fats such as margarine. Margarines are left partially unsaturated because unsaturated fats are healthier than completely saturated ones.

(c) *Reactions with hydrogen halides*: Halides are binary compounds that contain halogens. Alkenes react with hydrogen halides such as hydrogen bromide and hydrogen iodide in addition reaction.

$$CH_2{=}CH_2(g) + HBr(g) \longrightarrow CH_3CH_2Br(l)$$

Bromoethane

$$CH_2{=}CH_2(g) + HI(g) \longrightarrow CH_3CH_2I$$

Iodoethane

During these reactions, the alkenes become saturated. Hydrogen chloride does not react with alkenes at room temperature due to its strong bond as compared to hydrogen bromide and hydrogen iodide. The reaction of hydrogen chloride with ethene requires heat and a catalyst.

(d) *Reaction with sulphuric acid*: Ethene reacts with concentrated sulphuric acid in an addition reaction to form ethyl hydrogensulphate.

$$CH_2{=}CH_2(g) + H_2SO_4(l) \longrightarrow CH_3CH_2OSO_3H(l)$$

Ethyl hydrogensulphate

(e) *Reaction with oxygen*: Alkenes burn in air to give water vapour and carbon dioxide. During burning, they produce energy, hence are used as fuel.

$$C_2H_4(g) + 3O_2(g) \longrightarrow 2H_2O(g) + 2CO_2(g)$$

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Uses of alkenes

Alkenes have different uses including the following:

1. Manufacture of plastics like polythene for making buckets, bowls, and bags, and polystyrene which is used in making car battery cases.
2. Alkenes are also used as starting materials in the preparation of other organic compounds such as alcohols (ethanol), alkanes and halogenated compounds (alkyl halides).
3. Manufacture of ethane-1,2-diol used as an anti-freeze for motor car radiators.
4. Making anti-knock for car engines.
5. Manufacture of rubber such as butyl rubber which is produced by polymerisation of isobutylene and isoprene monomers.

Exercise 2.3

1. Which of the following is true when a mixture of bromine and methane is left in darkness?
   (a) Ethane and hydrogen bromide are formed.
   (b) Hydrogen bromide and bromomethane are formed.
   (c) There is no visible reaction.
   (d) Bromine is decolourised.

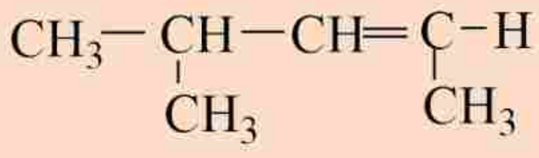
2. An organic compound has an empirical formula CH. The relative molecular mass of the compound is 28. The molecular formula of the compound is;
   (a) C_2H_2 (b) C_2H_4 (c) C_2H_6 (d) C_3H_6

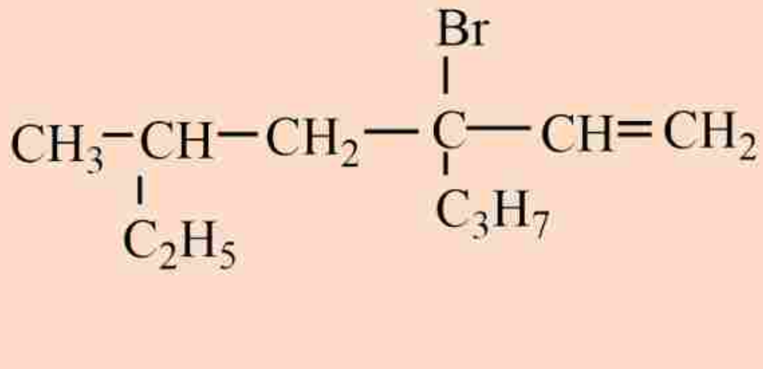
3. The following are isomers of a hydrocarbon:
   (a) $CH_2{=}CH{-}CH_2{-}CH_3$
   (b) $CH_3{-}CH{=}CH{-}CH_3$
   (c)
   $$H_2C{=}\overset{\displaystyle CH_3}{\overset{|}{C}}{-}CH_3$$
   (i) Give the molecular formula of the hydrocarbon.
   (ii) Give the IUPAC name of each of the isomers.

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4. Name the following organic compounds:

(i) 

(ii) 

5. Draw the condensed and open structures for each of the following compounds:
   (a) 3-ethyl-2-pentene
   (b) 4-methyl-2-hexene
   (c) 5-methyl-1-hexene

Alkynes

Alkynes are unsaturated hydrocarbons which contain at least one triple bond (–C≡C–) in the main carbon chain.

General formula

The general formula of alkynes is C_nH_{2n-2}. Consider an alkyne with six carbon atoms. The molecular formula of the alkyne is $C_6H_{(2\times6)-2}$. This is the same as C_6H_{10}. This generalisation applies to alkynes with one triple bond. Since there must be at least two carbon atoms for a triple bond to form alkynes, therefore, the first member in the homologous series of alkynes is ethyne (H−C≡C−H).

Naming of alkynes

The root names used in naming alkanes and alkenes are also used in naming alkynes. However, the suffix –ene in alkenes is replaced by *–yne* in alkynes. All the other rules used in naming alkenes also apply when naming alkynes. The number (locant) indicating the position of the triple bond (−C≡C−) in the longest continuous carbon chain should be included. Table 2.12 shows the names, molecular formulae and structural formulae of the first nine alkynes.

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Table 2.12: *Homologous series of alkynes*

Name	Molecular formula	Structural formula
Ethyne	C_2H_2	$HC{\equiv}CH$
Propyne	C_3H_4	$CH_3C{\equiv}CH$
But-1-yne	C_4H_6	$CH_3CH_2C{\equiv}CH$
Pent-1-yne	C_5H_8	$CH_3(CH_2)_2C{\equiv}CH$
Hex-1-yne	C_6H_{10}	$CH_3(CH_2)_3C{\equiv}CH$
Hept-1-yne	C_7H_{12}	$CH_3(CH_2)_4C{\equiv}CH$
Oct-1-yne	C_8H_{14}	$CH_3(CH_2)_5C{\equiv}CH$
Non-1-yne	C_9H_{16}	$CH_3(CH_2)_6C{\equiv}CH$
Dec-1-yne	$C_{10}H_{18}$	$CH_3(CH_2)_7C{\equiv}CH$

Isomerism in alkynes

Isomerism in alkynes starts with butyne (C_4H_6) which has two positional isomers.

$H-C{\equiv}C-CH_2CH_3$ But-1-yne

$CH_3-C{\equiv}C-CH_3$ But-2-yne

The number of possible isomers of alkynes increases with the increase in molecular mass (chain length).

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Preparation of alkynes

Ethyne can be prepared in the laboratory by the action of water on calcium carbide (CaC_2). In this reaction, calcium carbide is hydrolysed by water to give ethyne and calcium hydroxide. Sand is added in the reaction flask to prevent possible cracking of the flask due to exothermic nature of the reaction.

$$CaC_2(s) + 2H_2O(l) \longrightarrow C_2H_2(g) + Ca(OH)_2(aq)$$

Activity 2.6

Aim: To prepare ethyne

Requirements: Round-bottomed flask, thistle funnel with a tap, water trough, beehive shelf, spatula, retort stand and clamp, four gas jars with covers, dropper, wooden splints, calcium carbide, water, bromine water, acidified potassium manganate(VII), and clean sand

Caution: Calcium carbide causes skin and respiratory irritations. Thus, this experiment should be carried out in a fume chamber or using full-face respirator.

Procedure

1. Put two spatulaful of clean sand into a round-bottomed flask.
2. Place about five lumps of calcium carbide on the sand.
3. Put some water in the thistle funnel.
4. Set the apparatus as shown in Figure 2.22.

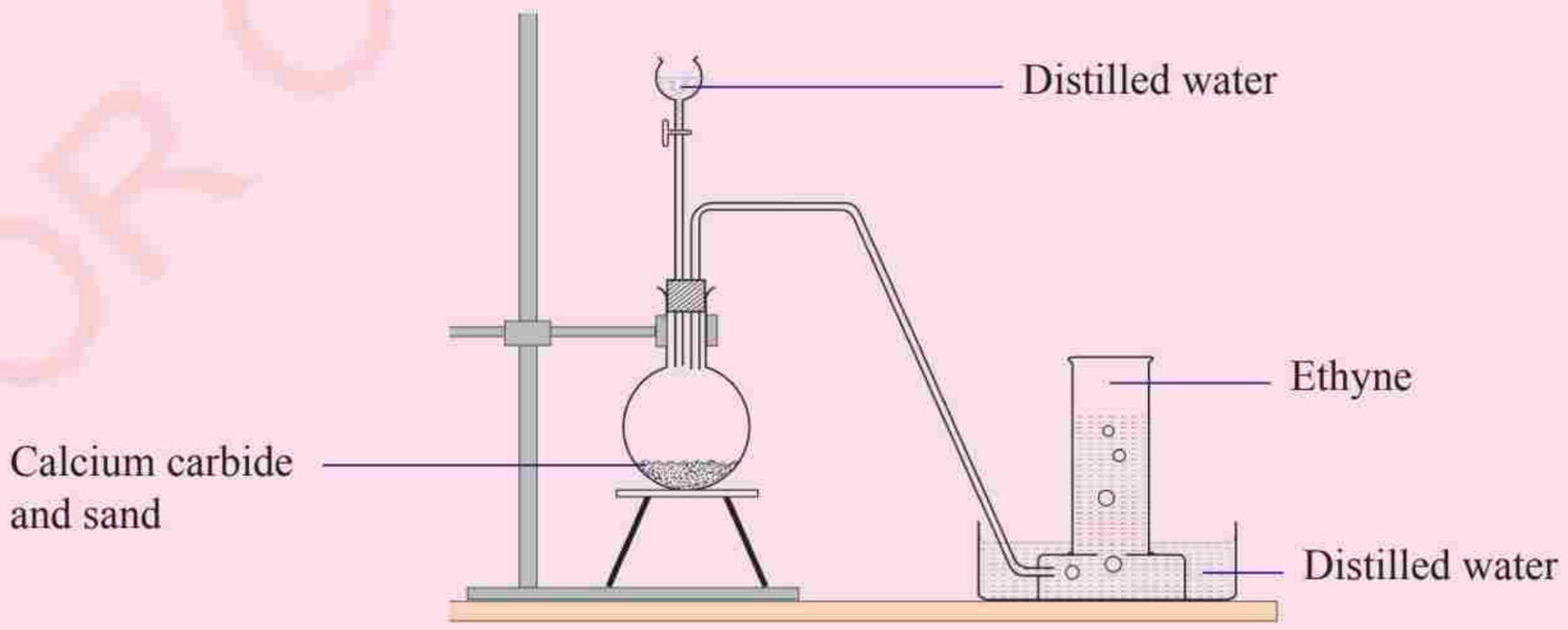


Figure 2.22: *Set-up for the preparation of ethyne*

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5. Add water, dropwise, into the mixture in the round-bottomed flask.
6. Collect four gas jars of the gas produced.

Questions

1. Why was ethyne collected over water?
2. What was the use of the sand in the reaction flask?

Properties of alkynes

The following are some of the physical and chemical properties of alkynes:

Physical properties

The first three alkynes (ethyne, propyne, and butyne) are all gases at room temperature. The boiling points of alkynes increase with the increase in molecular mass (chain length). Alkynes have slightly higher boiling points than alkanes and akenes. Table 2.13 summarises some physical properties of alkynes.

Table 2.13: *Physical properties of the first nine alkynes*

Name	Molecular formula C_nH_{2n-2}	State at room temperature	Boiling point (°C)	Melting point (°C)	Density (g cm^{-3})
Ethyne	C_2H_2	Gas	–84.0	–81.5	0.62
Propyne	C_3H_4	Gas	–23.2	–102.7	0.67
But-1-yne	C_4H_6	Gas	8.1	–122.5	0.69
Pent-1-yne	C_5H_8	Liquid	39.3	–90.0	0.71
Hex-1-yne	C_6H_{10}	Liquid	71.0	–132.0	0.72
Hept-1-yne	C_7H_{12}	Liquid	100.0	–80.0	0.73
Oct-1-yne	C_8H_{14}	Liquid	126.0	–70.0	0.75
Non-1-yne	C_9H_{16}	Liquid	151.0	–65.0	0.76
Dec-1-yne	$C_{10}H_{18}$	Liquid	174.0	–36.0	0.77

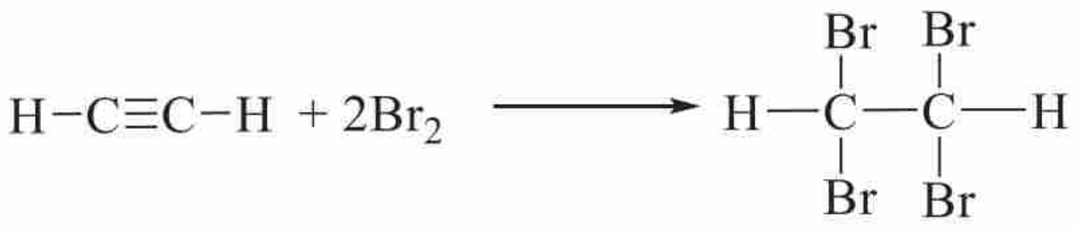
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Chemical properties

Alkynes undergo addition reactions to form alkanes. However, they are less reactive than their corresponding alkenes.

(a) *Halogenation of alkynes*: Alkynes react with halogens in the same way as alkenes. The reaction between alkynes and bromine is used as a test for unsaturation of alkynes where bromine is decolourised immediately by the alkenes. In this reaction, UV light is not necessary for the reaction to take place.



1,1,2,2-tetrabromoethane

Activity 2.7

Aim: To investigate the reaction between ethyne and dilute potassium permanganate or bromine water

Requirements: Two gas jars of ethyne, aluminium foil, dilute potassium permanganate, and bromine water

Caution: Bromine is very poisonous, thus, this experiment should be performed in a fume chamber or using full-face respirator.

Procedure

1. Collect two gas jars of ethyne. Wrap the whole outer surface of one gas jar with an aluminium foil.
2. In the unwrapped gas jar, add about 5 cm^3 of dilute potassium permanganate or two drops of bromine water.
3. Repeat step 2 with the wrapped gas jar by adding two drops of bromine water. Leave the gas jar in a dark cupboard for some time.
4. Unwrap the gas jar and make observations.

Questions

1. Explain the observations made when potassium permanganate solution or bromine water was added in both gas jars.
2. Why was the wrapping of the gas jar important?

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(b) *Hydrogenation of alkynes*: Like in alkenes, it is possible for hydrogen atoms to add across the triple bond in alkynes. This reaction takes place in the presence of a nickel catalyst. The hydrogenation of alkynes first gives alkenes. For example;

$$HC{\equiv}CH(g) + H_2(g) \xrightarrow[150\ ^\circ C]{\text{Nickel}} CH_2{=}CH_2(g)$$

Further hydrogenation gives alkanes.

$$CH_2{=}CH_2(g) + H_2(g) \xrightarrow[150\ ^\circ C]{\text{Nickel}} CH_3CH_3(g)$$

(c) *Reactions with hydrogen halides*: Alkynes react with hydrogen halides at room temperature. Ethyne reacts with hydrogen bromide in stages as follows:

Stage I

$$HC{\equiv}CH(g) + HBr(aq) \longrightarrow CH_2{=}CHBr(g)$$

Stage II

$$CH_2{=}CHBr(g) + HBr(aq) \longrightarrow CH_3{-}CHBr_2(g)$$

The overall equation is

$$HC{\equiv}CH(g) + 2HBr(aq) \longrightarrow CH_3{-}CHBr_2(g)$$

(d) *Reaction with oxygen*: Alkynes burn in air with a luminous smoky flame. The smoky flame is caused by incomplete combustion of alkynes due to high proportion of carbon compared to hydrogen in alkynes. Alkynes produce carbon monoxide as a result of incomplete combustion. This occurs when the reaction takes place in a limited supply of air. The following reactions take place when ethyne is burnt in air:

In sufficient supply of air:

$$2C_2H_2(g) + 5O_2(g) \longrightarrow 4CO_2(g) + 2H_2O(g)$$

In limited supply of air:

$$2C_2H_2(g) + 3O_2(g) \longrightarrow 4CO(g) + 2H_2O(g)$$

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Uses of alkynes

Alkynes have different uses including the following:

Making organic compounds: Some of these alkynes are used to make organic compounds such as ethanoic acid, acrylic acid, and ethanol.

Organic solvents: Alkynes, for instance ethyne, are used in the preparation of organic solvents.

Polymers: Vinyl chloride which is a product of the reaction between acetylene and hydrogen chloride is used as a monomer in manufacture of polyvinyl chloride (PVC).

Artificial ripening of fruits: Alkynes, for instance ethyne, are used as plants hormone for artificial ripening and preserving fruits.

Portable lighting: Acetylene, also called ethyne, was first used to light portable lamps, which were known as acetylene gas lamps. The lamps where installed in homes, bicycles and on cars.

Welding and cutting: Acetylene is used to join or cut materials that require high temperatures.

Polyethylene plastics: Ethylene is derived from acetylene, which helps in the production of the polyethylene plastics.

Chemical production: Acetylene is also used in the production of several inorganic compounds that are used in the synthesis of vitamins like vitamin A and E.

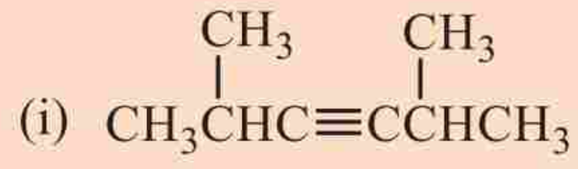
Manufacturing products in industries: Acetylene is useful in the manufacture of several other products in industries because of its ability to undergo several chemical reactions.

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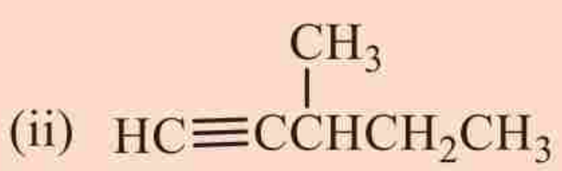
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Exercise 2.4

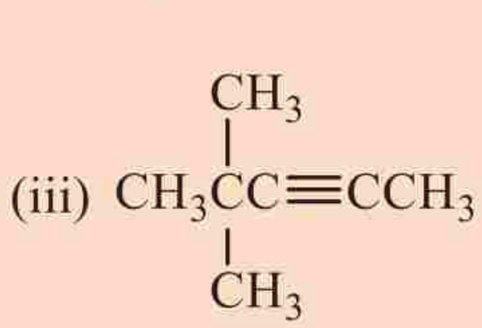
1. (a) Provide the IUPAC names of the following compounds:



(i) $CH_3CHC{\equiv}CCHCH_3$ (with CH_3 on each C)



(ii) $HC{\equiv}CCHCH_2CH_3$ (with CH_3 on the second C)



(iii) $CH_3CC{\equiv}CCH_3$ (with CH_3 on each C)

(b) Write the structures of the following alkynes:
   (i) 2,2-dimethyl-3-hexyne
   (ii) 3-bromo-1-chloro-4-methylpent-1-yne
   (iii) 4-methylpent-2-yne

2. Suggest two ways in which alkynes are applied in our daily life.

3. (a) Draw two possible isomers of the alkyne C_4H_6.
   (b) What type of isomerism is portrayed by the isomers in 3(a)?

Task 2.1

By applying some physical and chemical properties of compounds, collect the items from your local environment that are

(i) organic in nature.

(ii) inorganic in nature.

(iii) both organic and inorganic in nature.

Give reasons to support your classification.

Project 2.1

Design a simple biogas digester using locally available materials such as plastic bucket, bicycle tyre tube, plastic bottles, waste materials, and any other materials around your area. Evaluate the variations in the gas yields upon changing of the waste materials used.

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Alcohols

Alcohols are organic compounds which contain one or more hydroxyl (–OH) functional group(s) attached to a carbon atom. The systematic name for alcohols is *alkanols* because their names are derived from the corresponding alkanes. The carbon to which the hydroxyl group is attached can be single or part of a long chain of carbon atoms. Alcohols are named by taking the name of the alkane with the same number of carbon atoms and changing the ending (suffix) from –ane to *–anol*.

General formulae

Alcohols are represented by the general formula R−OH, where R is the alkyl group. The alkyl group can be represented with a general formula similar to that of an alkane but with less by one hydrogen atom. Thus, they form a homologous series characterised by the general formula $C_nH_{2n+1}OH$.

Molecular formula

The first member of the homologous series is methanol, which has the molecular formula CH_3OH. The second member is ethanol with the molecular formula C_2H_5OH. Table 2.14 shows the molecular formulae of the first five members of the homologous series of alcohols.

Table 2.14: *Molecular formulae of some alcohols*

Name	Molecular formula
Methanol	CH_3OH
Ethanol	C_2H_5OH
Propan-1-ol	C_3H_7OH
Butan-1-ol	C_4H_9OH
Pentan-1-ol	$C_5H_{11}OH$

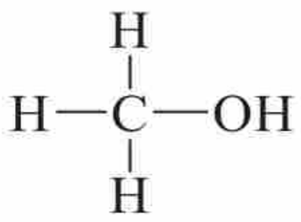
Structural formulae

Figure 2.23 shows the structural formulae of some alcohols. The condensed structural formula of butanol ($CH_3CH_2CH_2CH_2OH$) can be simplified further to $CH_3(CH_2)_3OH$.

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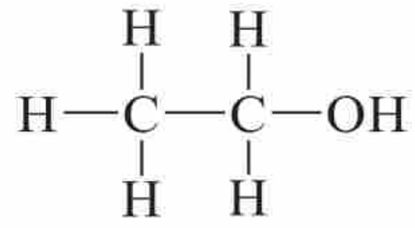
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(a) Methanol



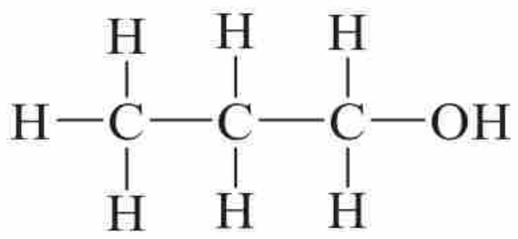
CH_3OH

(b) Ethanol



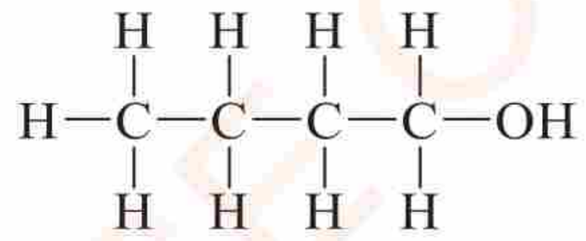
CH_3CH_2OH

(c) Propan-1-ol



$CH_3CH_2CH_2OH$

(d) Butan-1-ol



$CH_3CH_2CH_2CH_2OH$

Figure 2.23: *Structural formulae of the first four alcohols*

Naming of alcohols

Alcohols are named by replacing the '-e' ending of the parent alkane compounds by '*-ol*'; for example, ethane becomes ethanol. The rules that are used in naming hydrocarbons also apply to alcohols. The rules for naming alcohols include the following.

1. The longest continuous carbon chain that has the −OH group is taken to be the parent chain.
2. When assigning numbers to substituents, the parent chain is numbered in such a way that the carbon atom having the −OH functional group is assigned the least possible number.
3. Indicate the position of –OH and other substituents by numbers. For example,

$CH_3CH_2CH(OH)CH_2Br$ — 1-bromobutan-2-ol

$CH_3CH(CH_3)CH_2OH$ — 2-methylpropan-1-ol

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The parent carbon chain in 1-bromobutan-2-ol is numbered from right to left, so the –OH functional group is attached to carbon number 2 and bromine on carbon number 1. Numbering the parent chain from the left would have the –OH functional group attached to carbon number 3, and bromine on carbon number 4. Since the parent carbon chain has four carbon atoms, the name of the alcohol is 1-bromobutan-2-ol. The names of some alcohols are presented in Table 2.15.

Table 2.15: *The first five members of alcohols*

Structural formula	**Name**
CH_3OH	Methanol
CH_3CH_2OH	Ethanol
$CH_3CH_2CH_2OH$	Propan-1-ol
$CH_3CH_2CH_2CH_2OH$	Butan-1-ol
$CH_3CH_2CH_2CH_2CH_2OH$	Pentan-1-ol

Isomerism in alcohols

Like in alkenes, alcohols form positional isomers by changing the positions of the –OH functional groups. As the number of carbon atoms increases, the number of possible isomers of the alcohols also increases. The first two alcohols, that is, methanol (CH_3OH) and ethanol (CH_3CH_2OH), have no isomers. Propanol (C_3H_7OH) and butanol (C_4H_9OH) have two and four isomers, respectively. Pentanol has eight isomers. Table 2.16 shows the isomers of propanol and butanol.

Table 2.16: *Some alcohols and their isomers*

Molecular formula	**Isomers**	**Names of isomers**
C_3H_7OH (Propanol)	$CH_3CH_2CH_2OH$	Propan-1-ol or 1-propanol
	$CH_3\underset{\displaystyle OH}{\underset{\vert}{C}}HCH_3$	Propan-2-ol or 2-propanol

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Molecular formula	Isomers	Names of isomers
C_4H_9OH (Butanol)	$CH_3CH_2CH_2CH_2OH$	Butan-1-ol or 1-butanol
	$CH_3CH_2\underset{\displaystyle OH}{\underset{\vert}{C}}HCH_3$	Butan-2-ol or 2-butanol
	CH_3CHCH_2OH $\vert$ CH_3	2-methylpropan-1-ol 2-methyl-1-propanol
	$CH_3\underset{\displaystyle CH_3}{\underset{\vert}{C}}CH_3$ $\vert$ OH	2-methylpropan-2-ol 2-methyl-2-propanol

Classification of alcohols

Alcohols are classified into three main groups depending on the position of the hydroxyl (–OH) group in the main carbon chain. These are *primary*, *secondary* and *tertiary* alcohols. In primary alcohols, the carbon atom carrying the –OH group is bonded with at least two hydrogen atoms and sometimes one alkyl group. Figure 2.24 shows some examples of primary alcohols.

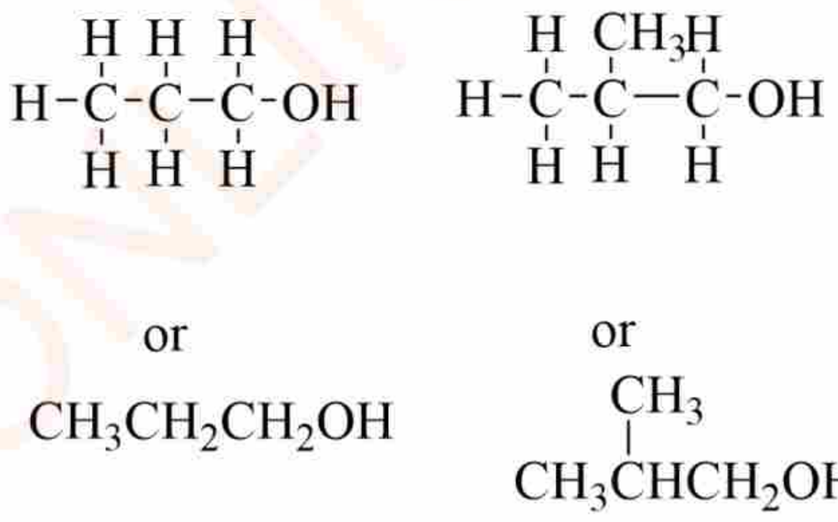


Figure 2.24: *Some primary alcohols*

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In secondary alcohols, the carbon atom carrying the –OH group is attached to two other carbon atoms and one alkyl group as shown in Figure 2.25.



Figure 2.25: *Examples of secondary alcohols*

In tertiary alcohols, the carbon atom carrying the –OH group is attached to three other carbon atoms. Figure 2.26 shows some examples of tertiary alcohols.

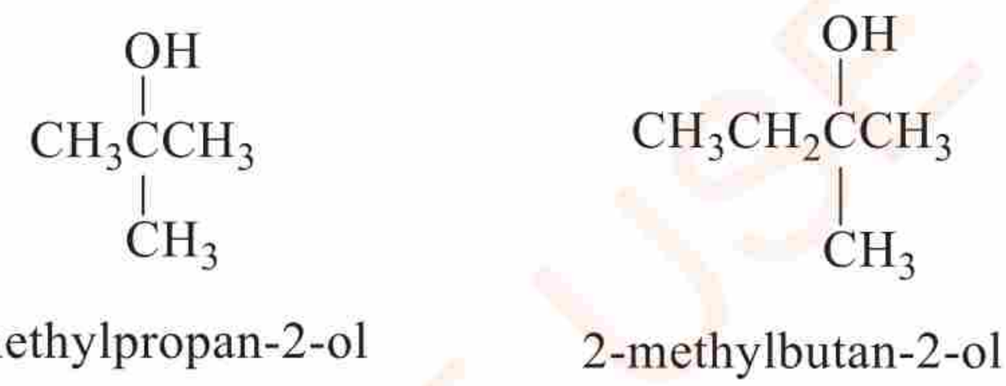


Figure 2.26: *Examples of tertiary alcohols*

Preparation of ethanol

(a) *Hydrolysis of alkenes*: Ethanol is obtained by the hydrolysis of ethene in the presence of concentrated sulphuric acid as a catalyst.

$$CH_2{=}CH_2 + H_2O(l) \xrightarrow{H_2SO_4} CH_3CH_2OH(aq)$$

(b) *Fermentation of carbohydrates*: Ethanol is produced through fermentation of carbohydrates. Fermentation is the slow decomposition of complex organic molecules into simpler organic compounds by the action of enzymes of certain organisms such as bacteria, yeasts, moulds, and fungi. The action of yeast on the raw materials such as sucrose leads to the formation of expanded and spongy mixture. At the optimum temperature of 37 °C, the organisms produce enzymes that ferment the sucrose. The following reactions take place during fermentation of sucrose:

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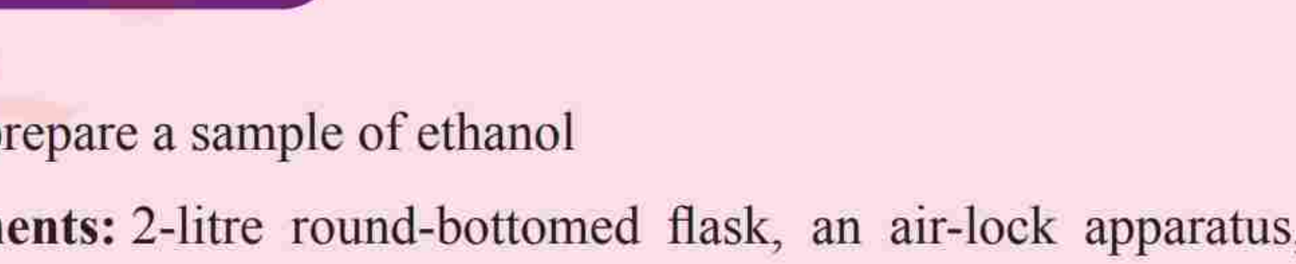
(i) The sucrose is converted to glucose and fructose:

$$\underset{\text{Sucrose}}{C_{12}H_{22}O_{11}(s)} + H_2O(l) \xrightarrow{\text{Yeast}} \underset{\text{Glucose}}{C_6H_{12}O_6(aq)} + \underset{\text{Fructose}}{C_6H_{12}O_6(aq)}$$

(ii) The glucose and fructose produced are then converted to ethanol and carbon dioxide.

$$C_6H_{12}O_6(aq) + C_6H_{12}O_6(aq) \xrightarrow{\text{Yeast}} 4C_2H_5OH(aq) + 4CO_2(g)$$

Note that: fructose is an isomer of glucose. The two compounds therefore have the same molecular formula. The differences between them is shown by the open structures in Figure 2.27.



Glucose Fructose

Figure 2.27: *Open structures of glucose and fructose*



Activity 2.8

Aim: To prepare a sample of ethanol

Requirements: 2-litre round-bottomed flask, an air-lock apparatus, 250-cm^3 measuring cylinder, pieces of porcelain, stopper, thermometer (ranging from –10 °C to 110 °C), analytical balance, condenser, 1-litre beaker, retort stand, clamp, Bunsen burner, sucrose, yeast, water and limewater.

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Procedure

1. Dissolve 50 g of sucrose in 500 cm^3 water at 30 °C in the reagent bottle.
2. Add about 10 g of dry yeast and stir well. Set up the air-lock apparatus containing limewater as shown in Figure 2.28.

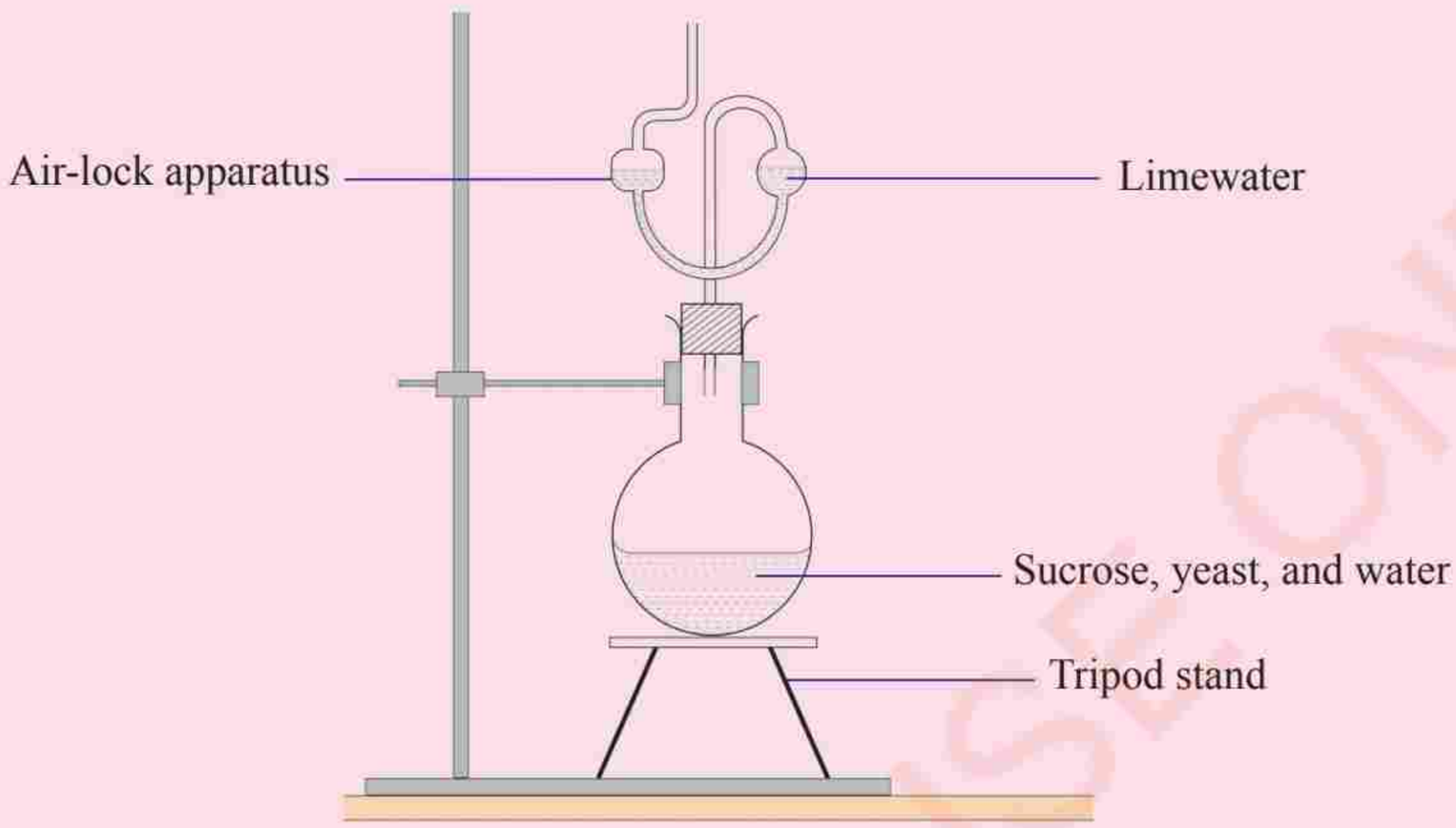


Figure 2.28: *Set-up for the fermentation of sucrose*

3. Leave the mixture in a warm place for three to seven days and then filter it into another round-bottomed flask containing the pieces of porcelain.
4. Distill the filtrate as shown in Figure 2.29 at a temperature between 75 °C and 85 °C.

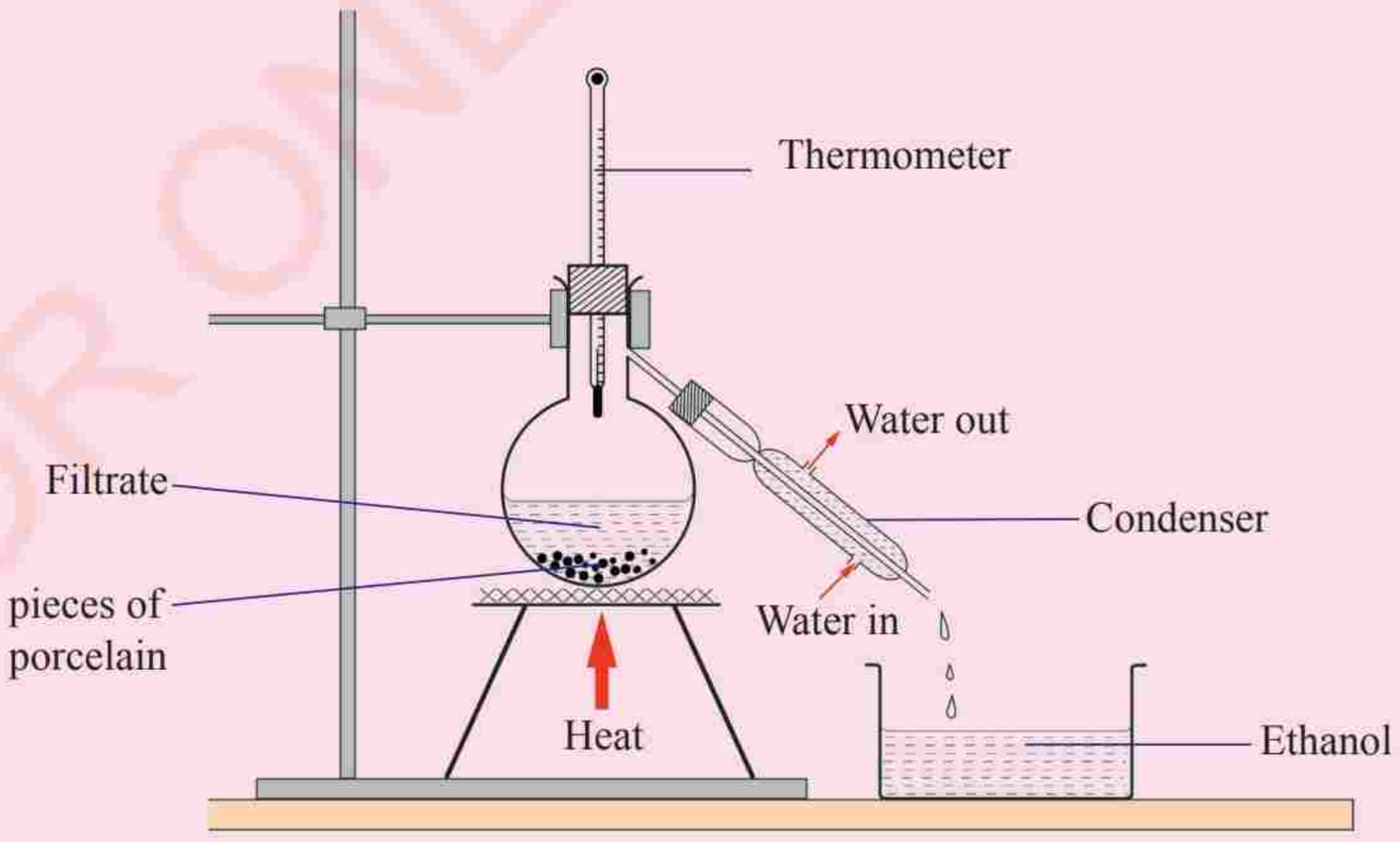


Figure 2.29: *Set-up for the distillation of filtrate into alcohol*

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Questions

1. What was the appearance of the mixture during the fermentation process?
2. Which gas evolved during the fermentation process?
3. What was the role of the pieces of porcelain in the reaction?
4. What was the role of yeast in the reaction?
5. Write an equation for the fermentation of glucose.
6. What was the role of limewater in the air-lock apparatus?

Properties of alcohol

The following are some of the physical and chemical properties of alcohol:

Physical properties

(a) *Physical states*: Lower alcohols (C1 to C4) are colourless liquids at room temperature, while higher alcohols (C5 to C10) are viscous or oily substances.

(b) *Boiling points*: Alcohols have higher boiling points than alkanes of similar molar masses because the OH group allows alcohol molecules to interact through hydrogen bonding. Their corresponding alkane molecules cannot engage in hydrogen bonding, and therefore have lower boiling points. Table 2.17 shows the boiling points of some alkanes and alkanols or alcohols.

(c) *Solubility*: Lower alcohols (C1 to C3 atoms) are miscible with water because they can form hydrogen bonding with water molecules.

(d) *Density*: The density of alcohol increases with an increase in the length of carbon chains. Lower alcohols (methanol, ethanol and propanol) have low densities.

Table 2.17: *Molar masses and the boiling points of some alkanes and alcohols*

Formula	Name	Class	Molar Mass	Boiling Point (°C)
CH_4	Methane	Alkane	16	–162
C_2H_6	Ethane	Alkane	30	–89
C_3H_8	Propane	Alkane	44	–42
C_4H_{10}	Butane	Alkane	58	–1
CH_3OH	Methanol	Alcohol	32	65
CH_3CH_2OH	Ethanol	Alcohol	46	78
C_3H_7OH	Propanol	Alcohol	60	97

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Chemical properties

The chemical reactions of alcohols are due to the presence of –OH functional group and include the following:

(a) *Combustion of alcohols*: Alcohols burn in air to give carbon dioxide and water. Ethanol is highly flammable and therefore ignites readily when lit. It burns in air with a blue flame to give carbon dioxide and water vapour.

$$CH_3CH_2OH(aq) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(g)$$

(b) *Oxidation of alcohols*: Acidified potassium dichromate oxidises primary alcohols to carboxylic acids. The oxidation takes place in two stages. The alcohols are first partially oxidised to a group of compounds known as *aldehydes*. For example, ethanol is first oxidised to ethanal, which is an aldehyde. Aldehydes are named by replacing the –ol in the alcohol with *–al*.

$$\underset{\text{Ethanol}}{CH_3CH_2OH(aq)} + [O] \longrightarrow \underset{\text{Ethanal}}{CH_3CHO(aq)} + H_2O(l)$$

The aldehydes are then oxidised to carboxylic acids.

$$\underset{\text{Ethanal}}{CH_3CHO(aq)} + [O] \longrightarrow \underset{\text{Ethanoic acid}}{CH_3COOH(aq)} + H_2O(l)$$

The overall equation for the complete oxidation is:

$$\underset{\text{Ethanal}}{CH_3CHO(aq)} + [O] \longrightarrow \underset{\text{Ethanoic acid}}{CH_3COOH(aq)} + H_2O(l)$$

The [O] represents the oxygen from the oxidising agent such as potassium dichromate or potassium permanganate.

(c) *Reaction with sodium metal*: Sodium reacts with ethanol to give sodium ethoxide and hydrogen gas.

$$2Na(s) + 2C_2H_5OH(aq) \longrightarrow 2C_2H_5ONa(aq) + H_2(g)$$

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(d) *Reaction with concentrated sulphuric acid*: When ethanol is treated with concentrated sulphuric acid followed by heating at a temperature between 160 °C and 180 °C, it dehydrates to give ethene.

$$C_2H_5OH(aq) \xrightarrow[170\ °C]{H_2SO_4} CH_2{=}CH_2(g) + H_2O(l)$$

This is a dehydration process because concentrated sulphuric acid removes water molecules from ethanol.

(e) *Reaction with carboxylic acids*: Alcohols react with carboxylic acids in the presence of a catalyst, usually concentrated sulphuric acid to form sweet-smelling compounds known as esters. For example, ethanol reacts with ethanoic acid to form an ester called ethyl ethanoate.

$$\underset{\text{Ethanol}}{CH_3CH_2OH(l)} + \underset{\text{Ethanoic acid}}{CH_3COOH(l)} \xrightarrow{\text{concentrated } H_2SO_4} \underset{\text{Ethyl ethanoate}}{CH_3COOCH_2CH_3(l)} + H_2O(l)$$

The first part of the name of an ester is derived by replacing the –ol in alcohol with *–yl*. The second part is derived by replacing the –oic in the carboxylic acid with *–oate*. The reaction of carboxylic acid with alcohol to form an ester and water is known as *esterification*.

Uses of alcohols

Alcohols have a variety of uses including the following:

Alcoholic drinks: Ethanol is used as an active ingredient in alcoholic drinks such as beers, spirits, and local brews.

Production of methylated spirits: Ethanol is usually sold as methylated spirits, where a small amount of methanol is added to make it unpalatable for human consumption. It is used as a disinfectant.

Use of methanol and ethanol as fuel: Ethanol burns to produce carbon dioxide and water, and can be used as a fuel. Methanol and ethanol can be blended with petrol to improve combustion in internal engines.

Alcohols as solvents: Ethanol and other alcohols are widely used as solvents. Ethanol is used to dissolve many organic compounds that are insoluble in water, and therefore can be applied in many perfumes and cosmetics production. It is used as an antifreeze for automotive radiators and screen wash.

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Methanol as an industrial feedstock (raw material): Methanol is converted to methanal (formaldehyde) which is largely used to make plastics, paints, explosives, textiles, and cosmetics. Butanol is used in ester (butyl ethanoate) formation for the synthesis of fruit flavouring in food and confectionary industries. Methanol is also used to synthesize gasoline (petrol).

Harmful effects of alcohols

The alcohols that are usually taken as drinks contain ethanol. The characteristic smell of the alcohols is actually that of ethanol. Excessive consumption of alcohol leads to *addiction*. Addiction is a situation where a person is unable to stop using a substance or engaging in certain behaviour. A person who is addicted to alcohol cannot stay for a long time without drinking it. A person who is addicted to alcohol is known as an *alcoholic*. Addiction to the consumption of alcoholic drink is called *alcoholism*. Alcoholism is the most severe form of alcohol abuse and involves the inability to manage drinking habits. The following are some of the negative effects of alcoholism:

Societal problems associated with alcoholism

(a) Neglecting families and other relationships: The neglected families suffer financial difficulties which could lead to lack of basic needs. Children from neglected families can also get involved in criminal activities.

(b) Violence and crimes: Alcoholics are sometimes violent and may cause injuries to other people. This can also lead to domestic violence and increase in social crimes such as rape.

Health effects associated with alcoholism

Excessive drinking of alcohol can cause many health problems which include the following:

(a) Damage of the liver: Alcohol is a dehydrating agent which causes the liver to change to a scar-like tissue and then shrink. Under severe conditions, cancer of the liver (hepatoma) may develop.

(b) Damages of brain cells.

(c) Moderate and excessive consumption of methanol affects the optic nerves

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and may lead to blindness and even death.

(d) Damage to the heart due to destruction of heart muscles.

(e) Anaemia development.

(f) Interference with the production of testosterone hormones and may lead to impotence.

(g) Defects in the unborn babies. Pregnant women should avoid excessive drinking of alcohol during pregnancy since it can interfere with foetus development.

(h) Alcohol is a diuretic, that is, it promotes water loss through urine by inhibiting production of antidiuretic hormone (ADH).

Task 2.2

Arrange a visit to a nearby sober house or health care facility in your area and carefully study the health effects associated with excessive drinking of alcohol. On your return, conduct a plenary presentation of what you observed.

Exercise 2.5

1. Which of the following statements is true about alcohols?
   (a) They readily undergo oxidation reactions.
   (b) Methanol is the only non-poisonous alcohol.
   (c) Alcohols with high molecular masses are solids at room temperature.
   (d) They are stronger acids than water.

2. When carbohydrates are mixed with water and kept for a few days, they undergo fermentation. Explain the chemical processes associated with such fermentation.

3. Write the structures and name all the isomeric compounds of the alkanol having the molecular formula C_4H_9OH.

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Carboxylic acids

A carboxylic acid is an organic acid that contains a carboxyl group attached to an alkyl group. It is derived by replacing one hydrogen atom of the alkanes with a *carboxyl group* (–COOH). Thus, the functional group in these compounds is the carboxyl group, –COOH, which has the structural formula shown in Figure 2.30. Carboxylic acids occur naturally but can also be manufactured. They do not fully dissociate to produce H^+. Due to their partial dissociation behaviour when dissolved in water, carboxylic acids are known to be weak acids.

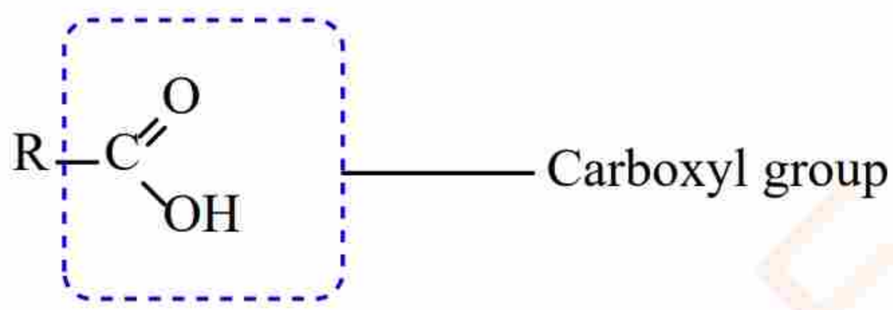


Figure 2.30: *Structure of carboxylic group*

Natural sources of carboxylic acids

The following are some natural sources of carboxylic acids:

(a) Methanoic (formic) acid is found in bees and ants. They use it as a defence against enemies. The acid also found in the stinging nettle plant.

(b) Ethanoic (acetic) acid is found in fermenting fruits.

(c) Octadecanoic (stearic) acid is found in many natural fats and oils.

(d) 2-hydroxypropanoic (lactic) acid is found in sour milk and in animal muscles.

(e) 2-hydroxypropan-1,2,3-tricarboxylic (citric) acid is found in citrus fruits such as lemons, oranges and limes. It is responsible for the characteristic sharp taste in these fruits.

(f) Ascorbic acid (vitamin C) is found in citrus fruits (Figure 2.31).

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Figure 2.31: *Some natural sources of vitamin C*

General formula

Carboxylic acids form a homologous series with the carboxyl group (–COOH) attached to the hydrocarbon chain. The acids share the same general formula $C_nH_{2n+1}COOH$, except the first member (HCOOH).

Note: Methanoic acid is the carboxylic acid with one carbon atom. A hydrogen atom is attached to the functional group (−COOH) in the place of the alkyl group as it is the case in the other members of the series.

Molecular formulae

The first member of the carboxylic acids homologous series is methanoic acid, which has the molecular formula of CH_2O_2. The molecular and structural formulae of the first five members of the homologous series are shown in Table 2.18.

Table 2.18: *First five members of homologous series of carboxylic acids*

Name	Molecular formula
Methanoic acid	CH_2O_2 or HCOOH
Ethanoic acid	$C_2H_4O_2$ or CH_3COOH
Propanoic acid	$C_3H_6O_2$ or C_2H_5COOH
Butanoic acid	$C_4H_8O_2$ or C_3H_7COOH
Pentanoic acid	$C_5H_{10}O_2$ or C_4H_9COOH

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Structural formulae

The structural formulae of carboxylic acids are written in the same way as that of alkanes. Figure 2.32 shows the structural formulae of the first four carboxylic acids.

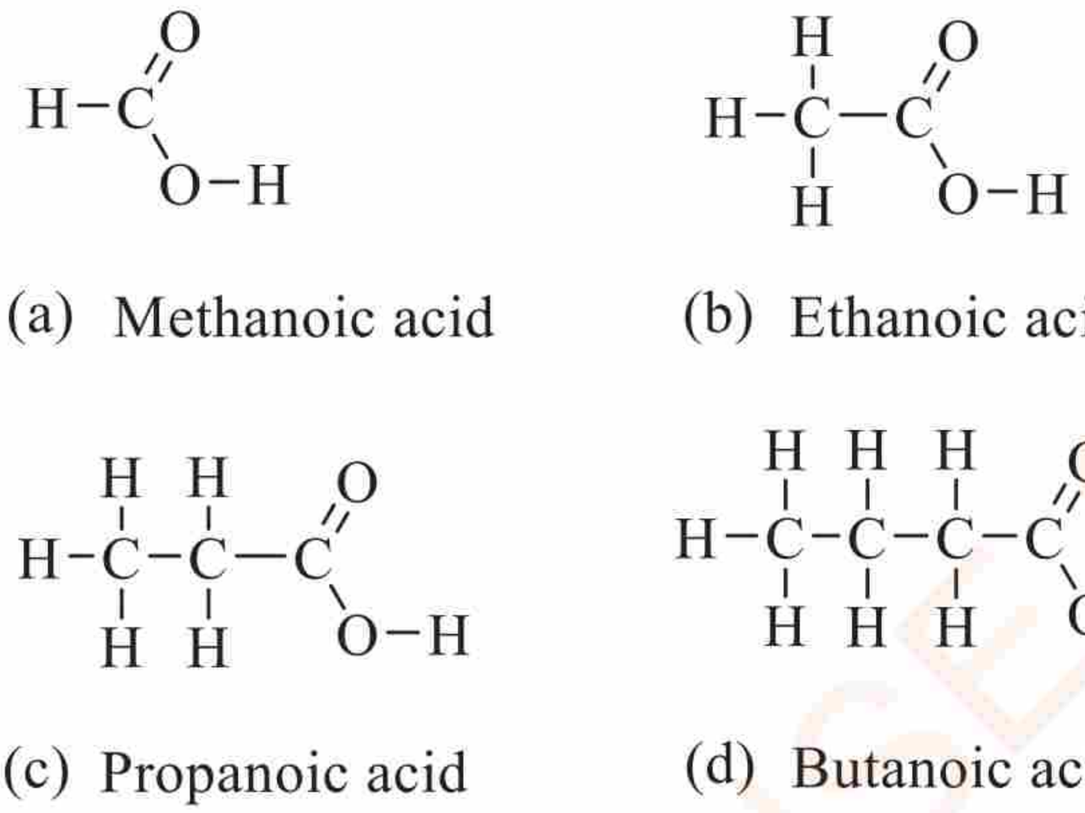


Figure 2.32: *Structural formulae of the first four carboxylic acids*

Naming of carboxylic acids

Carboxylic acids are named by replacing the suffix –e in the corresponding alkane with *–oic*. Unlike in alcohols, the functional group in carboxylic acids can only be at the end of the carbon chain, and therefore the position of the carboxylic group is not indicated in the name. The names of the first five carboxylic acids are shown in Table 2.19. The use of common name is discouraged as they do not aid in the drawing of structural formulae.

Table 2.19: *Naming of carboxylic acids*

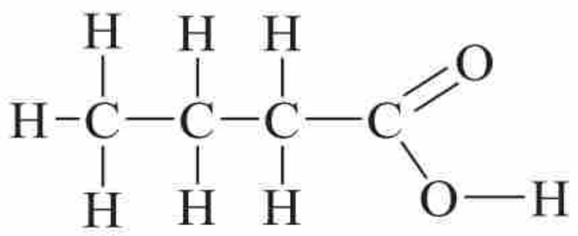
Common name	IUPAC name
Formic acid	Methanoic acid
Acetic acid	Ethanoic acid
Propionic acid	Propanoic acid
Butyric acid	Butanoic acid
Valeric acid	Pentanoic acid

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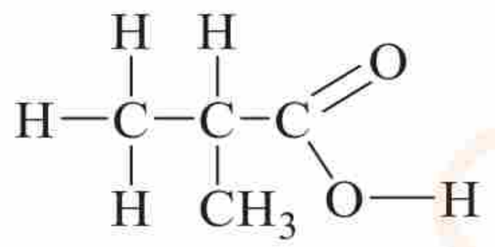
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Isomerism of carboxylic acids

Like many other organic compounds, carboxylic acids also have isomers. In naming the isomers, the carbon atom in the functional group (–COOH) is given the first position. The substituents are given locants, in reference to the carbon atom with carboxylic group. The first three carboxylic acids (methanoic acid, ethanoic acid, and propanoic acid) have no isomers. Butanoic and pentanoic acids have two and four isomers, respectively. These isomers are shown in Figures 2.33 and 2.34.

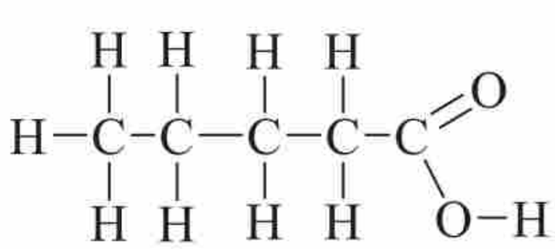


Butanoic acid

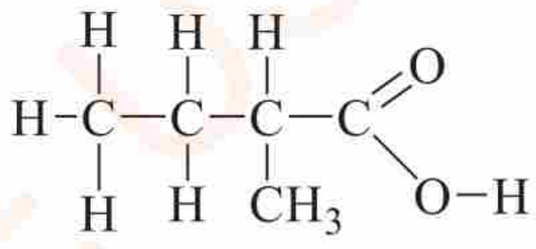


2-methylpropanoic acid

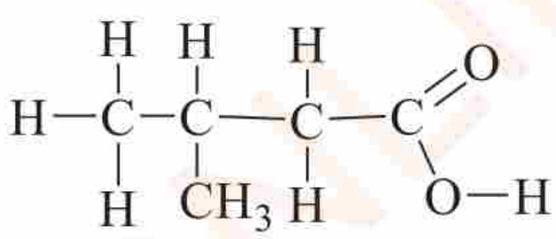
Figure 2.33: *Isomers of butanoic acid*



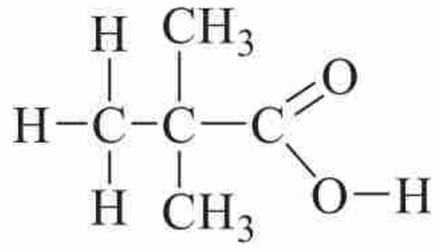
Pentanoic acid



2-methylbutanoic acid



3-methylbutanoic acid



2,2-dimethylpropanoic acid

Figure 2.34: *Isomers of pentanoic acid*

Properties of carboxylic acids

Some of the physical and chemical properties of carboxylic acids are as follows:

Physical properties

(a) *Physical state:* The first four members of the homologous series are liquids.

(b) *Smell:* Methanoic, ethanoic and propanoic acids have sharp smell similar to that of vinegar. Carboxylic acids with four or more carbon atoms have unpleasant smells. An example is butanoic acid found in human sweat.

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(c) *Solubility*: Carboxylic acids are soluble in less polar organic solvents such as alcohols, ether, and benzene. They exist as *dimers* in aprotic solvents (solvents that do not have O-H or N-H bonds). Dimers are pairs of molecules bridged by hydrogen bonding. The hydrogen bonds are so strong that they do not break even in the vapour phase. Figure 2.35 shows the structure of carboxylic acid dimer.

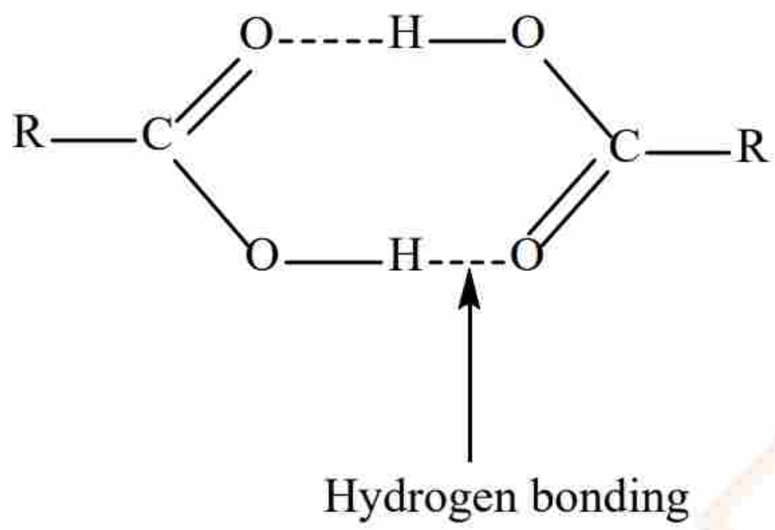


Figure 2.35: *Hydrogen bonding between carboxylic acid molecules*

Carboxylic acids of lower molecular mass dissolve completely in water. The dimers associate to form a single molecules which form hydrogen bonds with water molecules (Figure 2.36).

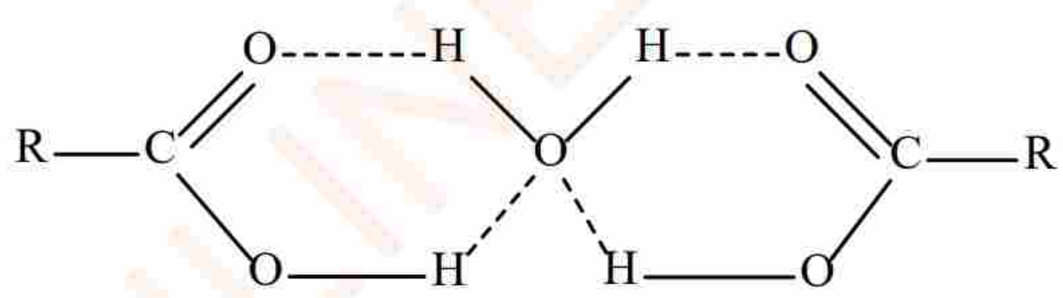


Figure 2.36: *Hydrogen bonding between a carboxylic acid and water*

(d) *Boiling and melting points*: Carboxylic acids have higher melting and boiling points compared to their corresponding alcohols. The boiling points of carboxylic acids increase with increase in their molecular masses. The differences in boiling points can be explained in terms of dimers. The dimers have double the mass of the individual molecules. Therefore, they require more energy to vaporise, hence carboxylic acids have higher boiling points than their corresponding alcohols. Anhydrous ethanoic acid freezes at 17 °C, which is also its melting point. When pure acetic acid melts, it forms a glacier, thus it is often called glacial acetic acid. This is because solid ethanoic acid resembles ice. Table 2.20 shows the boiling points of the first three carboxylic acids.

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Table 2.20: *Boiling and melting points of the first three carboxylic acids*

Carboxylic acid	Boiling point (°C)	Melting point (°C)
Methanoic acid	101	8
Ethanoic acid	118	17
Propanoic acid	141	–21

Chemical properties

(a) *Acidic nature*: Carboxylic acids are generally weak acids as they partially dissociate in water to produce carboxylate ions ($RCOO^-$) that can react with metals to produce useful salts such as soaps. They turn blue litmus paper red and their pH values are above 4.

$$R-COOH(aq) \rightleftharpoons H^+(aq) + R-COO^-(aq)$$

(b) *Reactions with sodium hydroxide and carbonates*: Carboxylic acids react with sodium hydroxide in a neutralisation reaction to form salt and water. Methanoic acid reacts with sodium hydroxide to form a salt, sodium methanoate (sodium formate), which is a deliquescent powder.

$$HCOOH(aq) + NaOH(aq) \longrightarrow HCOONa(s) + H_2O(l)$$

Carboxylic acids react with carbonates such as sodium carbonate, Na_2CO_3 to give salt, carbon dioxide, and water. For example, ethanoic acid reacts with sodium carbonate to give sodium ethanoate, carbon dioxide, and water.

$$CH_3COOH(aq) + Na_2CO_3(aq) \longrightarrow CH_3COONa(aq) + CO_2(g) + H_2O(l)$$

As the size of alkyl chain in these salts increases, the pH also increases, making its aqueous solution more basic. The colour of phenolphthalein normally turns pink on these salts. This is because the anion ($R\text{-}COO^-$) formed is hydrolysed to form a weak acid and hydroxyl ion indicating that the solution is basic.

$$R\text{-}COO^-(aq) + H_2O(l) \longrightarrow R\text{-}COOH(aq) + OH^-(aq)$$

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Activity 2.9

Aim: To investigate the reaction of ethanoic acid with sodium hydroxide

Requirements: Beaker, stirring rod, Bunsen burner, measuring cylinder, filter paper, universal indicator solution, pH colour chart, 1 M ethanoic acid, and 1 M sodium hydroxide solution

Procedure

1. Measure about 50 cm^3 of 1 M ethanoic acid and put it into a beaker.
2. Add about 50 cm^3 of 1 M sodium hydroxide solution and stir to mix.
3. Heat the mixture until all the water evaporates and collect the residue.
4. Dissolve a few crystals of the residue in 5 cm^3 of water and add 2 to 3 drops of the universal indicator solution. Read the pH of the solution on the pH colour chart.
5. Repeat step 4 using phenolphthalein indicator.

Questions

1. What was the colour of the salt formed when sodium hydroxide reacted with ethanoic acid?
2. Write an equation for the reaction between ethanoic acid and sodium hydroxide.
3. What was the pH of the salt solution formed? Explain.

Carboxylic acids can also react with sodium carbonate and sodium hydrogencarbonate to give salt, water, and carbon dioxide. The evolution of CO_2 gas differentiates the reactions of carboxylic acids with carbonates from the reactions of the acids with sodium hydroxide.

$$2CH_3CH_2COOH(aq) + Na_2CO_3(s) \longrightarrow 2CH_3CH_2COONa(aq) + H_2O(l) + CO_2(g)$$

$$CH_3CH_2COOH(aq) + NaHCO_3(s) \longrightarrow CH_3CH_2COONa(aq) + H_2O(l) + CO_2(g)$$

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Activity 2.10

Aim: To investigate the reaction between ethanoic acid and sodium carbonate, sodium hydroxide, and sodium hydrogencarbonate

Requirements: Test tube with a side arm, rubber bung with a hole to fit the test tube with side-arm, test tube, delivery tube, retort stand and clamp, spatula, small piece of rubber tubing, solid sodium carbonate, solid sodium hydrogencarbonate, sodium hydroxide solution, ethanoic acid, and limewater

Procedure

1. Put a spatulaful of sodium carbonate into a test tube with side-arm.
2. Fix a dropper containing ethanoic acid to a rubber bung.
3. Set the apparatus as shown in Figure 2.37.

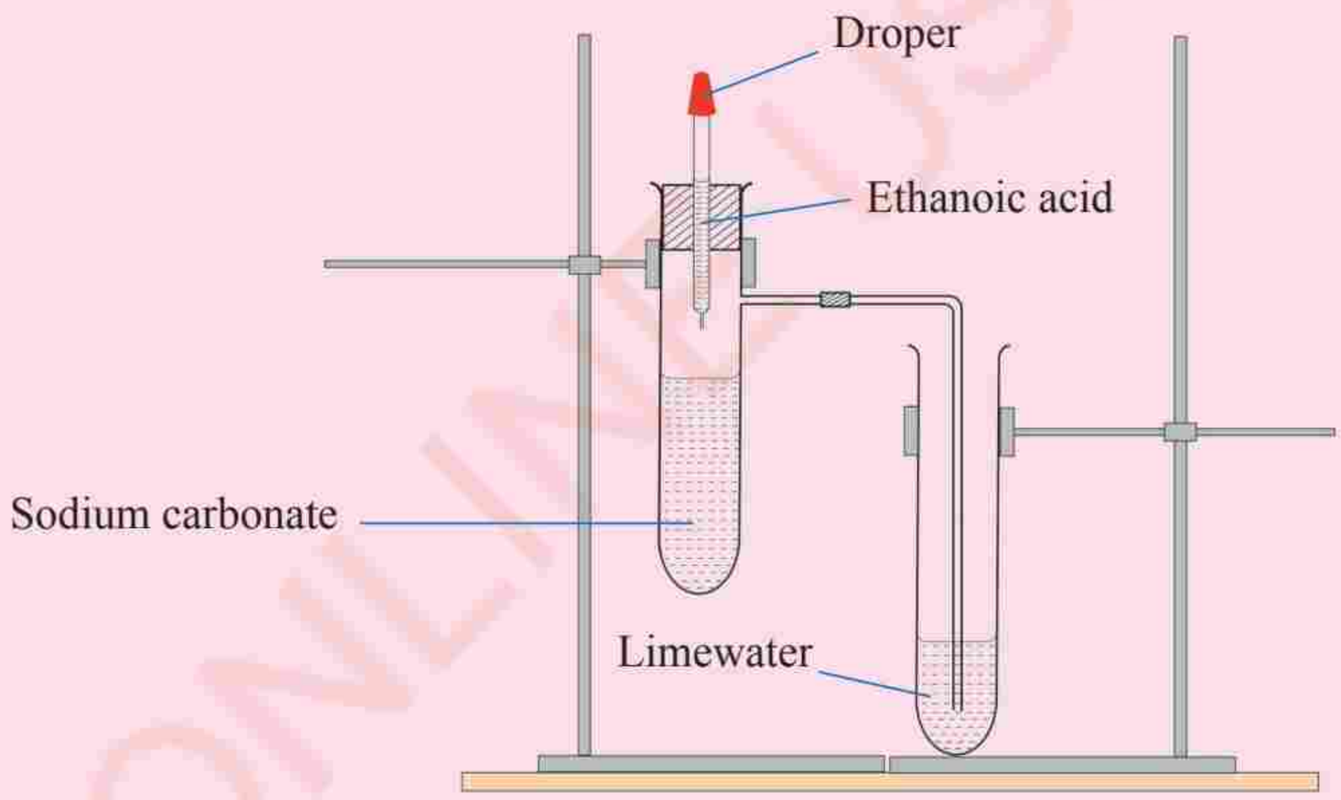


Figure 2.37: *Set-up for the reaction of ethanoic acid with carbonates*

4. Add ethanoic acid from the dropper to the sodium carbonate. Record the observations.
5. Repeat the procedure using sodium hydrogencarbonate, then sodium hydroxide in the place of sodium carbonate.

Questions

1. What was observed when ethanoic acid was added to sodium carbonate, sodium hydrogencarbonate, and sodium hydroxide?
2. What happened in the limewater when the acid reacted with bases?

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(c) *Reaction with alcohols*: Carboxylic acids react with alcohols in the presence of concentrated sulphuric acid to form esters. Esters are naturally found in various fruits and flowers.

$$CH_3COOH(aq) + CH_3CH_2OH(aq) \xrightarrow{\text{concentrated } H_2SO_4} CH_3COOCH_2CH_3(aq) + H_2O(l)$$

(d) *Oxidation of ethanol to ethanoic acid*: During fermentation, ethanol is formed. When the concentration of alcohol reaches above 14%, fermentation stops and the ethanol formed is oxidised to ethanoic acid.



Activity 2.11

Aim: To investigate acidity in soured milk and local brews

Requirements: Beakers, milk, local brews, and blue litmus paper

Procedure:

1. Pour milk and local brew into separate beakers.
2. Test the milk and local brew with a blue litmus paper.
3. Leave the beakers with the contents exposed to the air for one week.
4. Test with a blue litmus paper again.

Questions

1. Why were the contents exposed to air for one week?
2. What was the colour change of the litmus paper in step 4?

Preparation of soap from animal fats or vegetable oils

Soaps are sodium salts or potassium salts of long-chain carboxylic acids (fatty acids) such as octadecanoic acid (stearic acid), $C_{17}H_{35}COOH$. Soaps are prepared by a process called *saponification*. The vegetable oils such as coconut oil and palm oils are boiled with an alkali solution (NaOH or KOH) and break into carboxylic acids and alcohol. The acids formed are neutralised by an alkali to form either sodium or potassium salts which are ideally soaps. The produced soap cleans all types of materials including oily clothes in a way similar to that of commercial soaps. Based on the saponification value (amount of alkali required to saponify a specific amount of oil or fat), the recommended oils for soap-making include palm oil, castor oil, and coconut oil.

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Activity 2.12

Aim: To prepare soap from animal fats or vegetable oils

Requirements: 250-cm^3 beaker, 50-cm^3 measuring cylinder, glass rod, Bunsen burner, wash bottle, tripod stand, spatula, two test tubes, stopwatch or clock, tap water, filter paper, 4 M sodium hydroxide, brine, castor oil or kernel seeds oil, and distilled water

Procedure

1. Measure about 25 cm^3 of castor oil or kernel seeds oil and put into the 250-cm^3 beaker.
2. Add 100 cm^3 of 4 M sodium hydroxide solution.
3. Heat the mixture gently on a non-luminous flame for 30 minutes.
4. Allow the mixture to cool and then add brine. Stir the mixture continuously for five minutes. After adding brine, soap in the suspension gets precipitated out as solid.
5. Pour out the liquid part and wash the solid with some cold distilled water from a wash bottle.
6. Remove the solid and press it between filter papers to dry.
7. Place a sample of the solid (soap) in a test tube and shake with warm distilled water.
8. Repeat step 7 using warm tap water in the place of the warm distilled water.
9. Use a small piece of the solid (soap) to clean an oily piece of cloth. Record the observations.
10. Repeat all the steps using coconut oil.

Questions

1. What was observed when the solid (soap) was mixed with warm distilled water, and tap water?
2. What was observed on the oily piece of cloth after cleaning using the soap?
3. Why was it important to add brine?

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Uses of carboxylic acids

The following are some uses of carboxylic acids:

1. Long chain fatty acids such as palmitic acid and stearic acid are used to make soap.
2. They are used in making cosmetics, candles and protective coatings.
3. They are used in manufacturing of soft drinks and food products. For example, acetic acid is used in making vinegar, and sodium salt of organic acids are used as food preservatives.
4. In the pharmaceutical industry, organic acids such as acetic acid are used in making aspirin (an ester of salicylic acid).
5. Acetic acid is often used as a coagulant in the natural rubber production.
6. Organic acids find vast application in making dyestuff, perfumes, and rayon.

Exercise 2.6

1. Arrange the following compounds in order of increasing boiling point. Give reasons for your arrangement.
   (a) 1-pentanol (b) hexane (c) butanoic acid
   (d) ethanoic acid (e) propanol
2. Which member from each of the following pairs of compounds would be expected to have a higher solubility in water? Give a reason.
   (a) butanoic acid or propanoic acid
   (b) hexanoic acid or ethanoic acid
3. A 30 cm^3 of 20% NaOH was added to 20 cm^3 of castor oil in a beaker; the beaker suddenly became hot. What conclusion can be made from this reaction?
4. Describe the raw materials and processes used in the laboratory preparation of soap.
5. Justify that butanoic acid has two isomers whereas pentanoic acid has four isomers.

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Chapter summary

1. Organic chemistry is a branch of chemistry that involves the study of the structures, preparation, properties, and reactions of organic compounds.

2. Organic chemistry is important in the sustenance of life, and in the manufacture of various organic substances such as medicines, textiles, plastic products, fuels, pesticides, cosmetics, soaps, dyes, food additives and explosives.

3. The sources of organic compounds include prehistoric sources, organisms, and synthetic compounds.

4. Crude oil is made up of different organic compounds. The separation of crude oil into various groups of organic substances is done by the process called *fractional distillation*.

5. Hydrocarbons are organic compounds consisting of carbon and hydrogen atoms only. Hydrocarbons include alkanes, alkenes, and alkynes.

6. Alkanes are saturated hydrocarbons which have the general formula of C_nH_{2n+2}.

7. Alkyls are derived from alkanes by the loss of one hydrogen atom and they have the general formula of C_nH_{2n+1}.

8. Alkenes are unsaturated hydrocarbons with at least one carbon-carbon double bond in the main carbon chain. They have the general formula of C_nH_{2n}.

9. Alkynes are unsaturated hydrocarbons with at least one carbon-carbon triple bond in the main carbon chain. They have the general formula of C_nH_{2n-2}.

10. Alcohols are organic compounds whose molecules contain one or more –OH functional groups attached to saturated carbon atom(s). Alcohols have the general formula of $C_nH_{2n+1}OH$.

11. Carboxylic acids are organic compounds that contain a carboxyl group attached to an alkyl group. Carboxylic acids have the general formula of $C_nH_{2n+1}COOH$.

12. Soaps are sodium or potassium salts of long-chain carboxylic acids. Soaps are prepared by reacting alkalis such as potassium hydroxide or sodium hydroxide with natural fats or oils. The process of preparing soap is known as *saponification*.

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Revision exercise 2

Choose the correct answer in items 1-4.

1. Which of the following compounds is not a member of the homologous series of alkanes?

   (a) CH_4 (b) C_2H_4 (c) C_3H_8 (d) C_4H_{10}

2. Which one of the following is a general formula of an alkyl group?

   (a) C_nH_{2n} (b) C_nH_{2n-1}

   (c) C_nH_{2n+2} (d) C_nH_{2n+1}

3. A certain compound reacts with sodium to give hydrogen gas and it also reacts with acidified potassium dichromate to give a green solution. The compound is most likely to be

   (a) an alkene. (b) an alkane.

   (c) an alcohol. (d) a carboxylic acid.

4. Identify the general formula of alcohol among the following:

   (a) $C_nH_{2n}OH$ (b) $C_nH_{2n+2}OH$

   (c) $C_nH_{2n-1}OH$ (d) $C_nH_{2n+1}OH$

5. Draw the structure of the following alkenes:

   (a) 2-methylpent-2-ene (b) 2-methylpentene

   (c) 4-methylhex-1-ene (d) 3-ethylpent-1-ene

6. How does incomplete combustion of alkanes affect engine performance? Explain.

7. What are the advantages and disadvantages of organic compounds?

8. (a) Draw all possible isomers of the alcohols with the molecular formula $C_5H_{12}O$.

   (b) Why is methanol added into ethanol in the production of methylated spirit?

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9. Match each of the molecular formula of the organic compounds in Column A with the family names in Column B.

Column A	Column B
(a) C_5H_{12}	(i) Alkyl
(b) C_4H_6	(ii) Alkene
(c) C_9H_{19}	(iii) Alkyne
(d) C_8H_{16}	(iv) Alkane
(e) $C_7H_{14}O_2$	(v) Alcohol
(f) $C_{17}H_{36}O$	(vi) Aldehyde
	(vii) Carboxylic acid

10. From the structural formulae of the hydrocarbons $HCCCH_2CH_3$, $CH_3(CH_2)_2CH_3$, and $H_2CCHCH_2CH_3$:

(a) Which family does each of the compounds belong?

(b) Identify the compound that will decolourise bromine water in the:

(i) dark, and in the presence of UV light.

(ii) presence of UV light only.

(iii) dark only.

11. The compounds (a) to (c) are the three isomers of an organic compound Z.

(a) $CH_3(CH_2)_2C{\equiv}CH$ (b) $CH_3C{\equiv}CCH_2CH_3$

(c) $HC{\equiv}C\overset{\displaystyle CH_3}{\overset{|}{C}}HCH_3$

(i) Give the molecular formula of the compound Z.

(ii) Give the IUPAC name of each isomer.

(iii) With the aid of chemical equation, show how many moles of hydrogen molecules will be needed for complete unsaturation of 'Z'.

12. How can combustion be used to differentiate between ethyne and ethane?

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13. (a) Write an equation for the reaction between ethanol and butanoic acid.

(b) Give the IUPAC name of the major product formed in (a).

(c) Write an equation for the reaction between ethanoic acid and ethanol.

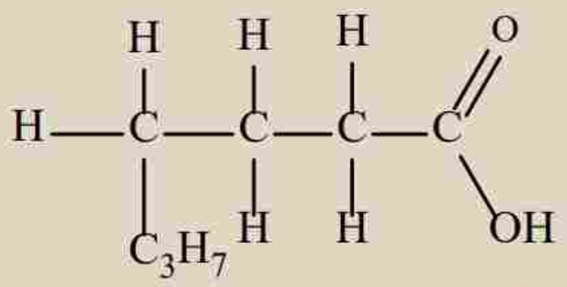
(d) Give the name of the major product formed in (c).

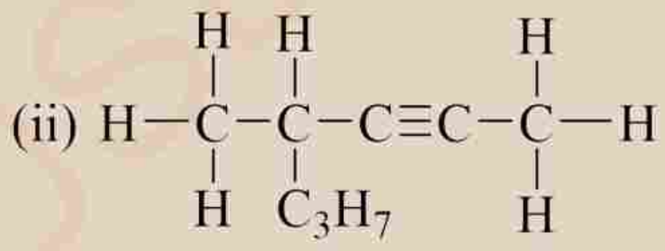
(e) What name is given to reactions in (a) and (c)?

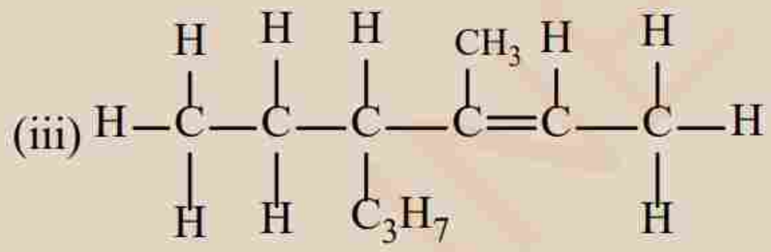
14. (a) Explain the importance of organic compounds.

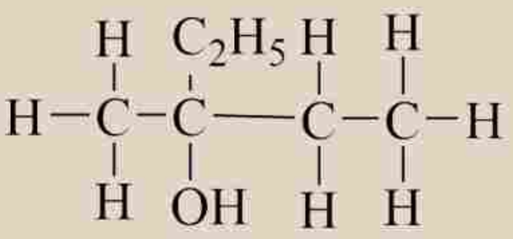
(b) Explain any two sources of organic compounds.

(c) Name each of the following compounds and state the family to which each belongs.

(i) 

(ii) 

(iii) 

(iv) 

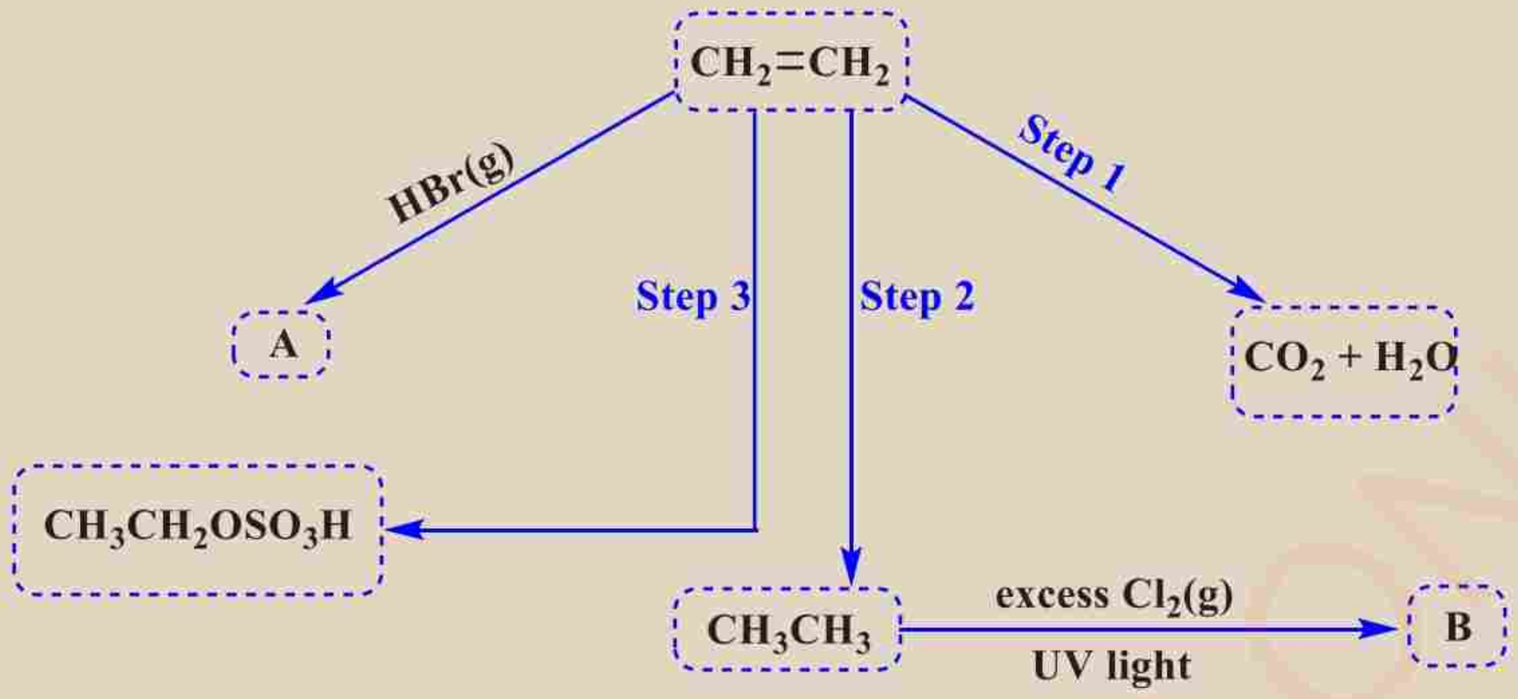
(d) Explain the trend in boiling points shown by alkenes.

(e) Write an equation to show the reaction of ethene with hydrogen chloride gas and name the products formed.

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15. The scheme below shows the different reactions of ethene. Study it and answer the questions that follow.



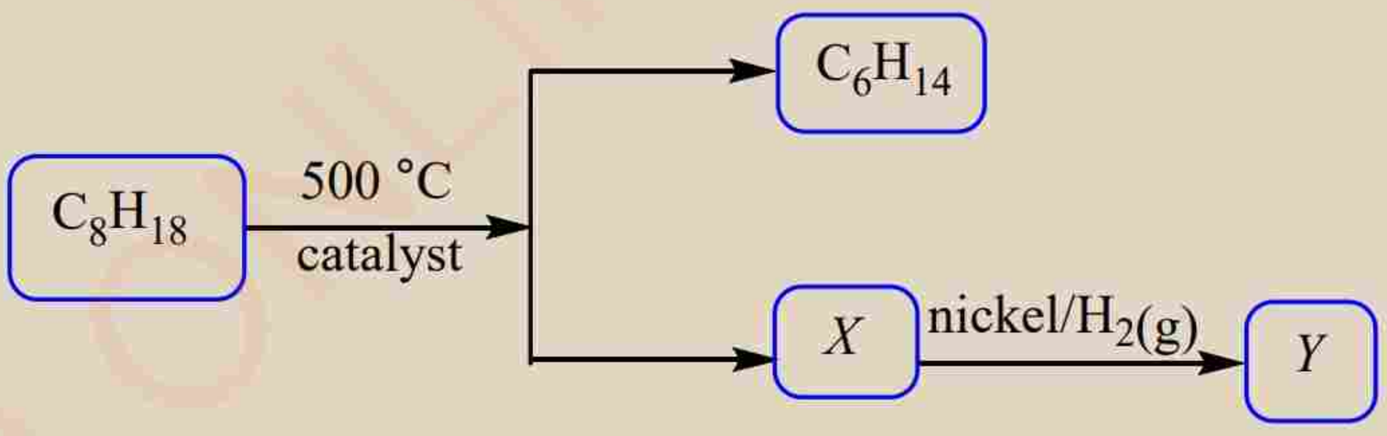
(a) Give the reagents and types of reactions in steps 1 and 3.

(b) Give the reagent and condition for step 2.

(c) Suggest the type of reaction that produces compound B.

(d) What IUPAC name is given to products A and B?

16. Study the following diagram and answer the questions that follow.



(a) Write the molecular formula and the IUPAC name of compound X.

(b) Write the reaction that is used to produce C_6H_{14} and X.

(c) How are the compounds X and Y differentiated chemically?

(d) Give the IUPAC name of compound Y.

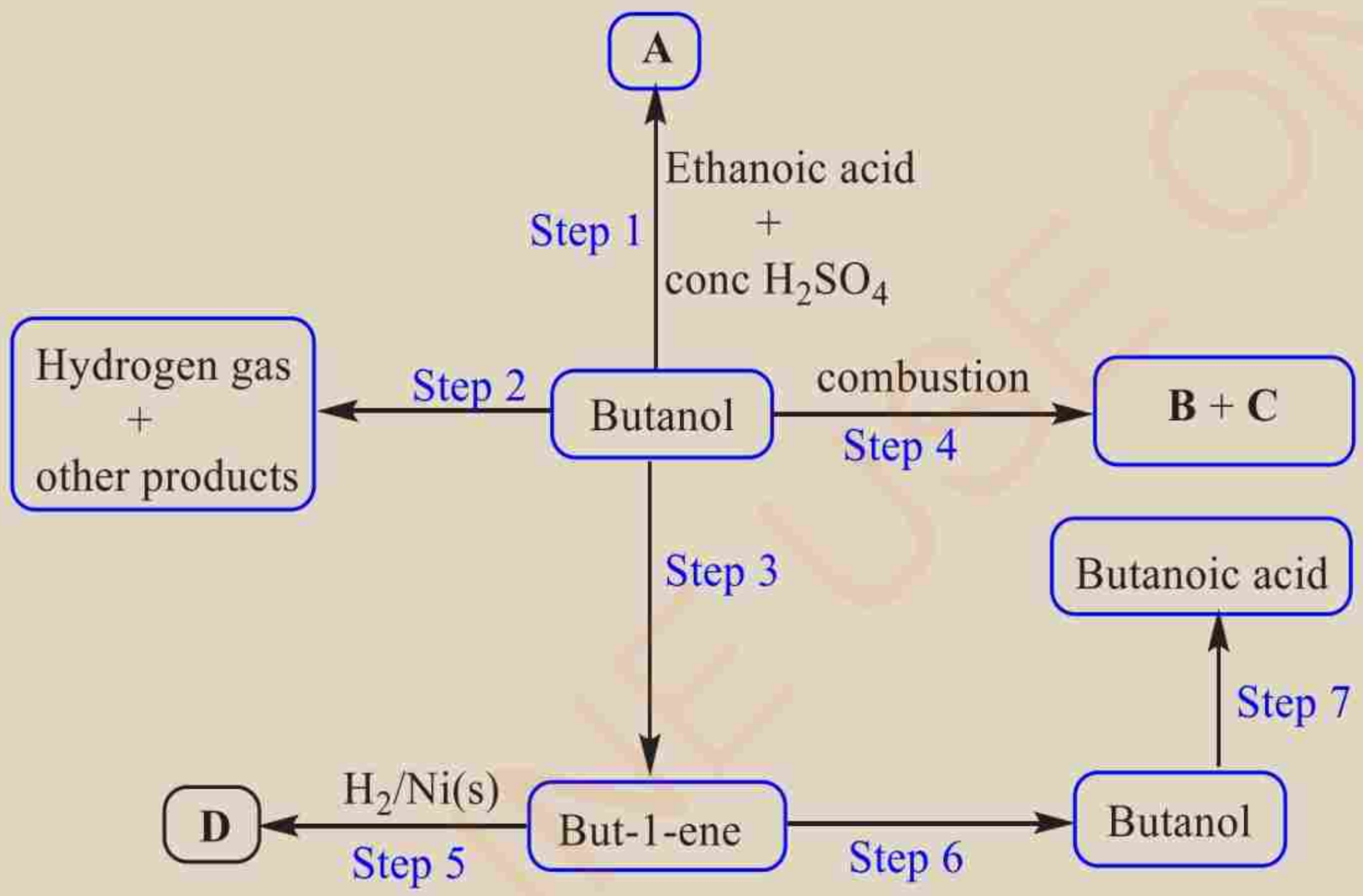
(e) Name the process which leads to the formation of compound Y.

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17. Compound A($C_4H_{10}O$) is oxidised with acidified potassium dichromate to give compound B. When it is dehydrated with conc. H_2SO_4, compound A gives compound C which undergoes hydrogenation to give compound D, that is capable of undergoing a substitution reaction. Identify the compounds B, C, and D, and write their structures.

18. Use the information in the following scheme to answer the questions that follow.



(a) Give the structure of product **A**.

(b) Write the class of compounds to which product A belongs.

(c) Give the name and the structure of product **D**.

(d) What is the class of compounds for product **D**?

(e) Write the chemical equation for Step 4.

(f) Suggest the missing chemical reagent(s) for the reaction in Step 2.

(g) Name the reagents and conditions for the reactions in Step 3 and Step 6.

(h) What is the type of reaction in Step 3?

(i) Name the type of reaction in Step 6.

(j) What is the name of the reaction in Step 7?

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Chapter Three

Soil chemistry

Introduction

Plants grow and derive most of their requirements from soil. Soil is also a habitat for other organisms such as animals and microorganisms. Thus, soil is the uppermost layer of the Earth's crust composed of a mixture of organic matter, minerals, gases, liquids, and organisms, that together support life. Soil chemistry is the study of chemical composition, properties, and reactions of soil. The soil components determine its quality. Soil quality is the ability of soil to support ecosystems to sustain biological productivity, maintain environmental quality, and promote plant and animal health. In this chapter, you will learn about soil formation, plant nutrients, soil reactions, manures and fertilisers, and soil fertility and productivity. The competencies developed will enable you to apply appropriate skills and practices to improve and conserve soil quality for maximum and sustainable utilisation.

Soil formation

Soil is formed by the breakdown of rocks and organic matter such as plant materials through *weathering*. Weathering is the means by which rocks, minerals, wood, and other materials are changed by physical and chemical processes into soil components. It involves a series of complex changes that alter the form, colour, texture, and composition of the rock particles and other materials. The rock starts by breaking down into smaller fragments and eventually into individual constituent minerals. The weathered rock materials combine with decomposing organic matter to form soil layers. Weathering is therefore a combination of disintegration (breaking down) and synthesis (building up) processes. In fact, the processes are continuous.

Agents of weathering

Agents of weathering are factors that facilitate the weathering process. They include; water, ice, gravity, wind, gases (oxygen and carbon dioxide), salts, plants, animals, microorganisms, temperature changes, and human being.

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Types of weathering

There are three main types of weathering, namely physical weathering, biological weathering, and chemical weathering.

Physical weathering

Physical weathering is the disintegration of rocks into tiny rock fragments of different sizes without changing their chemical composition. Physical weathering is more effective in areas with little vegetation, a large diurnal temperature range, and temperatures falling as low as 0 °C. The agents of physical weathering include wind, moving water, ice, gravity, temperature changes, pressure changes, plant and animal actions, and human activities. Physical weathering can take place through *pressure release*, *exfoliation*, *abrasion, frost shattering, crystallisation*, and *thermal expansion*.

Pressure release is a weathering process caused by the expansion and fracturing of underlying rocks through the removal of overlying rocks mostly through erosion. Rocks found deep below the Earth's surface are usually under immense pressure due to overlying materials. With the release of pressure, the rocks expand, and cause stress within the rocks. Cracks are formed parallel to the rock surfaces and over a period of time, the outer layers of the rocks break away into sheets.

Exfoliation or sheeting occurs in hot deserts where day temperatures rise to over 40 °C and night temperatures fall below 10 °C. The repeated heating by day and cooling by night causes the outer layers of the rocks to expand and contract alternately. This creates stress in the rocks, causing them to crack and eventually, the outer layers of the rocks peel off. Figure 3.1 shows weathering of rocks by exfoliation process.

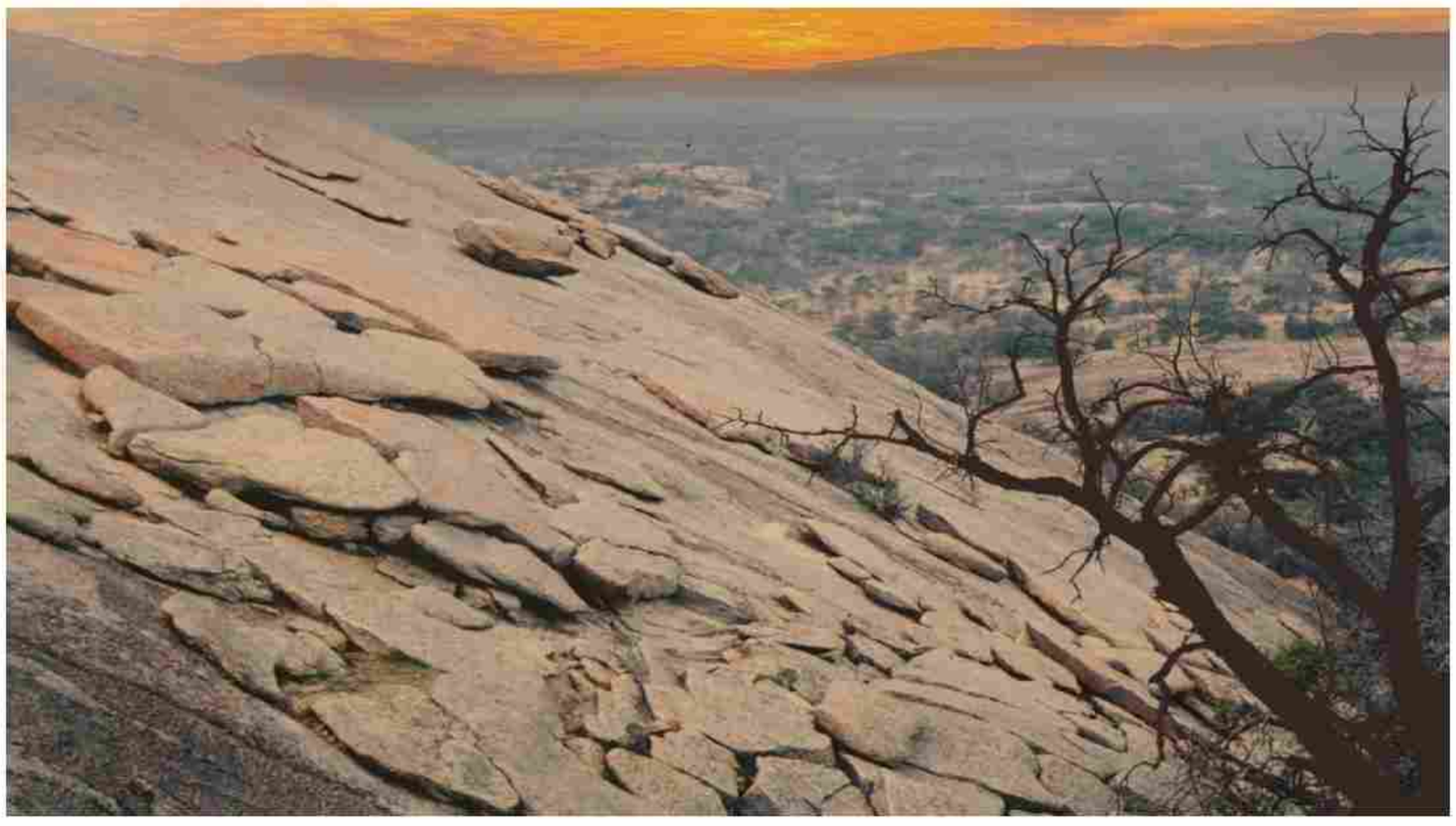


Figure 3.1: *Exfoliation*

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Another agent of physical weathering is known as abrasion. It is the process by which fragments of rocks or minerals are broken through direct collisions with each other. Gravity causes abrasion as rocks tumble down a mountain side or cliff. Abrasion also occurs in river beds where rocks fragments tumble along the bottom with the current or sand dunes where wind causes grains of sand and silt to collide with the exposed rock. Rocks can undergo abrasion with glaciers as well, where fragments embedded in ice grind along the rock.

Frost shattering occurs in cold temperate regions and mountain tops, where temperatures are just above or below freezing point of water. Water fills the cracks or joints in the rocks and freezes at night or during winter. Repeated freezing and melting eventually shatters the rocks along the cracks or joints. The broken materials collect at the foot of the slope. Figure 3.2 shows the weathering process through frost shattering.

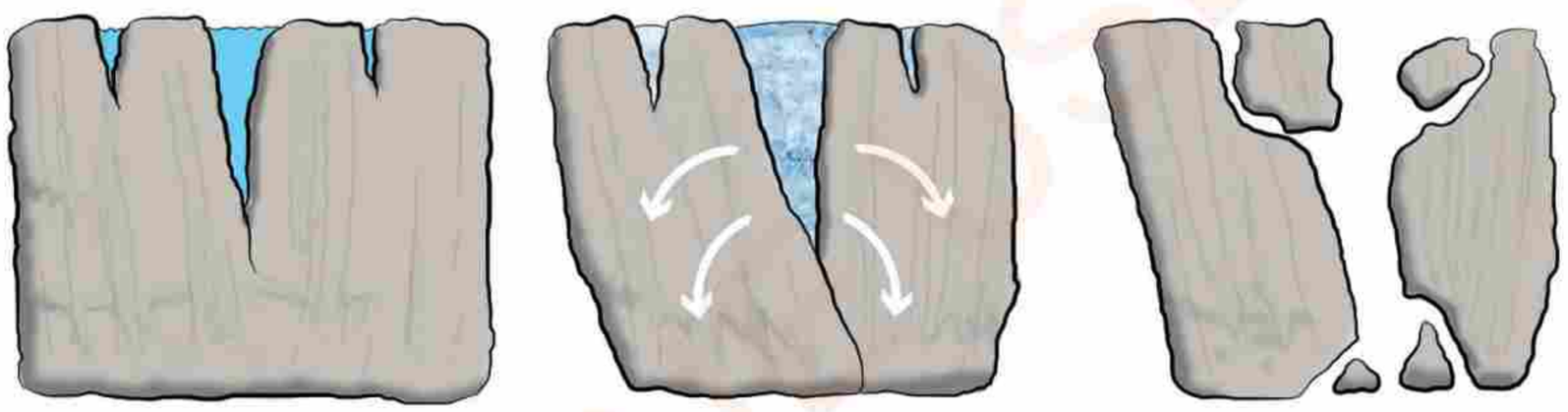


Figure 3.2: *Frost shattering*

Thermal expansion is also one of the agents of physical weathering. When rocks are subjected to different temperature ranges, they expand and contract. Temperature fluctuations such as day-night cycles can cause rocks to expand and contracts at different rates. Such process cause breaking of the rock into small particles which separates themselves from the parent rock. The process can also involve formation of fractures which favour further breaking down of the rock which contributes to physical weathering. Areas that experience rapid temperature changes such as deserts show this type of weathering.

Crystallization is the weathering by growth of salt crystals. This takes place in deserts where evaporation draws groundwater containing dissolved salts upwards into the pores of the rocks. When water evaporates, salts are left behind as crystals. The build-up of the salt crystals creates stress in the rocks, weakens, and breaks them down into grains.

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Biological weathering

Biological weathering is caused by living organisms such as animals, plants, and microorganisms. Living organisms contribute to the weathering process in many ways including roots growing into the cracks and joints of rocks. As the trees grow, the roots gradually expand and break the rock apart. It also involves burrowing animals such as moles, earthworms and termites which make tunnels or holes in the ground by excavation and move rock fragments to the surface. As a results, these fragments become more exposed to other environmental factors that can further enhance their weathering. Similarly, when animals search for seeds, insects, and earthworms, they create holes and erode the upper surface of the rocks or soil and thus contribute to weathering. Organisms contribute to weathering through organic compounds that acidify and corrode rock minerals. When organisms die, their parts are decomposed and are later converted to organic matter which produces carbon dioxide. The carbon dioxide when combined with water produces carbonic acid which can degrade the surfaces of rocks and rock particles. Some microorganisms such as algae and fungi can also break rocks by releasing chemicals. Moreover, biological weathering involve human activities, such as constructions and land cultivation.

Chemical weathering

Chemical weathering is the breakdown of rocks by chemical alteration of constituent minerals to form other minerals (e.g. clay) and salts. In chemical weathering, the internal structures of the minerals are destroyed. Chemical weathering is common in warm and moist areas. The main agents of chemical weathering are water, acids, carbon dioxide, and oxygen. The common acid that occurs in surface water is carbonic acid produced by the reaction of the rainwater with carbon dioxide gas in the atmosphere.

$$CO_2(g) + H_2O(l) \longrightarrow H_2CO_3(aq)$$

The H_2CO_3 dissociates in water to give H^+ and HCO_3^- in solution.

$$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$$

The hydrogen ions (H^+) can easily enter in the crystal structures of the rocks, causing the rocks to release other ions into the water. Chemical weathering takes place through *dissolution*, *hydration*, *hydrolysis*, *oxidation,* and *acidification.*

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Dissolution: In dissolution, minerals are dissolved in water. The carbonic acid (H_2CO_3) reacts with rocks, especially limestone or calcite, causing decomposition. The weathering involving carbonic acid formed from carbon dioxide and water is also called *carbonation*.

$$\underset{\text{Calcite rock}}{CaCO_3(s)} + H_2CO_3(aq) \longrightarrow Ca(HCO_3)_2(aq)$$

$$Ca(HCO_3)_2(aq) \rightleftharpoons Ca^{2+}(aq) + 2HCO_3^{-}(aq)$$

The calcium hydrogencarbonate formed by this reaction is soluble in water and eventually the process effectively dissolves the rocks. Calcite also dissolves in hydrochloric acid. When hydrochloric acid is added to calcite, effervescence of carbondioxide gas is observed.

$$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$



Activity 3.1

Aim: To investigate the dissolution of marble by dilute acid

Requirements: Boiling tube, glass rod, dropper, marble (limestone), dilute hydrochloric acid, and limewater

Procedure

1. Put a piece of marble into a boiling tube.
2. Add about 2 cm^3 of 1 M hydrochloric acid.
3. Place a glass rod with a drop of limewater at the mouth of the boiling tube. Record the observations.

Questions

1. With the aid of a chemical equation, explain what was observed on the drop of limewater.
2. How can the reaction between hydrochloric acid and marble be used to explain the weathering process?

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Hydrolysis: Hydrolysis takes place in the presence of water. It is a process by which soluble cations are leached from silicates, dissolved, and carried away by water. In hydrolysis, the H^+ and OH^- from water replace other ions in a mineral. For example:

$$4KAlSi_3O_8(s) + 4H^+(aq) + 2H_2O(l) \longrightarrow 4K^+(aq) + Al_4Si_4O_{10}(OH)_8(s) + 8SiO_2(s)$$

Orthoclase — Clay mineral — Silica

Oxidation: In oxidation, oxygen reacts with other minerals, changing the oxidation state of an ion. Oxidation is common in iron-bearing minerals. For example:

$$6FeSiO_3(s) + O_2(g) \longrightarrow 2Fe_3O_4(s) + 6SiO_2(s)$$

Iron silicate — Magnetite — Silica

Note that the oxidation state of iron is +2 in $FeSiO_3$ and +3 in Fe_3O_4.

Minerals with high iron content are affected by oxidation. Their oxides give these minerals a reddish look, very similar to the patina on a car.

Hydration: This is the type of chemical weathering where water reacts with the rocks, modifying its chemical structure. An example of mineral hydration is when water (H_2O) is reacted with calcium sulphate ($CaSO_4$) to form calcium sulphate dihydrate ($CaSO_4.2H_2O$), commonly known as gypsum.

Acidification: This is caused by acidic precipitation in which acid gases such as sulphur dioxide and nitrogen dioxide dissolve in water vapour to produce acid rain. The acid rains fall on the rocks causing their surfaces to wear or soften.

Factors influencing soil formation

Soil forms layers or horizons that are almost parallel to the Earth's surface in response to five soil-forming factors. These factors include nature of parent material, climate, organisms, topography of the location, and time and they cause the entire soil to develop naturally from the surface to the deepest depths. If any one of the five factors is changed but the remaining four factors remain the same, a new soil will form. These factors are discussed in detail as follow:

Nature of the parent material: Parent material refers to the primary material from which the soil is formed. Soil parent material include rocks, organic materials, deposit from water, wind, glaciers, volcano, and materials moving down a slope. These influence the rate of soil formation. For example, basic rocks such as limestone are easily weathered. On the other hand, acidic rocks which contain silicates are more resistant to weathering. Some rocks are porous, and

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hence provide large surface areas for chemicals to act on them. Such rocks are easily weathered by chemical processes. The parent material therefore influences the physical and chemical properties of the soil and determines the type of the soil formed. The parent material also affects the soil texture, that is, the relative proportions of different particle sizes in the soil. Soil texture in turn influences the water permeability of the soil.

Climate: Weathering is influenced by climatic factors such as rainfall, temperature, sunlight, relative humidity, and wind. Rainfall provides water, which is the main weathering agent. Temperature changes cause the occurrence of alternating expansion and contraction of rocks. These result in the breakdown of the rocks into smaller particles. High temperatures speed up the rates of chemical reactions, and consequently increase the rate of weathering. Conversely, low temperatures slow down chemical reactions and the activities of microorganisms. This in turn slows down the rate of soil formation. Wind acts as a transport agent and carries weathered materials from one place to another. Soils are deep where large amounts of weathered materials are deposited. However, when wind carries away the top soil, the soil becomes shallow and in some cases it results into bare rocks.

Organisms: Organisms such as plants and animals contribute towards the organic matter present in the soil. The soils formed in areas that have a lot of vegetation cover, for example forests, have high organic matter content. Organic matter preserves soil nutrients thus improving soil fertility. Plant roots and burrowing animals also help in breaking the rocks into small particles.

Topography: This is the general appearance of the landscape. The nature of the slope determines the type of soil formed in an area. Soils on the top of highland areas are heavily leached, while soils found in basin land and low-lying areas tend to be more fertile and deeper, mainly because of deposition of soil and other materials. Soils on low and flat land tend to be darker in colour because they have more organic matter compared to those higher up the slope. Such soil profile differences is known as *soil catena*.

Time: The length of time over which soil forming processes have been taking place affects the age of the soil. Deep soils are found in places where the process of soil formation has been going on for a long time. Shallow soil is an indicator of young soil or erosion activities.

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Exercise 3.1

1. How do plants cause weathering?
2. Why is cracking an important process in soil formation?
3. Explain how each of the following climatic factors influences soil formation:
   (a) Rainfall, (b) Temperature,
   (c) Sunlight, (d) Wind.
   (e) Relative humidity, and
4. How are the following chemical processes linked to soil formation?
   (a) Dissolution, (b) Hydration,
   (c) Oxidation, (d) Acidification, and
   (e) Hydrolysis.
5. Describe any five soil forming factors.

Plant nutrients

One of the most important characteristics of a fertile soil is its ability to supply the nutrients needed by plants. Most of these nutrients are released into the soil from the parent material during the process of weathering. The nutrients exist in soil solutions ready for plants assimilation. Essential plant nutrients include elements such as carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, zinc, molybdenum, manganese, iron, copper, boron, magnesium, chlorine, and cobalt. The essential plant nutrients are mainly categorised into two groups, namely, *non-mineral nutrients* (carbon, hydrogen, and oxygen) which are found in air and water, and *mineral nutrients* (calcium, potassium, iron, zinc, and phosphorus) which are found in soil. The carbon, hydrogen, and oxygen are mainly obtained from CO_2 and H_2O, while the mineral nutrients are absorbed from the soil solution.

Classification of essential plant nutrients

Essential plant nutrients are classified into *macronutrients* and *micronutrients* depending on the amounts required for healthy growth of plants. Both macronutrients and micronutrients are important for the betterment of plant growth and metabolism. Table 3.1 summarises classification of the essential plant nutrients.

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Macronutrients: These are also known as *major nutrients*. They are essential nutrients that are required by plants in large quantities. Each plant needs essential nutrients for its growth and metabolism. Macronutrients are divided into *primary* macronutrients and *secondary* macronutrients. Primary macronutrients are the elements that are required by plants in relatively large quantities and they include carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), and potassium (K). The primary macronutrients are subdivided into two categories, namely *non-mineral macronutrients* which include carbon (C), hydrogen (H), and oxygen (O); and *mineral macronutrients* which include nitrogen (N), phosphorous (P), and potassium (K). The secondary macronutrients are nutrients required by plants in relatively smaller quantities than primary macro-nutrients. They include calcium (Ca), magnesium (Mg), and sulphur (S).

Micronutrients: These are also referred to as *trace elements*. Trace elements are chemical elements required by plants in very small amounts. Nevertheless, micronutrients must be present for proper plant growth. They include manganese, molybdenum, iron, cobalt, zinc, boron, copper, and chlorine.

Table 3.1: *Essential plant nutrients*

Categories of nutrients	Element	Chemical symbol	Forms taken up by plants
Primary non-mineral macronutrients	Carbon	C	CO_2
	Hydrogen	H	H_2O
	Oxygen	O	H_2O
Primary mineral macronutrients	Nitrogen	N	NH_4^+, NO_3^-
	Phosphorus	P	$H_2PO_4^-$, HPO_4^{2-}
	Potassium	K	K^+
Secondary macronutrients	Calcium	Ca	Ca^{2+}
	Magnesium	Mg	Mg^{2+}
	Sulphur	S	SO_4^{2-}
Micronutrients	Iron	Fe	Fe^{2+}, Fe^{3+}
	Manganese	Mn	Mn^{2+}
	Boron	B	H_3BO_3
	Chlorine	Cl	Cl^-
	Zinc	Zn	Zn^{2+}
	Copper	Cu	Cu^{2+}
	Molybdenum	Mo	MoO_4^{2-}

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Functions of primary macronutrients in plant growth

Macronutrients are essential for the overall states of the plant growth. The primary mineral macronutrients are nitrogen (N), phosphorus (P), and potassium (K). The functions of primary mineral macronutrients in plant growth are described as follows:

Nitrogen (N): Naturally, nitrogen occurs as a gas in the atmosphere. However, plants can only absorb it when it is in the form of nitrate ions (NO_3^-) or ammonium ions (NH_4^+). Some plants can obtain nitrogen from the atmosphere by means of nitrogen-fixing bacteria. The following are the functions of nitrogen:

(a) Nitrogen is a constituent element of proteins and protoplasm of all plant cells. It is therefore needed in larger amounts than any other element.

(b) It forms part of the chlorophyll molecule which gives plants the green colour. Chlorophyll is necessary for photosynthesis.

(c) Nitrogen promotes vegetative growth in crops. It is therefore important in crops in which leaves are harvested, for example cabbages.

(d) It is an essential element in cell division, and therefore it is needed for plant growth.

(e) It controls the availability of phosphorus and potassium in plants.

(f) It increases grain size and protein content in cereals.

(g) It helps in the manufacture of enzymes and plant hormones.

(h) Nitrogen promotes root growth.

When nitrogen is absorbed in a sufficient amount, it produces a strong, durable plant; nevertheless, when nitrogen is applied in excess, the opposite occurs. Plants with too much nitrogen become spindly and have fragile stems. The weak stems become less able to support the plants as the leaves continue to grow abundantly. Root growth is also stunted, resulting in even less plant support. The plants eventually die since they can no longer sustain themselves.

Plants that are deficient in nitrogen have the following symptoms:

(a) Early senescence of old leaves.

(b) Stunted growth.

(c) Chlorosis, that is, leaves lose chlorophyll and turn yellow or yellowish green.

(d) In some crops like tomatoes, deficiency of nitrogen causes production of pigments such as anthocyanins (purplish colouration) instead of chlorophyll. This lowers the efficiency of the plants to photosynthesize.

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Phosphorus (P): Phosphorus exists in soil either in the organic or inorganic form. The microorganisms in the soil convert organic phosphorus into phosphates, which can be absorbed by plants. Phosphates are relatively insoluble in soil water, and therefore, are not easily leached. The following are the functions of phosphorus:

(a) It helps in root nodule formation in leguminous plants such as beans and groundnuts.
(b) It strengthens plant stems.
(c) It is a constituent of nucleoproteins, which are required during cell division.
(d) Phosphorus is essential in flowering, fruits and seed formation.
(e) It is important in protein synthesis, fat synthesis, and carbohydrate synthesis.
(f) It promotes resistance to diseases in plants.
(g) It increases grain yields in cereals.
(h) It hastens plant maturity.

Excessive soil phosphorus reduces the plant's ability to take up the required micronutrients, particularly iron and zinc, even when soil tests show there are adequate amounts of those nutrients in the soil.

Plants that are deficient in phosphorus have the following weaknesses:

(a) Stunted growth.
(b) Increased production of anthocyanins.
(c) Poor development of roots, barks, flowers, and seeds.

Potassium (K): Potassium is abundantly found in clay soils since it is a constituent element of clay particles. It is the second most essential element, after nitrogen. The following are the functions of potassium:

(a) It is important in carbohydrate formation and translocation of food.
(b) It is useful in neutralising organic acids in plants.
(c) It regulates nitrogen and phosphorus uptake.
(d) It is a component of the chlorophyll molecule.
(e) It regulates osmosis in plant cells.
(f) It improves tissue formation.
(g) It assists in protein synthesis.
(h) It strengthens plant stalks, hence preventing lodging and microbial attack.

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When plants get too much potassium, the absorption of other nutrients is inhibited, which leads to the symptoms caused by the deficiency of these nutrients.

Plants that are deficient in potassium have the following characteristics:

(a) Leaf curling.
(b) Leaf surfaces lose chlorophyll and become yellow.
(c) Premature leaf fall.
(d) Leaf margins become scorched while the central part remains green.
(e) Stunted growth.

Functions of secondary macronutrients in plant growth

Secondary macronutrients are also essential, even though they are needed in smaller quantities than primary macronutrients. The secondary macronutrients are calcium (Ca) magnesium (Mg) and sulphur (S). The following are the functions of each secondary macronutrient:

Calcium (Ca): Plants absorb calcium from the soil in the form of calcium ions (Ca^{2+}). Sources of calcium are dolomitic lime, gypsum, and superphosphate. The roles of calcium in plant growth are:

(a) Calcium attaches to walls of plant tissues thus stabilising the cell walls and favour cell walls formation.
(b) Improves plant vigour, activating the formation of roots and their growth.
(c) It improves mineral retention in the soil and transportation of such minerals.
(d) It neutralises toxic substances in plants and contributes to seeds formation.
(e) It is involved in cell growth and development.

Magnesium (Mg): Plants absorb magnesium from soil in the form of magnesium ions (Mg^{2+}). The soil minerals, organic materials, fertilisers, and dolomitic limestone are sources of magnesium for plants. The roles of magnesium in plant growth are:

(a) Magnesium is part of the chlorophyll in all green plants and it is essential for photosynthesis.
(b) It activates many plant enzymes needed for growth.

Sulphur (S): Plants obtain sulphur in the form of sulphate ions (SO_4^{2-}). Sulphur may be supplied to the soil from rainwater. It is also added through some fertilisers as part of plant nutrients. The use of gypsum ($CaSO_4 \cdot 2H_2O$) also increases soil sulphur levels. The roles of sulphur in plant growth are:

(a) It promotes the activities and development of enzymes as well as vitamins.
(b) It helps in chlorophyll formation.
(c) It improves root growth and seed production.

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Nutrient culture

Nutrient culture is a specific mixture of nutrients and other substances that support plant growth. A plant nutrient culture can be prepared in the laboratory by dissolving selected chemicals in water or other media. When water is used as a culture medium, the culture is referred to as a *water culture*. Nutrient culture can be *complete* or *incomplete*. A complete culture solution contains all the essential elements required by plants in their correct proportions where as the incomplete culture solution lack some plant nutrients. In a complete culture solution, plants display normal growth, even without soil. A plant nutrient culture can be prepared in the laboratory using selected chemicals.

The flasks used in nutrient culture storage are painted or wrapped with aluminium foil to prevent the entrance of light. The absence of light prevents the growth of algae which would damage the roots. Materials that come in contact with stems such as stopper and cotton wool must be dry. This prevents the risks of the stems being infected with bacteria and fungi which would cause the roots to rot. The bent-glass tube is inserted in flask in order to supply air (oxygen) to the roots. The seedling in the complete culture solution will be healthy and strong with dark green leaves. The other seedlings in various incomplete culture solutions will display various symptoms of nutrient deficiencies, depending on the element(s) missing from the culture. For instance, the seedling in distilled water will hardly grow and will appear very weak to the point of dying.



Activity 3.2

Aim: To prepare nutrient culture in the laboratory

Requirements: Four flat-bottomed flasks, two-hole rubber stopper, analytical balance, droppers, gas jars, bent glass-tube, aluminium foil, calcium sulphate, calcium phosphate, magnesium sulphate, potassium nitrate, iron(III) chloride; 1% solutions of copper(II) chloride, ammonium molybdate, manganese(II) chloride, sodium borate, and zinc chloride, distilled water, marker pen, beaker, cotton wool, and 20 bean seeds

Advance preparation

Prepare some bean seedlings a week before this experiment by soaking about 20 bean seeds in water overnight followed by placing the seeds in moistened cotton wool in a beaker. Keep the beaker in a dark place until the beans germinate and are about 2 cm tall.

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Procedure

Label the four flasks A, B, C, and D, respectively.

Flask A

1. Put about 0.5 g of each of the following reagents in the flat-bottomed flask:
   (a) Calcium sulphate,
   (b) Calcium phosphate,
   (c) Magnesium sulphate, and
   (d) Potassium nitrate.

2. Add 3 drops of each of the following solutions into the flask:
   (a) copper(II) chloride,
   (b) ammonium molybdate,
   (c) manganese(II) chloride,
   (d) sodium borate, and
   (e) zinc chloride.

3. Add distilled water while shaking, to dissolve the salts.
4. Top up with distilled water until to the neck of the flask.
5. Plug the flask with a rubber stopper and wrap it with aluminium foil or paint.
6. Insert a bean seedling through one of the holes in the stopper and a bent glass tube through the other hole as shown in Figure 3.3.
7. Observe the seedling for about two weeks.

Flask B

1. Put approximate amounts of the nutrients as explained in step 1 in flask A.
2. Top up the flask with distilled water while shaking.
3. Repeat step 5 to 7 of flask A.

Flask C

1. Put approximate amounts of the nutrients as explained in step 2 in flask A.
2. Top up the flask with distilled water while shaking.
3. Repeat step 5 to 7 of flask A.

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Flask D

Fill the flask with distilled water and repeat steps 5 to 7 of flask A.

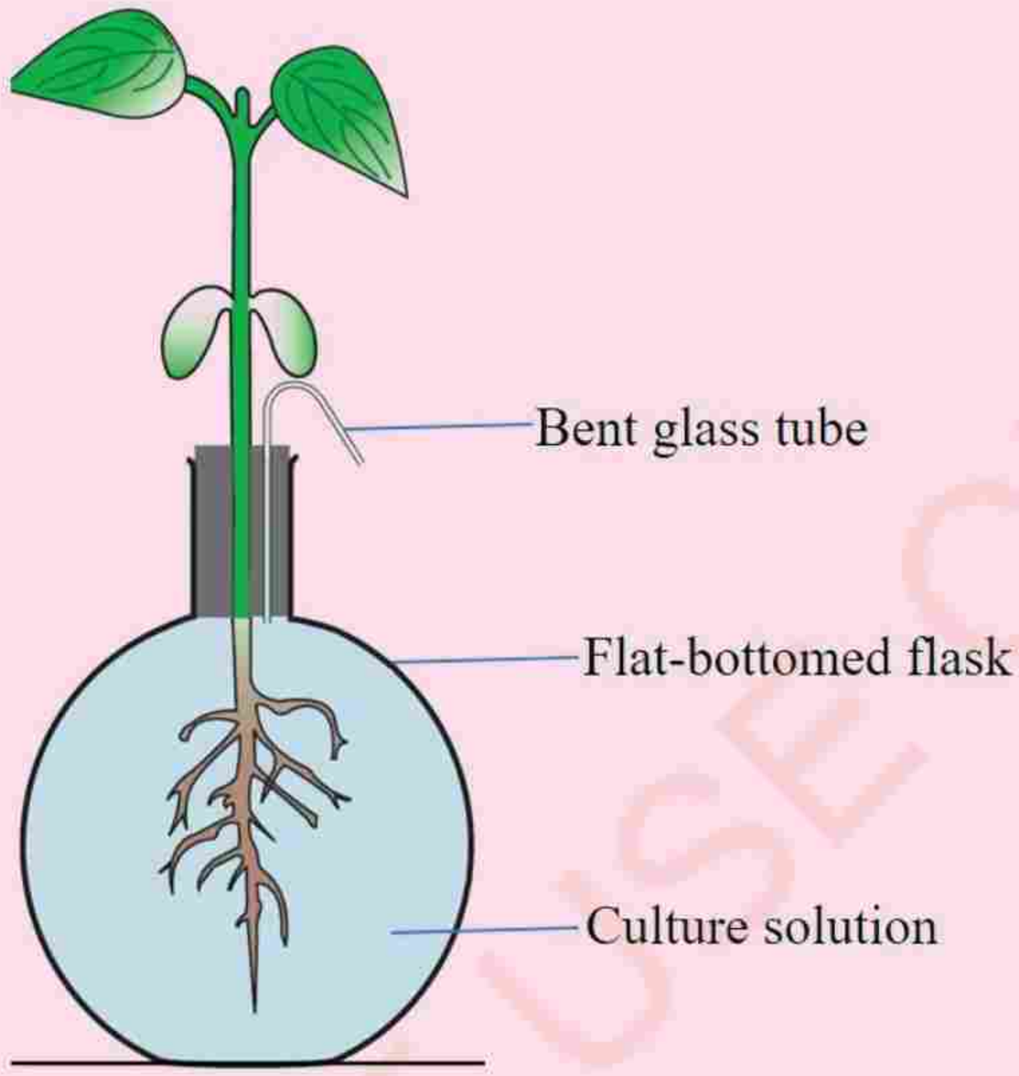


Figure 3.3: *Bean seedling in nutrient culture*

Questions

1. Identify the elements required by the plants which are present in the nutrient culture you have prepared.
2. What other elements required by the plants are not provided in the nutrient culture?
3. What was the purposes of experiments in the flasks A, B, C, and D? Explain.
4. Why should the flask be painted or wrapped with aluminium foil?
5. Describe the appearance of the seedling in each flask in the course of time.
6. What does the experiment show about the importance of soil for plant growth? Explain.

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Activity 3.3

Aim: To investigate the effects of certain element deficiencies on plant growth

Requirements: Nine flat-bottomed flasks painted black on the outer surface, bicycle pump, nine pieces of bent glass-tubes, 1% solutions of calcium chloride, magnesium chloride, calcium nitrate, potassium sulphate, sodium nitrate, and sodium phosphate, nine two-hole stoppers, cotton wool, labels, dry cotton wool, beaker, and 20 bean seeds

Advance preparation

Prepare some bean seedlings by soaking about 20 bean seeds in water overnight. Place the seeds in moistened cotton wool in a beaker. Keep the beaker in a dark place until the beans germinate and are about 2 cm tall. The advance preparation should be done about 1 week before this experiment.

Procedure

1. Prepare a complete water culture as outlined in Activity 3.2 for flask A.
2. Pour the complete culture solution into one flask to fill it to about three quarters.
3. Prepare incomplete culture solutions using different flasks as follows:
   (a) Culture solution lacking sulphur. Use calcium chloride in place of calcium sulphate and magnesium chloride instead of magnesium sulphate. Label the flask *'No sulphur'*.
   (b) Culture solution lacking phosphorus. Use calcium nitrate in place of calcium phosphate. Label the flask *'No phosphorus'*.
   (c) Culture solution lacking nitrogen. Use potassium chloride in place of potassium nitrate. Label the flask *'No nitrogen'*
   (d) Culture solution lacking calcium. Use sodium phosphate in place of calcium phosphate, and potassium sulphate in place of calcium sulphate. Label the flask *'No calcium'*.
   (e) Culture solution lacking magnesium. Use potassium sulphate in place of magnesium sulphate. Label the flask *'No magnesium'*.
   (f) Culture solution lacking potassium. Use sodium nitrate in place of potassium nitrate. Label the flask *'No potassium'*.
   (g) Culture solution lacking iron. Do not add iron(III) chloride. Label the flask *'No iron'*.

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4. Put distilled water into one flask to fill it to about three quarters.
5. From the seedlings prepared earlier, select some seedlings with about the same stage of development and place one seedling in each culture solution and in the distilled water.
6. Leave the set-ups in an open room in a place where there is no direct sunlight for about four weeks. Keep topping up the solutions with distilled water, and gently pump some air into each culture solution daily.
7. Note and record the growth characteristics of each seedling with time.

Questions

1. Why should the stopper and the cotton wool be dry?
2. What was the function of the bent glass-tube?
3. Describe the growth characteristics of the seedlings over the four-weeks observation period.

Loss of plant nutrients from the soil

The soil that is not well managed loses its fertility with time. *Soil fertility* is the ability of soil to provide sufficient amount of nutrients and in the forms available for plant uses. If the nutrients are not supplied in correct quantities, the plants and their yields are affected. The soil may lose its nutrients in any of the following ways: *soil erosion, monocropping, overgrazing, overstocking, deforestation, burning of vegetation cover,* and *leaching*.

Soil erosion: Soil erosion is the removal of top fertile soil by agents of soil erosion such as animals, moving water, and wind. Organic matter and plant nutrients are carried away in the process leading to the loss of soil nutrients.

Monocropping: This is the practice of growing one type of crop repeatedly on the same piece of land. This exhausts the soil nutrients by reducing the organic matter and sometimes causing significant erosion that make the soil less productive over time. When annual crops are harvested, there is no natural soil protection from erosion caused by wind and run-offs. This makes it easy for the top soil to be carried away by agents of erosion leading to loss of soil nutrients.

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Overgrazing: This is the practice of feeding animals on the same piece of land repeatedly such that vegetation are depleted leaving a bare land. This exhausts the soil nutrients by reducing the availability of organic matter in the soil. Overgrazing also causes destruction of the soil structure by making the upper soil loose and making lower soil compact with limited soil air. The loose top soil is vulnerable to soil erosion.

Overstocking: This is the keeping of too many animals on a piece of land than it can support. The animals eat most of the vegetation which are responsible for organic matter formation, leaving a bare land. They also stumble on the soil making it loose and vulnerable to soil erosion.

Deforestation: This is the cutting down of trees and clearing forests without replacement (Figure 3.4). This leaves the soil unprotected against agents of erosion, making it easier for the nutrients to be carried away by agents of erosion.



Figure 3.4: *Deforested area*

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Burning of vegetation cover: The practice of burning vegetation (Figure 3.5), especially for cultivation, destroys some organic matter, microorganisms, and nutrients. It also exposes the soil to agents of erosion such as moving water and wind.



Figure 3.5: *Burning vegetation*

Leaching: This is the process through which water-soluble plant nutrients are washed into the lower layers of the soil and beyond the root zone. This makes the nutrients unavailable to plants.

Management of soil nutrients

Nutrients management in the soil is vital for improvement of soil health. This management assists to meet the nutrient requirements of plants. Without proper management, nutrients can dissolve in soil solution and move beyond the root zone through leaching. The following are some of the methods used for management of soil nutrients.

Prevention of soil erosion

Soil erosion causes loss of soil nutrients in the given area, thus needs to be prevented. The following are some of the ways in which soil erosion can be prevented.

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(a) *Terracing*: This is basically, grading steep land, such as hillsides into a series of levelled sections called *terraces*. A terrace is a levelled section of a cultivated hilly area designed to control the flow speed of water on the surface. Terraces are constructed to follow the contour of the land as shown in Figure 3.6. They keep rain water on the land rather than let it run down the slope. There are two main types of terracing which are *level terracing*, in which the soil is removed from both sides of the terrace line, and *drain terracing*, in which channels are made across the slope. Both terrace types control water run-offs.



Figure 3.6: *Terraced land*

(b) *Contour farming*: This is cultivation across the slope through contours. Contour farming aims at controlling surface runoff. The ridges and depressions made by the cultivation process across the slope slow down the speed of surface run-off and trap any eroded soil.

(c) *Strip cropping*: This refers to planting alternate strips of crops on the contour to protect the soil from erosion.

(d) *Increase vegetation cover on the land*: This is done by planting windbreakers. These are plants which help to reduce both wind and surface run-off speed to prevent wind and water erosion. Wind breakers can be trees and tall grasses planted in strips to reduce the speed and intensity of wind. Grasses and shrubs are very effective for stopping soil erosion from surface run-off.

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Crop rotation: This is the practice of growing different crops on the same field at different times in an orderly sequence. The sequence involves a leguminous crop in order to improve nitrogen content of the soil. The method ensures a balance in utilising the soil nutrients. This is because, different crops have significantly different growth habits and nutritional requirements. It also helps in controlling pests and diseases. The practice is however, not recommended on steep slopes where perennial crops like trees should be planted.

Good harvesting practices: These aim at restoring the fertility of the soil after harvesting since plants absorb nutrients from the soil to make plant tissues, thus, exhausting nutrients from the soil. Leaving plant remains to rot or decompose in the soil instead of removing them helps to restore soil fertility by returning the nutrients back into soil.

Controlled grazing: Keeping the right number of animals on a piece of land prevents overgrazing. Rotational grazing can be practised when large land is available to allow growth of pasture in sections that are exhausted. Figure 3.7 shows the rotational grazing in a farm.

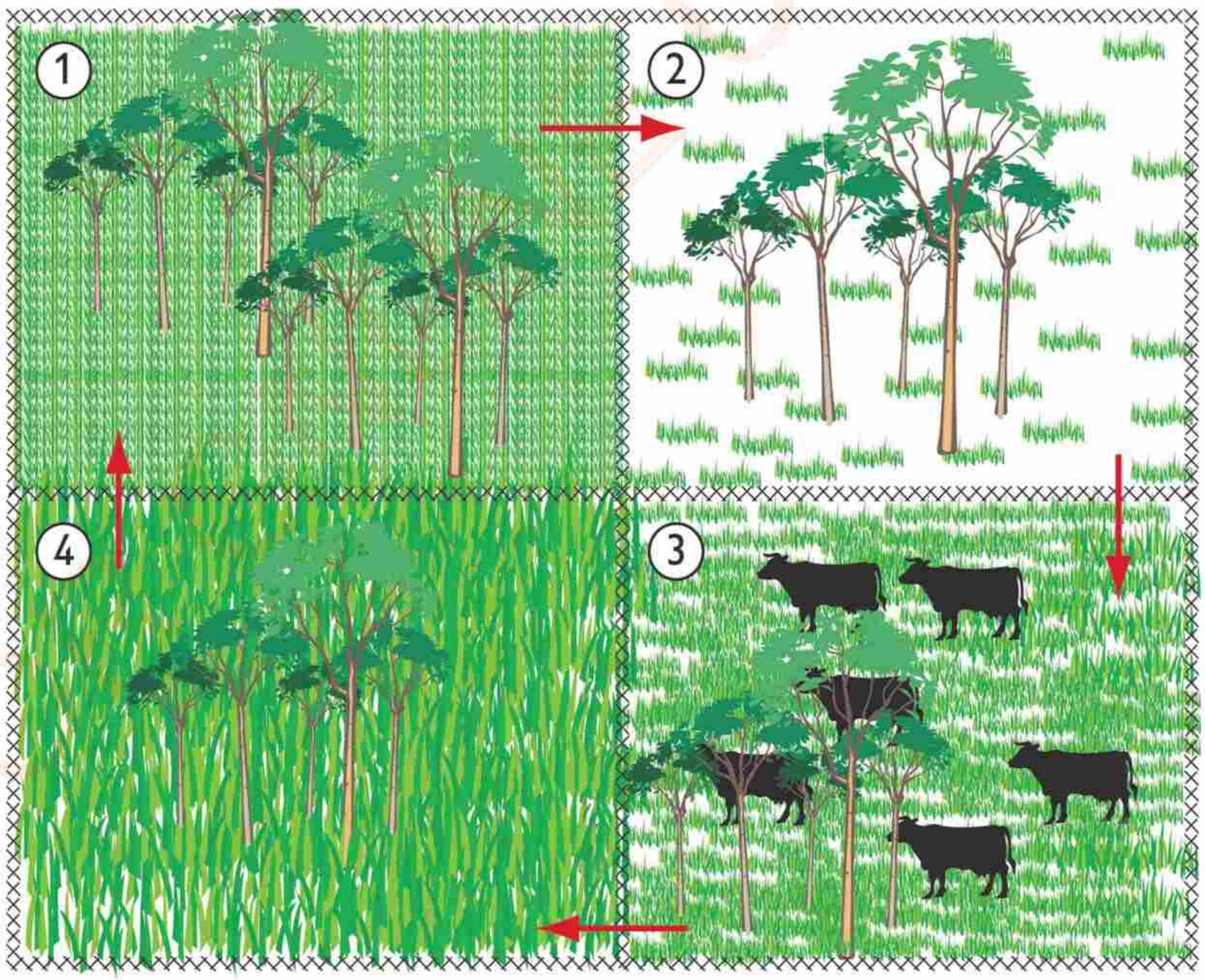


Figure 3.7: *Rotational grazing*

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Mixed cropping (intercropping): This is a farming practice where different crop families are grown simultaneously on the same piece of land as shown in Figure 3.8. Cereal crops are usually grown together with legumes. For example, maize can be grown with beans. The legumes fix nitrogen into the soil which is utilised by cereals. The methods also offers a good ground cover thus conserve soil moisture.



Figure 3.8: *Intercropping*

Use of manures: Manures are derived from decomposing organic matters such as plant remains and animal wastes. Manures are the main sources of humus in the soil. The humus from organic matter binds the soil particles together, forming stable aggregates which protect the soil against erosion. The decomposed organic matter (humus) also increases the water holding capacity of the soil, regulates pH, improves soil structure, which in turn improve soil air, and releases nutrients into the soil. This replenishes the soil with nutrients as well as preventing leaching of essential nutrients. Manures are also major sources of energy for growth and development of microorganisms.

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Minimum tillage: This refers to the practice of keeping operations on land such as ploughing at a minimum level. This is done in order to avoid over-cultivation, which destroys the soil structure and leads to erosion and leaching. Minimum tillage can be achieved by using alternative methods such as fallowing, uprooting, and slashing of weeds.

Agroforestry: This is the practice of planting trees together with other agricultural crops as shown in Figure 3.9. This is done in order to protect the soil from erosion, especially after the crops are harvested. The trees grown are also used for other purposes, for example, as sources of fodder, firewood, timber, and fruits.



Figure 3.9: *Agroforestry*

Mulching: This is the covering of the bare soil with a layer of organic or inorganic materials such as straw, grasses, leaves, rice husks, black plastics, and geotextiles. This protects the soil against soil erosion. Mulching also helps to conserve soil moisture and suppresses the growth of weeds. It also keeps the soil cool and if organic mulches are used they add organic matter in the soil.

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Exercise 3.2

1. Differentiate between the following terms:
   (a) Complete nutrient culture and incomplete nutrient culture
   (b) Macronutrients from micronutrients
2. How can the farmer ensure that the farm has optimal levels of both macronutrients and micronutrients?
3. Describe any three methods that are suitable for maintaining soil nutrients in the farms planted with the following crops:
   (a) Maize (b) Tomatoes (c) Beans
4. Describe the process for preparing a complete culture solution.

Soil reaction

Soil reaction refers to the degree of soil acidity or alkalinity. It is the condition of the soil solution which may be acidic, basic (alkaline) or neutral in its reactions. Soil reaction is important because it affects nutrient availability, microbial activities, and plant growth. It is measured in the units of pH.

The concept of soil reaction

The reactions in the soil are determined by the levels of hydrogen ions (H^+) and hydroxide ions (OH^-) in the soil solutions. The hydrogen ions make soils acidic while the hydroxyl ions make the soils basic or alkaline. When the H^+ are in higher concentrations than the OH^-, the soil becomes acidic. When the OH^- are in higher concentrations than H^+, the soil becomes basic. When both ions are of equal concentration, the soil becomes neutral. Soils that are acidic are said to have an acidic reaction, while alkaline soils have an alkaline reaction. Acidic soils result from parent materials that are acidic and naturally low in the basic cations such as (Ca, Mg, K, and Na), or because these elements are leached from the soil, reducing the pH, and the buffering capacity of the soil. Soil reaction is measured by a scale known as *soil pH* which is the measure of acidity or alkalinity of the soil. It is usually expressed as the negative logarithm of hydrogen ions concentration,

that is: $\text{pH} = -\log[\text{H}^+] = \log\frac{1}{[\text{H}^+]}$,

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where, $[H^+]$ is the concentration of hydrogen ions in moles per litre, or molarity. The pH values range from 0 to 14. Soils with pH values below 7 are acidic, while those with a pH values above 7 are basic. Soils with pH values of 7 are neutral. The pH values of most soils range from 3.5 to 11. Figure 3.10 shows the pH scale, while Table 3.2 shows the strengths of acids and bases in relation to the pH ranges.

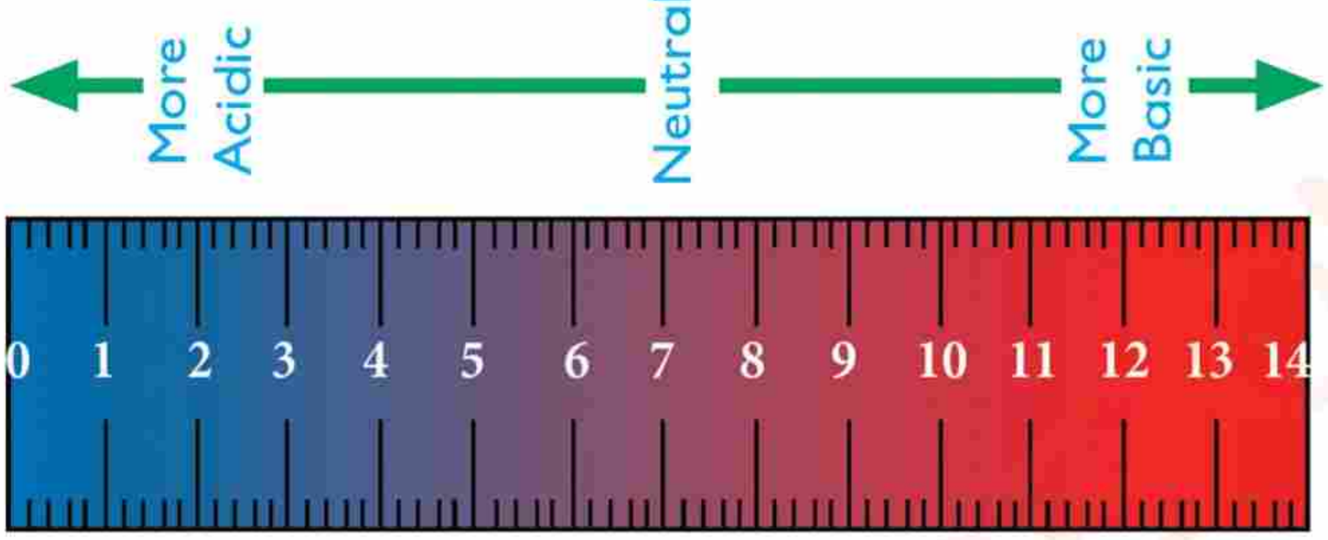


Figure 3.10: *pH scale*

Table 3.2: *Description of pH ranges*

pH	Description
0.0 – 4.0	Very strongly acidic
4.0 – 5.0	Strongly acidic
5.0 – 6.0	Moderately acidic
6.0 – 6.9	Slightly acidic
7.0	Neutral
7.1 – 8.0	Slightly alkaline
8.0 – 9.0	Moderately alkaline
9.0 – 10.0	Strongly alkaline
10.0 – 14.0	Very strongly alkaline

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Importance of soil pH

The soil pH is a key factor that controls soil nutrient availability, soil microbial activities, and crop growth and development. The availability of nitrogen, phosphorus, potassium, and magnesium to plants is within the pH range from 6.5 to 7.5. On the other hand, the availability of iron, chlorine, copper, manganese, and zinc is favoured in acidic soils. Most plants grow well in soils with a pH range between 6 and 8. The tolerance to acidity or alkalinity varies with plant varieties. Some plants such as tea do well in acidic soils. The pH also influences the activities of microorganisms in the soil. Soils that are very acidic or very alkaline do not support microbial activities.

Factors affecting soil pH

The pH of a soil is affected by different factors. These include the nature of *parent materials*, *rainfall*, *human activities*, and *applications of fertilisers* as described below.

1. Nature of parent material: The pH value of the soil is influenced by the parent material from which the soil was formed. Soils formed from basic rocks generally have higher pH values than those formed from acidic rocks.
2. Heavy rainfall: Heavy rainfall may cause water logging in soil which in turn causes leaching of some water soluble basic nutrients such as calcium and magnesium from the soil. These minerals are replaced by acidic metal ions such as aluminium and iron. Soils formed under heavy rainfall conditions are therefore more acidic than those formed under dry conditions.
3. Human activities: Human activities, such as industrial processes which contribute to pollution alter the soil pH. Acidic gases released by vehicles after fuel burning also affect the pH of the soil by forming acidic rain.
4. Applications of fertilisers: Application of fertilisers containing ammonium ions or urea lowers the pH because they increase the acidity of the soil. The decomposition of organic matter also adds to the soil acidity when they decompose to give humic acid.

Testing soil pH

Soil pH is tested in order to assess soil nutrients available for crop suitability or that may be lacking in a particular area. The pH testing is also carried out in order to determine the pH adjustments that may be required. There are two main methods that are used to collect soil samples for pH testing. These are *transverse method* and *zigzag methods*.

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The transverse method involves collecting samples diagonally within the farm. In zigzag method, locations for collecting samples are arranged in such a way that they form a zigzag pattern. Figure 3.11 shows both the transverse and zigzag methods.

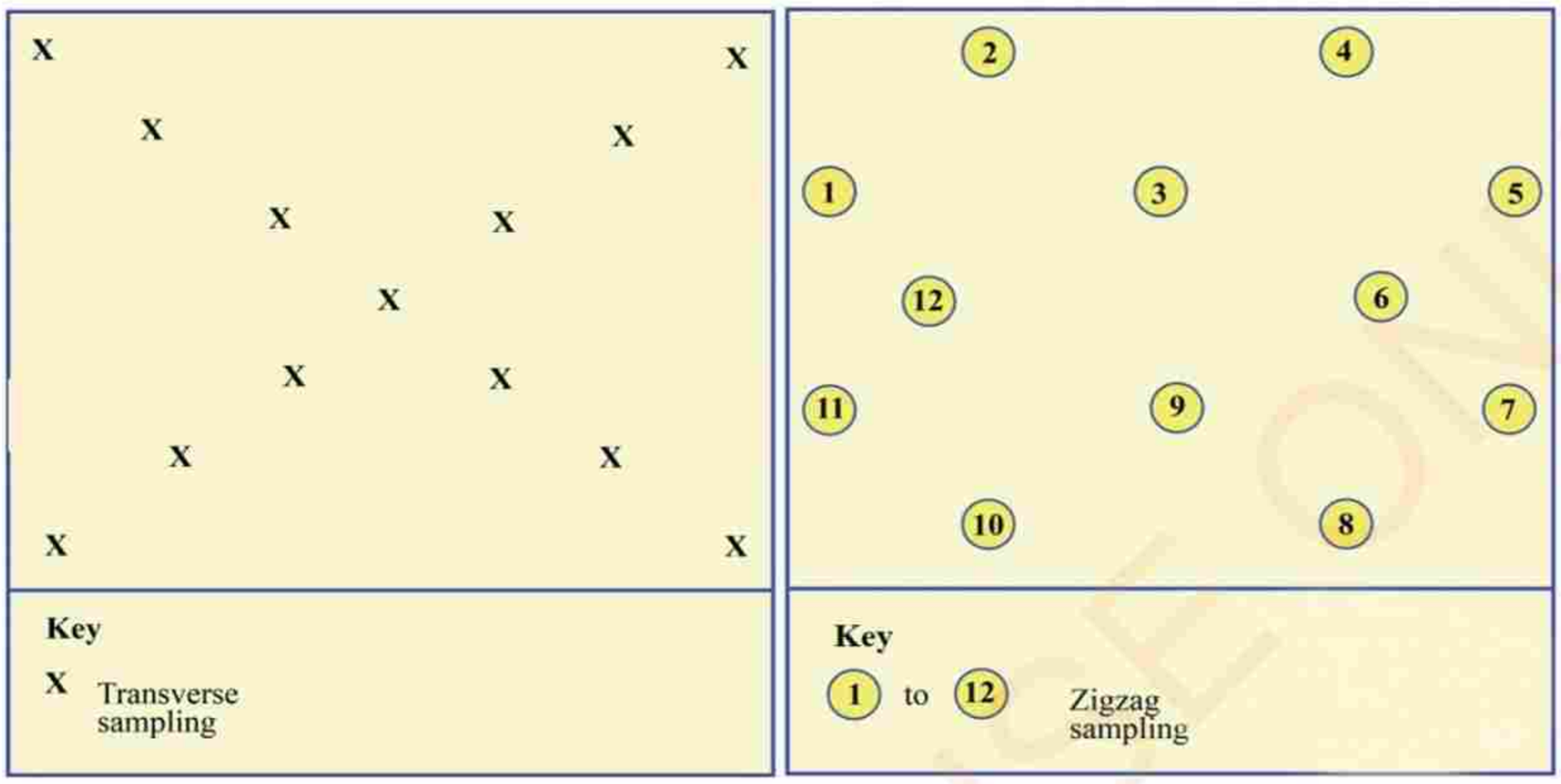


Figure 3.11: *Transverse and zigzag soil sampling methods*

When taking soil samples, avoid sampling from unusual areas such as old manure heaps and along paths. These may give misleading results of the soil. The pH of a soil sample is measured using the pH meter or colour indicator dyes. The use of universal indicator dyes is the easiest and most convenient method of determining soil pH. The universal indicator is used alongside the pH colour chart. The pH value must be obtained from a pH chart corresponding to the specific pH paper to avoid misleading results if a different pH chart is used. Litmus papers are not appropriate in this experiment because they do not give a definite pH values. They only show whether the soil is acidic or alkaline.



Activity 3.4

Aim: To measure the pH of a soil sample using a universal indicator paper

Requirements: Conical flask, trowel, 50-cm^3 measuring cylinder, analytical balance, 30-cm ruler, universal indicator paper, and boiled distilled water

Procedure

1. Using a hand trowel, collect some soil from 0 to 10 cm depth from different spots in the farm using transverse or zigzag method. Mix thoroughly and spread out the soil sample to sun-dry.

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2. Put about 50 g of the soil sample into a clean conical flask.
3. Add about 25 cm^3 of boiled distilled water in the soil sample and shake thoroughly.
4. Use the filter paper to clean the resulting solution.
5. Dip a pH indicator paper into the cleaned solution.
6. Compare the colour of the indicator paper against the pH colour chart to obtain the pH value of the soil.

Questions

1. Why was it necessary to boil the distilled water before being added to the soil sample?
2. Report the pH values of the soil sample.
3. Why is litmus paper not appropriate to use in this experiment?



Activity 3.5

Aim: To determine the pH of a soil sample using a pH kit

Requirements: pH kit, conical flask, 50-cm^3 measuring cylinder, test tube, dropper, a soil sample, analytical balance, indicator solution (available in the test kit), and boiled distilled water

Procedure

1. Put about 50 g of the soil sample in a clean conical flask.
2. Add about 30 cm^3 of boiled distilled water and shake thoroughly. Leave the mixture to settle.
3. Decant 3 cm^3 of the soil solution into a clean test tube.
4. Use the filter paper for further cleaning of the solution.
5. Add 3 drops of the indicator solution. Make the observations.
6. Compare the colours of the solution with the colours on the colour chart and assign the soil pH value.

Questions

1. What was the pH of the soil sample?
2. What could be the results if the sample contained more organic matter, such as garden compost and manure?

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Managing soil pH

Soil pH is usually adjusted to a required range using an appropriate method. The common methods of modifying soil pH include the addition of amendments, liming materials, use of fertilisers, tillage practices, using organic matter, and improving drainage. *Soil amendment* refers to practices used to improve the physical or chemical properties of the soil. The method chosen depends on whether the soil is acidic or alkaline.

Managing alkaline soils

A common amendment used to acidify alkaline soils is to add sulphur (S). Elemental sulphur is oxidised by microorganisms to produce sulphate ions (SO_4^{2-}) and hydrogen ions (H^+). The hydrogen ions lower the pH of the soil. Iron(II) sulphate, $FeSO_4$ and aluminium sulphate, $Al_2(SO_4)_3$ can also be used to lower the pH of the soil. This is because they contain acidic cations ($Fe^{2+}$and Al^{3+}). The amount of the amendment applied depends on properties of the product (particle size, and oxidation rate) and soil conditions (original pH and minerals present). Ammonium-based fertilisers and soil organic matter are also used to lower the pH values of alkaline soils. Ammonium-based fertilisers, such as urea and ammonium phosphates are oxidised by soil microorganisms, producing hydrogen ions (H^+). This process is known as *nitrification*. Nitrification is the process by which ammonia (NH_3) or ammonium (NH_4^+) are converted to nitrate (NO_3^-) by nitrifying bacteria. Nitrification is the net result of two distinct processes; oxidation of ammonium to nitrite (NO_2^-) by ammonia-oxidizing bacteria (AOB) and oxidation of nitrite (NO_2^-) to nitrate (NO_3^-) by the nitrite-oxidising bacteria (NOB).

$$2NH_4^+(aq) + 3O_2(g) \longrightarrow 2NO_2^-(aq) + 2H_2O(l) + 4H^+(aq)$$

$$2NO_2^-(aq) + O_2(g) \longrightarrow 2NO_3^-(aq)$$

$$NH_3(g) + O_2(g) \longrightarrow NO_2^-(aq) + 3H^+(aq) + 2e^-$$

$$NO_2^-(aq) + H_2O(aq) \longrightarrow NO_3^-(aq) + 2H^+(aq) + 2e^-$$

Ammonium ions can also undergo hydrolysis in soil solution to give an acidic solution.

$$NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_4OH(aq) + H^+(aq)$$

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Managing acidic soils

The most common method of increasing the soil pH is by *liming*. The process involves the applications of calcium in various forms to soil in order to increase the pH of the soil. Agricultural lime replaces exchangeable acidic ions such as hydrogen ions, with calcium and some magnesium ions which are considered basic. The commonly used liming materials are limestone ($CaCO_3$), quicklime (CaO), and slaked lime, $Ca(OH)_2$. For example, when the agricultural limestone ($CaCO_3$) is added in the soil, it dissolves partially to form calcium bicarbonate, and hydroxide ions. The hydroxide ions neutralise the soil acidity by combining with hydrogen ions to form water. As the concentration of hydrogen ions decreases, the pH increase. The chemical equations representing these reactions are shown as follows:

The first step involves partial dissolution of limestone in water

$$CaCO_3(s) + H_2O(l) \rightleftharpoons Ca^{2+}(aq) + HCO_3^-(aq) + OH^-(aq)$$

The second step involves reaction of hydroxide ions with hydrogen ions

$$\underset{\text{Hydrogen ions (In soil solution)}}{Ca^{2+}(aq) + HCO_3^-(aq) + OH^-(aq) + 2H^+(aq)} \longrightarrow \underset{\text{Exchangeable calcium ions}}{Ca^{2+}(aq)} + 2H_2O(l) + CO_2(g)$$

When magnesium carbonate ($MgCO_3$) is used, similar reaction patterns are followed.

Task 3.1

Collect soil samples from 5 different points around your school campus. Label the samples as A, B, C, D, and E. For better results of your task, make sure that the soil samples are collected from a deep source so that the organic matter; horizon A, and perhaps horizon B are visible. Use the following guide to study the collected soil samples:

(a) Observe the colour of soil.

(b) Measure the soil pH.

(c) Observe the soil uniformity in terms of composition of organic matters, and types of soil.

(d) Identify the growing vegetation in each point.

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Use the task to answer the following questions:

(i) Describe the information based on the colour of the soil.

(ii) Describe the observed relationships of the type of soil and soil composition in each point.

(iii) Describe the reaction of the soil in each point (if is basic or acidic).

(iv) Propose measures to be taken to improve soil fertility for any point of your choice in which the soil need improvements.

Exercise 3.3

1. What are the roles of organic matter in soil reaction?
2. Explain the significance of soil pH.
3. Describe the major causes of soil acidity.
4. Describe the major causes of soil alkalinity.
5. With the aid of chemical equations, explain the significance of the following processes:
   (a) Liming by $CaCO_3$
   (b) Soil amendment by sulphur.

Manures and fertilisers

Constant cultivation of land removes much of the plant nutrients and organic matter from the soil. As such, it becomes necessary to apply materials that can help to restore and maintain soil fertility. These materials include manures and fertilisers.

Manures

Manures are organic substances derived from animal waste and plant residues. They are added to the soil to provide one or more plant nutrients required for proper growth. These organic substances usually undergo complete decomposition. Organic manures are classified into four main types, namely *farmyard manure*, *green manure*, *compost manure*, and *vermi-compost manure*. Farmyard manure is the organic manure made from the waste of farm animals such as cattle, horses,

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sheep, pigs, rabbits, and chicken (Figure 3.12). The nutrient content of farmyard manure varies from one animal to another. It also depends on the type of food eaten by the animals and its storage before use. Farmyard manure should be stored where there is access to optimum air and water. Anaerobic treatment of manure results in considerable loss of nitrogen, mostly in the form of ammonia due to volatilization. Too much water would cause loss of nutrients through leaching. Farmyard manure should be stored in a closed shed.



Figure 3.12: *Heap of farmyard manure*

Green manures are made by ploughing green plant materials with the soil. The use of green manures helps to maintain and improve the organic matter of the soil, hence conserving plant nutrients. Since most of the plants used for green manure are legumes, the nitrogen content of the soil is improved.

Compost manure is made from different types of decayed organic matter such as animal waste and plant residues. Compost manure can also be prepared from plant materials only. These materials are heaped together and left to decompose. Compost manure has high nutrients content.

Vermi-compost manure refers to the manure that is made from the excreta of worms and other microorganisms. The worms and microorganisms are allowed to feed on organic compounds and cast their excreta which is mixed with soil.

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Preparation of compost manure

Preparation of compost manure involves two main stages. These are *site selection* and *preparation*.

The site selection for preparing the compost manure is done by considering the following factors:

(a) Drainage: The site should be well drained to prevent water logging which causes leaching of nutrients from manure. Drainage also ensures good aeration.

(b) Direction of the prevailing winds: The site should be located at a place where the prevailing winds does not blow from the compost manure to the homestead. This prevents bad odour drifting into the homestead.

(c) Size of the farm: The site should be located in a central point of the farm where the compost manure is to be used. This should be done for easy transportation of manure around the farm.

(d) Accessibility: The site used should be easily accessible for easy transportation of the materials needed and the prepared manure.

The preparation of compost manure is done using two methods, which are *pit* and *heap methods*. The following procedure is used in preparing compost manure using the pit method as shown in Figure 3.13.

1. Dig the compost pit. It should be about 1 m deep, 1.5 m to 2 m wide, and of a suitable length.
2. Fill the pit with the following materials in even layers of 10 cm to 15 cm.
   (a) Start with the fibrous materials such as maize stalks. This layer forms the foundation of the compost.
   (b) Pack the next layer with grasses, leaves or any decomposing refuse.
   (c) Add some well decomposed manure to provide nutrients to the microorganisms.
   (d) Add a layer of wood ash to improve the levels of phosphorus and potassium in the resulting manure.
   (e) Add a layer of top soil to supply the microorganisms necessary for the organic decomposition of the manure.

Note: Sprinkle some water over each layer to moist the pit.

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3. Repeat step 2 until the pit is full. Cover the pit with a layer of top soil.

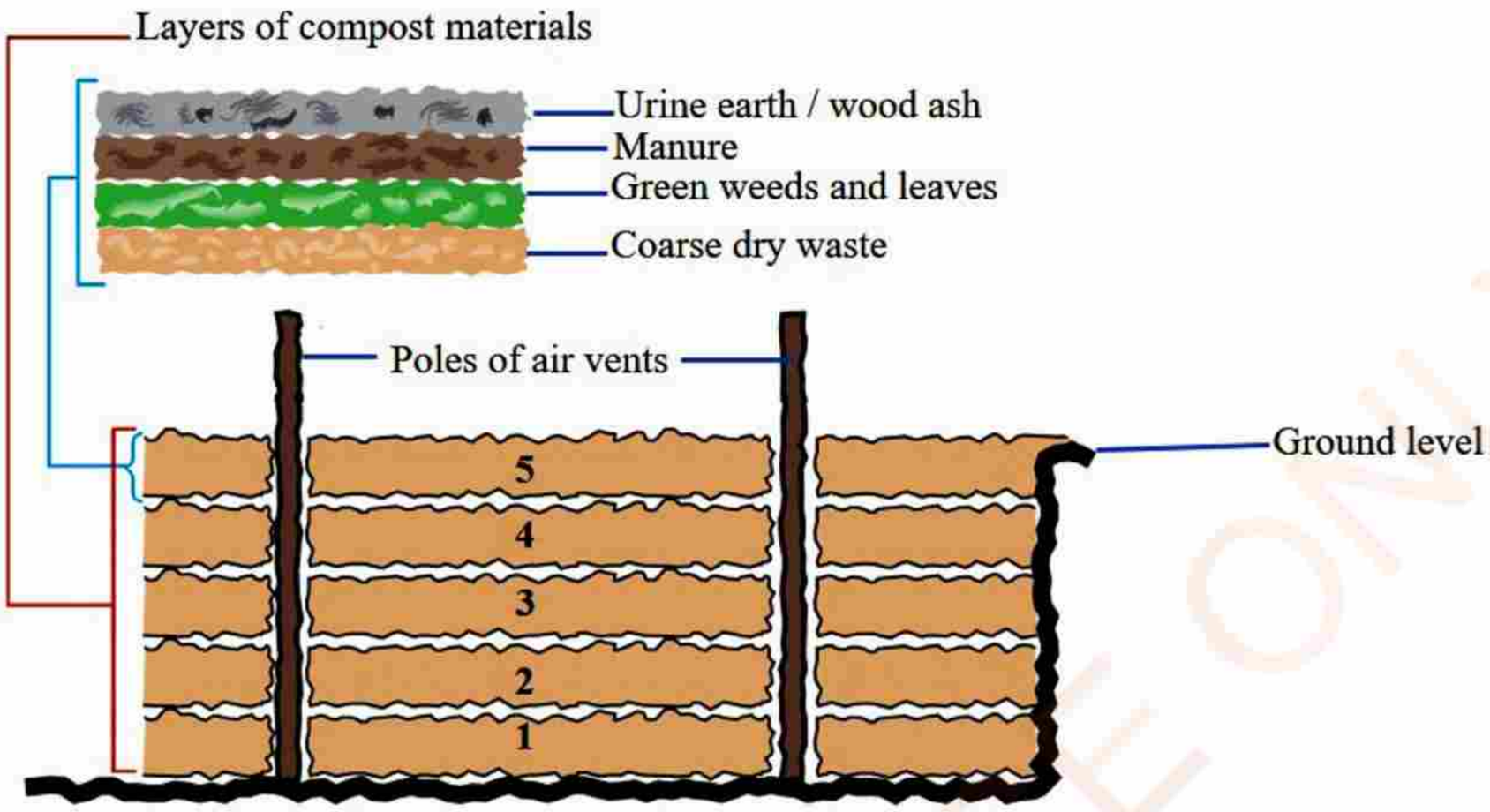


Figure 3.13: *Compost pit showing layers of materials used*

The material should be turned three times while in the pit. The first turning should be done after 15 days, the second after another 15 days and the last after a month. At each turning, the material should be mixed thoroughly and moistened with water. During the dry season, the materials should be kept moist by adding water. The vegetative materials used should be young. However, if old crop residues are used, nitrogenous fertilisers should be added to raise the level of nitrogen in the manure. Also the materials should not be packed tightly in order to increase air supply needed by the microorganisms that break down the organic matter. During the rainy season, the pit should be covered to prevent entry of too much water that could cause waterlogging. If waterlogging occurs, there will be poor decomposition of the materials. It will also cause leaching of the nutrients.

The heap method for preparing compost manure is also known as *stack method*. This method is used during the rainy season. The materials used are crop residues, animal waste, farmyard manure or compost manure, inorganic fertilisers, and top soil as shown in Figure 3.14. The following is the procedure used in preparing compost using the heap method.

1. Scrape off the surface vegetation and topsoil from the selected site. Level the ground.
2. Fix the pegs at a distance of 2 m apart to form the four corners of the heap. The heap should be about 1.5 m high.

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3. Start the heap with a 20 cm layer of fibrous materials such as leaves, hay, straw or any other refuse materials. Cover the layer of the fibrous materials with a 10 cm layer of nitrogenous materials such as fresh grasses, weeds, fresh or dry manure or digested (disintegrated) sewage sludge. Repeat the pattern of 20 cm of fibrous materials and 10 cm of nitrogenous material until the desired height of the heap is achieved. Wet the heap after each layer. The wetting should be continued during the entire period of decomposition.

6. Fix the wood planks along the sides to hold the materials in position.

7. Cover the heap with soil or hay to retain heat. Turn the heap at intervals of 6 and 12 weeks, until complete decomposition of the compost has occurred. The turning helps to improve air circulation for proper decomposition. The manure is usually ready for use after about six months.

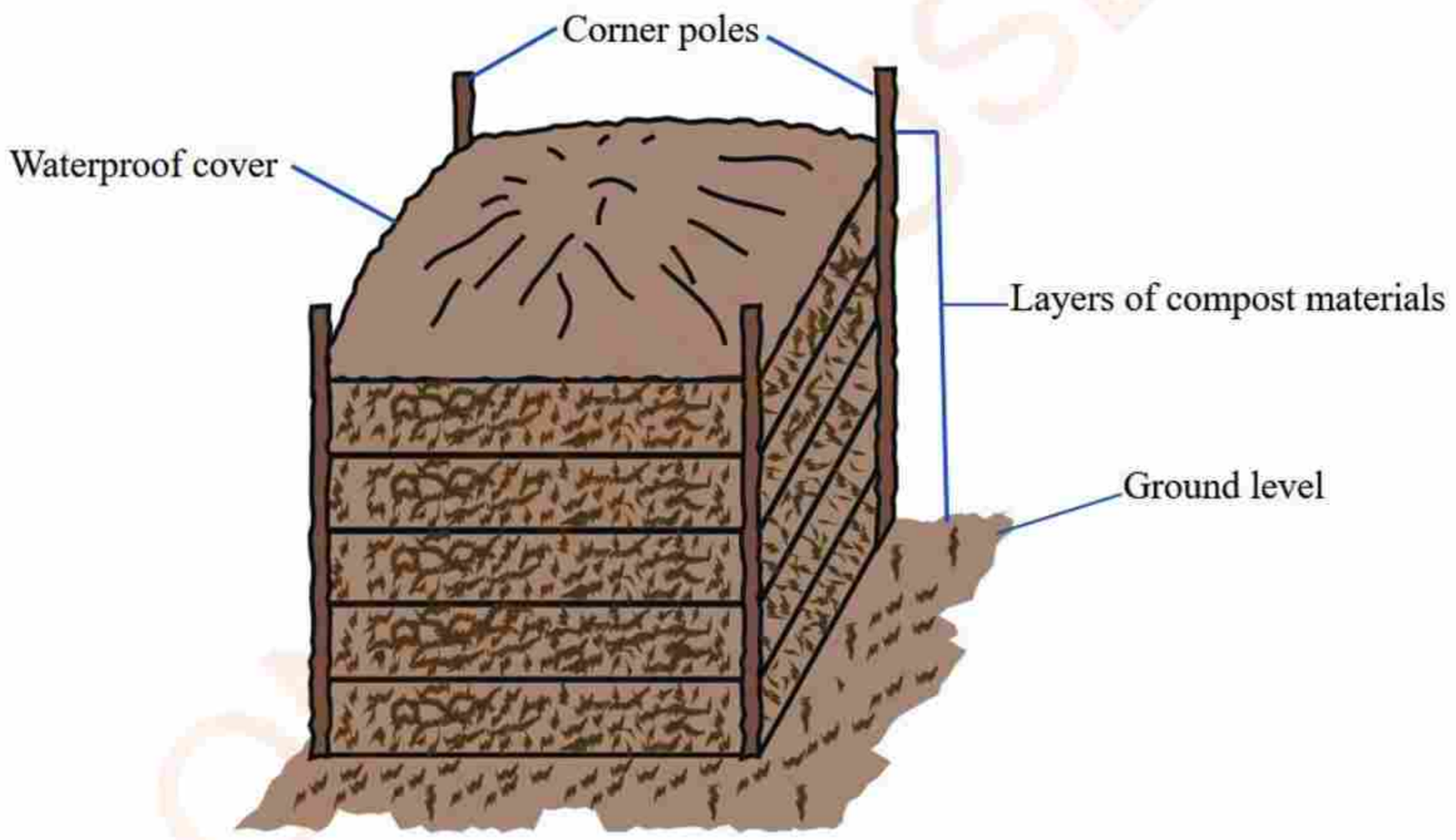


Figure 3.14: *Compost heap*

Advantages and disadvantages of manures

Apart from the fact that manures contain about 97% of the nutrients which are required by the plants, they have various advantages and disadvantages. Thus, an insight on their advantages and disadvantages is required in order to increase the effectiveness of manures and avoid some detrimental effects associated with improper applications of manures.

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Advantages

The following are some of the advantages of manures:

(a) Manures improve soil structure. Humus from decomposed organic matter binds soil particles together, thereby improving the structure. This improves soil aeration and drainage.

(b) Humus from organic matter is mostly dark in colour and gives the soil a characteristic dark colouration. Black colour absorbs more heat, and therefore helps to moderate soil temperature.

(c) Manures are not readily leached out. This is due to the long time it takes for manures to decompose and dissolve in water.

(d) They provide food and shelter for soil microorganisms responsible for decomposition of organic matter.

(e) They do not change the pH of the soil greatly.

(f) They improve soil fertility by releasing a wide range of nutrients into the soil over a long period.

Disadvantages

The use of manures is accompanied with some challenges, which include the following:

(a) Manures are bulky. Manures have low nutrients content, especially phosphorus, per unit volume, thus, they are used in large quantities to supply the required amounts of nutrients. They also occupy large storage space.

(b) If the plant materials used are infested with plant pests, diseases or weed seeds, there are risks of spreading the problems to other farms.

(c) Recovery of nutrients by plants is slow. Manures release nutrients slowly over a long time. In addition, if they are not fully decomposed, crops may not benefit from them.

(d) Manures can easily lose nutrients if poorly stored. Soluble nutrients can be easily washed away, while some may evaporate when exposed to the hot sun.

(e) They have high moisture content. This makes storage and transportation difficult.

Project 3.1

Select a suitable site within the school campus to prepare compost manure. Identify any waste materials to be used. Design experimental parameters for monitoring the maturity of the composite. Use your findings to convince the management to use the waste materials to make compost manure instead of burning or discarding them.

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Fertilisers

Fertilisers are inorganic chemical compounds which are added to the soil to supply one or more nutrients. They are also called *industrial fertilisers* or *mineral fertilisers*. They contain different macronutrients and micronutrients which increase fertility of the soil. Fertilisers are grouped into three classes on the basis of the *nutrient content*, *time of application*, and *effects on the soil* pH.

1. **Nutrient content:** Based on nutrient content, there are two categories of fertilisers, namely *straight fertilisers* and *compound fertilisers*.

A straight fertiliser contains one primary macronutrients (either nitrogen, phosphorus or potassium). Straight fertilisers are named according to the primary nutrients they contain. Thus, there are three classes of straight fertilisers, which are *nitrogenous fertilisers, phosphatic fertilisers,* and *potassic fertilisers.*

(a) Nitrogenous fertilisers: These contain nitrogen as the only primary macronutrient. Examples of nitrogenous fertilisers are calcium ammonium nitrate (CAN), ammonium sulphate nitrate (ASN), sulphate of ammonia (SA), and urea. The characteristics of some individual nitrogenous fertilisers are shown in Table 3.3. The following are the properties of nitrogenous fertilisers:

(i) They are highly soluble in water.

(ii) They are easily leached to lower soil horizons beyond the root zone of most crops. They should therefore be applied to growing crops.

(iii) They do not remain in the soil for a long time, and hence need to be applied frequently.

(iv) They have a scorching effect on plants. They should not come in contact with any part of the plant, especially the leaves. They should be applied a short distance from the plant stem or roots. This is with exception of foliar fertilisers, which are applied (sprayed) to the plants' foliage so that the plants can absorb nutrients through the leaves.

(v) They are highly volatile. Under hot weather conditions, they change into gaseous form and escape into the atmosphere.

(vi) They are hygroscopic due their ability to absorb moisture from the atmosphere.

(vii) Most nitrogenous fertilisers are corrosive and should not be handled with bare hands. They also corrode metal surfaces such as tin and iron.

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Table 3.3: *Characteristics of nitrogenous fertilisers*

Fertilisers	**Characteristics**
Sulphate of ammonia or ammonium sulphate (SA or AS), $(NH_4)_2SO_4$	It has 20% to 21% nitrogen which occurs in ammonium form and therefore it is slow acting. It is an acid-forming fertiliser. It has a white crystalline appearance, like white sugar. It is highly volatile.
Ammonium sulphate nitrate (ASN) $NH_4NO_3 + (NH_4)_2SO_4$	It is a mixture of ammonium nitrate and ammonium sulphate. It has a nitrogen content of 26%. It is less acidic compared to sulphate of ammonia. It is supplied in form of brownish orange or yellow granules. It is highly corrosive.
Calcium ammonium nitrate (CAN) $NH_4NO_3 + CaCO_3$	It is a mixture of ammonium nitrate and calcium carbonate. It has a nitrogen content of 21%. It is a neutral fertiliser. It is highly hygroscopic and non-corrosive. It is applied as a top dress. It is supplied in form of greyish granules.
Urea $CO(NH_2)_2$	It has 45% to 46% nitrogen. It is easily lost through evaporation and leaching. It is used on crops with high absorption capacity such as sugarcane. It has a scorching effect. It is soluble in water.

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(b) Phosphatic fertilisers: These contain phosphorus as the only primary macronutrient. Examples of phosphatic fertilisers are single superphosphate (SSP), double superphosphate (DSP) and triple superphosphate (TSP). Table 3.4 shows some individual phosphatic fertilisers and their characteristics. The following are the properties of phosphatic fertilisers:

(i) They remain in the soil for a long time. Because of this, they benefit subsequent crops in the second, third, and fourth seasons after application.

(ii) They are sparingly soluble in water.

(iii) They are not easily leached, and are therefore applied early at planting time.

(iv) They have a slight scorching effect and have to be mixed thoroughly with the soil to minimise the scorching effect.

Table 3.4: *Characteristics of phosphatic fertilisers*

Fertilisers	**Characteristics**
Single superphosphate (SSP) $Ca(H_2PO_4)CaSO_4$	It contains 20% to 21% phosphorus pentoxide (P_2O_5). It induces negligible acidity to the soil. It supplies phosphorus, calcium, and sulphur. The phosphorus in SSP is soluble in water. Due to the presence of calcium in the SSP, the fertiliser should not be stored with ammonia-containing fertilisers as they will react, leading to the escape of ammonia gas. It is supplied in form of white creamy granules.
Double and triple superphosphates (DSP and TSP) $Ca(H_2PO_4)_2$	Double and triple superphosphates contain two and three times the phosphorus content of single superphosphate (SSP), respectively. They contain 43% to 52% P_2O_5. They are supplied in the form of greyish granules but smaller than those of CAN. They are slightly acidic.

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(c) Potassic fertilisers: These contain potassium as the only primary macronutrient. They include potassium chloride or chloride of potash (KCl) and potassium sulphate or sulphate of potash (K_2SO_4). The following are the properties of potassic fertilisers:

(i) They have moderate scorching effect.

(ii) They are moderately soluble in water. They are more soluble in water than phosphatic fertilisers, but less soluble than nitrogenous fertilisers.

Compound fertilisers contain two or more of the primary macronutrients. They are made by mixing two or more straight fertilisers. The fertiliser that contains all the primary macronutrients is called *complete fertiliser*. Table 3.5 shows some compound fertilisers and their characteristics.

Table 3.5: *Some compound fertilisers and their characteristics*

Fertiliser	**Characteristics**
Diammonium phosphate (DAP) $(NH_4)_2PO_4$	It has a fertiliser grade of 18-46-0. It is moderately acidic because of the ammonium content. It contains both nitrogen and phosphorus. It is applied at planting time.
Nitrophos (NP)	It is moderately acidic. It contains both nitrogen and phosphorus.
Monoammonium phosphate (MAP), $NH_4H_2PO_4$	It is moderately acidic. It has the same characteristics as DAP.

2. **Time of application:** This group include fertilisers that are applied during planting and those that are applied when the crop is actively growing. During planting, phosphatic and compound fertilisers are usually applied. Therefore, they are called *planting fertilisers*. Fertilisers that are applied when the crop has active growth are called *top-dressing fertilisers*, and are mainly nitrogenous or potassic.

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3. **Effects on soil pH:** A fertiliser can either be acidic or neutral. Apart from calcium ammonium nitrate (CAN) which is neutral to slightly basic, almost all other fertilisers are acidic.

Fertiliser analysis and ratio

The nutrient content of a compound fertiliser is determined by *fertiliser analysis* (fertiliser grade) or by *fertiliser ratio*. Fertiliser grade refers to the percentage amount of each primary macronutrient, that is, nitrogen (N), phosphorus (P), and potassium (K) present in the fertiliser.

$$\text{That is, Percentage of nutrients} = \frac{\text{Nutrient content}}{\text{Total weight of fertiliser}} \times 100$$

The fertiliser grade is usually indicated on the fertiliser bag as NPK, where P and K are normally taken as P_2O_5 and K_2O, respectively. The percentages are given as ratios. For example, 100 kg bag of fertiliser grade 20-20-20 contains 20 kg of N, 20 kg P_2O_5, and 20 kg of K_2O. The fertiliser grades vary depending on the manufacturers' purposes and soil needs. For example, the fertiliser grade of urea is 46-0-0 meaning that the fertiliser contains 46% N, and no P and K. Also, the fertiliser grade for ammonium phosphate is 11-52-0 meaning that 11% is N, 52% P, and no K. Figure 3.15 shows some examples of fertilisers with their grades.



Figure 3.15: *Fertilisers with their grades*

The fertiliser ratio refers to the simple ratio of the nutrients relative to each other. For example, a fertiliser of grade 20:20:20 has a 1:1:1 ratio of $N:P_2O_5:K_2O$ (NPK). The fertiliser ratio is calculated from the fertiliser grade by dividing all grades by the smallest number of fertiliser grade. Thus, in the previous example for NPK, the fertiliser ratio was calculated by dividing all grades by 20.

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Determining the amount of fertiliser to apply

The fertiliser grade and fertiliser ratio are used in determining the amounts of fertilisers to be applied on a piece of land. The amounts of fertilisers to be applied per hectare depend on the amounts of nutrients required and the fertiliser grades available.

Example 3.1

A piece of land requires 120 kg of N, 60 kg of P_2O_5, and 80 kg of K_2O to be applied per hectare. The following fertilisers are available for application: sulphate of ammonia, SA (21% N), single superphosphate, SSP (18% P_2O_5), and nitrate of potash, NoP (60% K_2O). Calculate the amount of each fertiliser needed to be applied per hectare on the piece of land.

Solution

Given

21% N in SA = 21 kg of N in 100 kg of SA;

18% P_2O_5 in SSP = 18 kg of P_2O_5 in 100 kg of SSP, and

60% K_2O in NoP = 60 kg of K_2O in 100 kg of NoP

(a) The amount of SA which gives 120 kg of N = ?

100 kg of the sulphate of ammonia contain 21 kg of nitrogen. To get 120 kg of nitrogen will require:

100 kg of SA $\Rightarrow$ 21 kg of N

? kg of SA $\Rightarrow$ 120 kg of N

$$\frac{100 \text{ kg} \times 120 \text{ kg}}{21 \text{ kg}} = 571.43 \text{ kg of SA/ha}$$

(b) The amount of SSP which gives 60 kg of P_2O_5 = ?

100 kg of single superphosphate contain 18 kg of P_2O_5. To get 60 kg, you will require:

100 kg of SSP $\Rightarrow$ 18 kg of P_2O_5

? kg of SSP $\Rightarrow$ 60 kg of P_2O_5

$$\frac{100 \text{ kg} \times 60 \text{ kg}}{18 \text{ kg}} = 333.33 \text{ kg of SSP/ha}$$

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(c) The amount of NoP which gives 80 kg of K_2O = ?

100 kg of nitrate of potash contain 60 kg of K_2O. To get 80 kg you will require:

100 kg of NOP $\Rightarrow$ 60 kg of K_2O

? kg of NOP $\Rightarrow$ 80 kg of K_2O

$$\frac{100 \text{ kg} \times 80 \text{ kg}}{60 \text{ kg}} = 133.33 \text{ kg of nitrate of potash/ha}$$

Methods of fertiliser applications

The aim of using fertiliser is to obtain high yields. The right method of fertiliser application must be used for the fertiliser to be efficiently used by plants. The method used to apply a given fertiliser is determined by the type of soil, roots of the crop, the fertiliser being applied, and the weather conditions at the time of application. The following are some of the methods used in applying fertilisers.

Broadcasting methods: This involves the random scattering of fertilisers on the farm. Broadcasting is done either manually or by the use of fertiliser spreaders. This method is used to spread nitrogenous and potassic fertilisers when the soil is moist.

Placement method: In this method, the fertiliser is put in the planting holes or drills. The fertiliser is then mixed thoroughly with the soil before placement of seeds. This method is mainly used when applying phosphatic fertilisers.

Side dressing application: This is the placement of nitrogenous fertilisers at the side of the crop or around the growing crop. It is mainly used on perennial crops like coffee.

Foliar spraying: This is the application of fertilisers in solution form on the leaves of the crops. The fertilisers are directly absorbed by the leaves. This method is used when conditions do not allow the use of soil-applied fertilisers.

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For example, during a prolonged dry season. Foliar is sprayed to avoid formation of complex compounds which reduce the availability of plant nutrients.

Drip application: In this method, the fertiliser is dissolved in water and applied to individual plants through pipes or bottles. It is an uneconomical (costful) method, and is commonly used in horticultural crop fields.

Banding: In this method, the fertiliser is placed either below or on the side of the seed or plant, at a distance of 6 to 9 cm from the seed or plant.

Advantages and disadvantages of inorganic fertilisers

For effective use of fertilisers, an insight on their advantages and disadvantages is required in order to avoid some detrimental effects which can result from improper applications.

Advantages

Inorganic fertilisers are advantageous in that, they:

(a) are not bulky, and can therefore be transported easily,

(b) contain readily available nutrients for plant growth,

(c) are relatively easy to apply compared to manures, and

(d) enable the regulation of specific nutrients to the required levels for the growth of specific crops.

Disadvantages

Despite the advantages, inorganic fertilisers have some shortcomings. Some of them include the following:

(a) They are expensive.

(b) They cause rapid chemical changes in the soil, hence affecting the soil pH.

(c) They do not improve the physical properties of the soil.

(d) Nutrients from inorganic fertilisers are easily released, hence can be easily leached.

(e) Some inorganic fertilisers have a scorching effect on some crop parts such as leaves and stems.

(f) They do not promote the microbial activities.

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Soil fertility and soil productivity

Soil fertility is the ability of the soil to provide nutrients in proper and balanced quantities for the growth of plants. A fertile soil should have the correct proportions of plant nutrients and optimum pH. *Soil productivity* is the capacity of the soil in its normal environment to support crop production determined by the entire spectrum of its physical, chemical and biological activities. Soil fertility greatly affects soil productivity. A fertile soil always leads to high soil productivity. However, soil productivity is affected or influenced by other factors in addition to the soil fertility. For example, the presence of weeds in a farm may lower the levels of productivity of the soil, even when the soil is fertile. Other factors like the farming method used may also lower the productivity of the soil.

Factors affecting soil fertility and productivity

Soil fertility and soil productivity can be affected by different factors such as soil depth, drainage, water holding capacity, soil pH, pests, and diseases. These factors can be described as follows:

Soil depth: Deep soils give plant roots greater volume to obtain plant nutrients and provide strong anchorage.

Drainage: Good drainage is important for proper aeration of the soil, hence healthy root development.

Water holding capacity: A fertile soil should have good water holding capacity in order to retain enough water for plant uses.

Soil pH: Correct soil pH is important since the tolerance to acidity or alkalinity varies with plant families.

Pests and diseases: Productive and fertile soils are free from pests and diseases.

Causes of loss in soil fertility

Soil fertility may be lost through many ways. Some of the ways are caused by human activities, while others are through natural processes. The following are some of the ways through which soil fertility may be lost.

Leaching: This is common with nutrients that are highly soluble in water, such as nitrate which provide nitrogen. These nutrients are carried to lower levels far beyond the reach of many plant roots. Soils with many leached nutrients are infertile.

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Soil capping: This is when the soil is covered (capped) with an impervious material which prevents the penetration of rainwater into the soil. This leads to surface run-off. Soil capping denies the soil adequate moisture and exposes the soil to erosion.

Soil erosion: This is the carrying away of the top fertile soil by moving water and wind. Erosion leads to loss of the fertile top soil and plant nutrients. This makes the soil infertile.

Monocropping: This is the practice of growing one type of crop on a piece of land for a long time. The crop grown uses only those nutrients it needs, while other nutrients remain unused. This leads to exhaustion of some nutrients, and eventually to their deficiency in the subsequent years. There is also likelihood of building up of pests and diseases. The same pests and diseases are passed on from the residues of the previous crop. This leads to low yields.

Continuous cropping without nutrient replacement: Harvested crops remove large amounts of nutrients from the soil. If the nutrients are not replaced, the soil may eventually develop deficiency in the particular nutrients.

Accumulation of salts: Soil water contains dissolved mineral salts from the parent rock. Some of the salts come from decomposition of organic matter. Under normal conditions, the salts are washed away by rain water, thereby keeping their concentrations in the soil low. However, in arid and semi-arid areas, the rainfall is irregular and is not enough to remove the salts from the soils. This, together with high evaporation rate and poor drainage, lead to accumulation of salts on or below the soil surface. The salts cause deficiency of water in plants as water moves out of the roots into the soil solution due to osmotic pressure.

Change in soil pH: Inappropriate uses of fertilisers may change the soil pH. For example, the use of acidic fertilisers over a long period of time can make the soil acidic. Changes in pH affects the activities of the soil microorganisms and the availability of some nutrients. These, in turn, affect the fertility of the soil.

Burning of vegetation: When vegetation are burned, the organic matters are destroyed. This affects the activities of microorganisms such as nitrogen fixation and decomposition of organic matter. Accumulation of the resulting ash also causes imbalance of nutrients in the soil. Burning of vegetation also exposes the soil to agents of erosion, such as wind and water.

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Exercise 3.4

1. (a) Compare the richness in nitrogen content in each of the following pairs of manure:
   (i) Farmyard manure and green manure
   (ii) Green manure and compost manure
   (iii) Compost manure and farmyard manure

   (b) How can richness in nitrogen content be improved in each of the manures in (a)?

2. Differentiate between soil fertility and soil productivity.
3. Describe the factors affecting soil fertility and productivity.
4. Explain the disadvantages of fertiliser applications in farming activities.

Chapter summary

1. Soil is the top layer of loose materials that cover the Earth's surface.
2. Soil is formed through the process of weathering. There are three main types of weathering: physical (mechanical) weathering, biological weathering, and chemical weathering.
3. Soil formation is influenced by different factors. These include parent material, climate, topography, organisms, and time.
4. Essential plant nutrients are divided broadly into macronutrients and micronutrients. Micronutrients are required by plants in relatively small quantities. Macronutrients are needed by plants in large quantities.
5. Nitrogen, phosphorus and potassium are referred to as primary mineral macronutrients. They are needed by plants in relatively larger quantities.
6. Carbon, hydrogen, and oxygen are essential plant nutrients referred as primary non-mineral macronutrients. They are received by plants from the atmosphere and water.
7. Plant nutrients can be lost from the soil through various ways. Some of the ways include soil erosion, leaching, and poor farming methods.

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8. The loss of nutrients from the soil can be prevented by using various methods. Some of the methods include terracing, contour farming, crop rotation, planting vegetative covers, controlled grazing, good harvesting practices, mixed cropping, use of organic manures, and practising minimum tillage.

9. Manures are organic substances added to the soil to provide one or more plant nutrients. There are three main types of organic manures: compost manure, green manure, and farmyard manure.

10. Fertilisers are inorganic chemical compounds (mineral fertilisers) which are added to the soil to supply one or more nutrients.

11. There are two major categories of fertilisers. These are straight fertilisers and compound fertilisers.

12. The nutrient content of a compound fertiliser is determined by fertiliser analysis or by fertiliser ratio.

13. The methods used to apply fertilisers include broadcasting, placement, foliar spraying, side dressing, drip application, and banding.

14. Soil reaction is the acidity or alkalinity of the soil. Soil reaction is also known as soil pH.

15. Soil fertility is the ability of the soil to provide nutrients in proper and balanced quantities for the growth of plants.

16. Soil productivity is the capacity of the soil to support crop production determined by the entire spectrum of its physical, chemical, and biological activities.

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Revision exercise 3

Choose the correct answer in items 1 – 4.

1. Which of the following compounds can be used in liming?
   (a) Calcium hydroxide and calcium oxide
   (b) Magnesium oxide and sodium hydroxide
   (c) Calcium oxide and sodium hydroxide
   (d) Magnesium hydroxide and sodium oxide

2. Which of the following are primary macronutrients?
   (a) Phosphorus, calcium, and potassium
   (b) Potassium, calcium, and nitrogen
   (c) Phosphorus, nitrogen, and potassium
   (d) Magnesium, calcium, and nitrogen

3. Which of the following statements best describe manures?
   (a) They are plant wastes.
   (b) They are mixtures of different fertilisers.
   (c) They are products of parent rock disintegration.
   (d) They are organic substances of animal and plant origins.

4. One of the following represents the composition of straight fertilisers:
   (a) Two micronutrients
   (b) Two primary macronutrients
   (c) Only one primary macronutrient
   (d) At least one primary macronutrient and one micronutrient

5. With examples, distinguish between a straight fertiliser and a compound fertiliser.

6. (a) Explain three factors that influence soil formation.
   (b) How can low soil pH be managed?
   (c) Describe how plants obtain each of the non-mineral essential nutrients.

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7. A farmer wanted to improve the yields of the farm by adding nitrogen to the soil. The following are the fertilisers available from the local farm input shop: Calcium ammonium nitrate, $Ca(NH_4NO_3)_2$; urea, $CO(NH_2)_2$; and ammonium sulphate, $(NH_4)_2SO_4$. If the cost per 50 kg bag of each of the fertilisers is the same, which fertiliser would you advise the farmer to buy? Explain.

8. (a) Group the following plant nutrients into macronutrients and micronutrients: S, Zn, Mo, N, Cl, Mn, P, Fe, Co, K, Mg, and Ca

   (b) Give one function and two deficiency symptoms of each of the following essential plant nutrients:

   (i) N (ii) P (iii) K (iv) Zn

   (c) A certain soil requires 40 kg of nitrogen per hectare in order to meet the plants' nitrogen requirements. Calculate the quantity in kg of ammonium sulphate $[(NH_4)_2SO_4]$ fertiliser that must be applied in 5 hectares.

9. Describe any six methods that are used to manage losses of plants nutrients from the soil.

10. The pH of the soil was raised from 5 to 7 after calcium hydroxide treatment.
   (a) Write a balanced ionic equation for the reaction which caused the rise in pH.
   (b) Is it advisable to apply lime to a field that recently had an ammonium sulphate fertiliser application? Explain.

11. (a) What kinds of elemental nutrients do plants and animals obtain from the soil and atmosphere?
   (b) What information can be obtained from a label of the fertiliser's bag?
   (c) Give the similarities between organic manures and synthetic fertilisers.

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12. (a) Soil fertility and soil productivity are mistakenly used to mean the same concept. How do they differ from each other?
    (b) Describe four ways in which soil can lose its fertility.
    (c) Give four methods that can be used to improve soil fertility.

13. (a) Differentiate between manures and fertilisers.
    (b) Give four advantages and four disadvantages of manures.
    (c) Give four advantages and four disadvantages of fertilisers.

14. A fertile soil is not necessarily productive. Explain.

15. Can soil colour be used to predict its fertility? Explain.

16. Explain any five practices that can be used to maintain soil fertility.

17. If you managed to analyse the soil from a piece of land of a farmer and found that one of the primary macronutrients was missing. Being an expert, suggest the type of fertiliser(s) you would advise the farmer to apply.

18. Compare the efficiency of manures and fertilisers towards improving the soil fertility and productivity.

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Chapter Four

Pollution

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Introduction

The environment comprises both living and non-living things, such as animals, plants, bacteria, air, water, and soil. Any polluted environment is a result of introduction of harmful and unwanted materials. This may lead to changes in the energy patterns, radiation levels, and the physical and chemical constitution and abundances of these living and non-living things. The polluted environment may cause problems such as diseases and other disturbances. In this chapter, you will learn about the concept of pollution, land (terrestrial) pollution, water (aquatic) pollution, air pollution, noise pollution, global warming, ultraviolet radiation (UV radiation) protection and ozone layer depletion, and environmental conservation. The competencies developed will enable you to identify different causes and effects of pollution and design sustainable strategies to solve challenges associated with environmental pollution.

Concept of pollution

Pollution is the introduction of harmful or unwanted substances into the environment. These substances may cause undesirable changes in the physical, chemical or biological characteristics of air, water and soil. The harmful substances that cause pollution are referred to as *pollutants*, and they cause discomfort to the environment. They may harm the lives of organisms in the polluted area, or create potential health hazards to the organisms. Pollutants can be chemical substances, biological substances, and energy in the form of sound (noise), heat and light. There are three main types of pollution, namely: land (terrestrial) pollution, water (aquatic) pollution, and air pollution. Other types include noise pollution, visual pollution, light pollution, thermal pollution, and radiation pollution.

Land pollution

Land pollution is the degradation of the Earth's land surface at, and below the ground level through human activities. These activities include poor agricultural activities, mining activities, industrial activities, and poor waste disposal methods. The following are some of the causes of land pollution:

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Agricultural activities: Solid wastes from agricultural activities include waste matter produced by crops, animals, and farm residues. Mismanagement of these wastes can pollute the soil, air, and water.

Mining activities: Mining results in the production of solid waste in the form of mining waste rocks (Figure 4.1), overburden, tailings, and heap leach spent ores.



Figure 4.1: *Mining waste rocks*

Industrial activities: Industrial solid wastes are produced by industrial manufacturing processes or non-manufacturing activities. Examples include scrap metals, used tyres, masonry and concrete, and scrap lumber. Figure 4.2 shows examples of industrial solid wastes.



Figure 4.2: *Examples of industrial solid wastes*

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Sewage treatment plants: These are plants that treat wastewater to remove or reduce contaminants and produce effluents that can be safely discharged into the environment or reused. Sewage treatment plants may produce solid wastes in the form of biomass sludge and settled solids which can cause land pollution if inappropriately disposed.

Solid fuels: These refer to various types of solid materials which produce energy when burnt. The fuels include wood, charcoal, coal, peat, and animal dungs. These fuels produce smoke and ashes when burned, which pollute the environment.

Nuclear plants: Nuclear plants may produce solid nuclear waste from nuclear reactors, nuclear research projects, and nuclear bombing. The nuclear waste emit harmful radiations to the environment.

Garbage disposal: Garbage (trash, rubbish, or refuse) is a waste material discarded out of households, offices, schools or industries, usually due to lack of utility. The term does not encompass bodily waste products, purely liquid or gaseous wastes, or toxic waste products. Garbage is commonly classified into *biodegradable* and *non-biodegradable* materials. Biodegradable materials are those materials which are capable of being decomposed biologically. Examples include food remains, discarded animal matter and vegetable matter, clothes, and wood. Non-biodegradable materials cannot be decomposed biologically. Plastics and glasses are examples of non-biodegradable materials. Garbage should be sorted before disposal. Improper garbage disposal causes solid waste problems. Figure 4.3 shows an example of a waste disposal site with different types of wastes.



Figure 4.3: *Waste disposal site*

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Effects of land pollution

The following are some of the effects of land pollution on the environment:

1. The presence of non-biodegradable solid wastes in the environment pose threats to organisms.
2. Radiations from nuclear waste can cause abnormalities in organisms such as deformities or cancers.
3. The presence of piles of wastes on land can make the environment unattractive. Plastic wastes and heaps of rock wastes spoil the appearance of the natural environment.
4. Decaying wastes attract household pests. This makes homes and other places unhealthy, dirty, and unpleasant places to reside in.
5. Land pollution damages terrestrial lives of organisms.
6. Land pollution reduces the amount of useful land.

Methods of preventing and controlling land pollution

The following are some of the methods that can be used to prevent and control land pollution:

Reducing, re-using, and recycling (use of 3Rs): *Reducing wastes* involves producing less wastes at the sources. *Re-use* involves finding new ways to use materials that would otherwise have been thrown. For example, some plastic containers can be washed and used to store household items; old glass jars can be used to store food items, and old tyres can be used in the garden and in the play yard. *Recycling* is the collection, sorting, and reprocessing of materials that would otherwise be thrown away as wastes, into raw materials which can be used to make new products. Materials such as papers, metals, glasses, and plastics should be recycled instead of being disposed off into the environment. For example, papers can be recycled into paper towels, toilet paper, and napkins; glass can be recycled to make new glass items such as jars, bottles, vases, and containers; plastics can be made into new plastic bottles, and metal scraps can be used to make different products such as benches and gliders. In addition, metal scraps, can also be melted and moulded into other products such as nails, bars, and rods.

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Use of biodegradable plastics: Non-biodegradable plastics such as polypropylene, polyethylene, polyvinyl chloride, and polystyrene, greatly contribute to land pollution. They are non-biodegradable since they cannot be broken down by the actions of organisms in the environment, and therefore remain in the environment for a long time. Degradable plastics have been developed to solve the environmental problems posed by non-biodegradable plastics. Biodegradable plastics include biopolymers such as those used in making surgical sutures, photodegradable plastics which are normally incorporated with catalytic materials to facilitate the biodegradation process, and water soluble biodegradable plastics.

Use of designated dumping sites: Urban wastes should be discarded in designated sites to control the problem of littering. The waste should be treated accordingly in the disposal sites. Some of the methods that can be used to manage urban waste include incineration and establishing waste stabilising sites such as wastewater stabilisation ponds (WSP). Incineration is a process in which wastes (such as laboratory and medical wastes) are burned at high temperature (600 °C and above) until they are destroyed completely. This process is carried out in an incinerator (Figure 4.4). Wastewater stabilisation ponds are designed for the treatment of wastewater in order to reduce or remove wastes.



Figure 4.4: *Example of an incinerator*

Formulating and enacting policies and laws: The municipalities and communities should put in place laws and regulations to prevent and control terrestrial pollution. The laws and regulations should cover all aspects that contribute to the control and protection of terrestrial pollution. These include guidelines for the discharge and treatment of sewage, use of agricultural chemicals and fertilisers (agrochemicals), nuclear waste disposal, use of plastics and related materials, disposal of harmful chemicals and solid waste from industries, and disposal of urban waste.

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Creating awareness: Awareness should be created to the public on the importance of keeping the environment clean. This should be done in schools and colleges, at market places and other appropriate forums. Individuals, organisations, and institutions should also take part in global events such as the World Environment Day, which is observed on the 5th June of every year. Such events should be used to create awareness on the importance of a clean environment. The mass media such as television, radio, and newspapers can also be used to create awareness on environmental issues. Political wills from national leaders may also help to promote awareness and create responsibilities in waste management.

Exercise 4.1

1. (a) Discuss the causes of land pollution?
   (b) Most agrochemicals are regarded as soil pollutants. Explain.
2. How does land pollution pose dangers and risks for diseases and accidents to organisms?
3. Explain the disadvantages of polluted soil.

Water pollution

Water (aquatic) pollution is the contamination of water bodies by foreign substances that lower the quality of water. Water bodies include oceans, seas, lakes, dams, ponds, streams, and rivers. The introduction of harmful substances (pollutants) in water affects the aquatic organisms and also makes the water unsafe for domestic and industrial uses.

Sources of water pollution

The sources of water pollution can be categorised into *point sources* and *non-point sources*. Point sources of water pollution take place when harmful substances are released directly into the water bodies. Oil spills and the release of industrial effluents (liquid wastes) directly into water bodies are examples of point sources. Non-point source water pollution delivers pollutants into the water bodies indirectly. An example of this type of water pollution is when fertilisers and pesticides from a field are carried into streams by surface run-off.

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Causes of water pollution

Water can be polluted by pesticides, fertilisers, oil spills, chemicals and mining wastes from mining processes, sediments, wastewater from industrial processes, sewage, marine debris, poisonous gases and metals, microplastics, heat, and noise. These causes of water pollution are described as follows:

Pesticides: A pesticide is a substance or mixture of substances used to manage and control pests and diseases. A pest is an organism that competes with human for food, destroys property, and spreads and transmits diseases. Pesticides that are applied to crops, animals, and soil can be carried into streams and rivers by surface run-off. They can also drain down (be leached) into groundwater. These contaminate water hence affecting the aquatic organisms, making the water unsuitable for use.

Fertilisers: Fertilisers are organic or inorganic substances containing chemical elements that improve growth of plants and fertility or productivity of the soil. Manure, and chemical fertilisers contain nutrients such as nitrates and phosphates. These nutrients can be carried by rainwater into water bodies where they cause excessive growth of aquatic plants and algae. This phenomenon is known as *eutrophication*. Eutrophication clogs waterways and blocks light from penetrating into the deeper waters leading to the deaths of aquatic organisms. When aquatic plants and algae die, dissolved oxygen is used up during decomposition. This lowers the amount of oxygen available in water for other aquatic organisms. Such areas are commonly called *dead zones*. Nutrient pollution is a problem, particularly in estuaries and deltas, where run-off that was aggregated by watersheds is finally dumped at the mouths of major rivers.

Oil spills: The leakage of petroleum onto the surfaces of water bodies causes major water pollution to the aquatic environment. The spills form a thin layer of oil on the water surface, which affects the exchange of gases between water and the atmosphere. Land-based petroleum pollution is also carried into waterways by surface run-off. This includes drips of oil, fuels and fluids from vehicles, and drips from industrial machineries. Drilling and extraction operations for oil and gas can also contaminate coastal water and groundwater.

Mining: Mining activities are associated with the production of various wastes which can cause water pollution in a number of ways including the following:

(a) The mining process exposes toxic metals, non-metals and their compounds that were buried in the earth. Rainwater leaches these chemical substances as a result of acid drainage and toxic metal pollution that can persist long after the mining operations have ceased.

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(b) The action of rainwater on piles of mining waste (tailings) can also transfer pollutants to fresh water supplies.

(c) In gold mining, cyanide is usually poured on piles of mined rocks (a leach heap) for chemical extraction of gold from the ores. Some of the cyanide eventually find its way into nearby water bodies.

(d) Huge pools of mining waste slurries (semi-liquid mixtures) are often stored behind containment dams. If the dam is leached, leaks or bursts, chemical wastes may spread into nearby water bodies causing water pollution.

(e) Dumping mining wastes directly into water bodies as a method of disposal. This is done by some mining companies.

Sediments: When forests are cleared, soil gets exposed to the agents of erosion such as run-off. The eroded sediments get deposited into water bodies, affecting aquatic lives. Poor farming practices also cause soil erosion, thereby contributing to sediment pollution in water bodies.

Industrial processes: Water that is used in industrial production processes may be discharged into water bodies through industrial effluents as shown in Figure 4.5. This wastewater may contain harmful chemical substances that affect the quality of water and interfere with the lives of aquatic organisms.



Figure 4.5: *Industrial effluent*

Sewage: This happens when wastewater is discharged directly into rivers and streams without being treated. Untreated sewage wastes facilitate the growth of disease-causing organisms in water bodies. Wastewater should be treated in treatment plants or stabilisation ponds. Figure 4.6 shows an example of

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wastewater stabilisation ponds before being discharged to the receiving water bodies such as rivers, lakes, and oceans. Leaking septic tanks and sewarages can also cause groundwater and streams contamination.



Figure 4.6: *Wastewater stabilisation ponds*

Marine debris: These are also known as *marine litter* and they refer to scattered pieces of rubbish or remains that have been released into the sea or ocean. Plastic wastes, cans, and logs are examples of marine debris (Figure 4.7). These debris mainly come from urban wastes and garbage thrown overboard from ship and boats and through surface run-off.



Figure 4.7: *Marine debris*

Poisonous gases and metals: These pollutants contribute substantially to water pollution. Pollutants like mercury, sulphur dioxide, nitrogen oxides, and ammonia can get into the water bodies. The pollutants can cause problems like contamination in fish, acidification of lakes, and eutrophication. Most of the gases that affect water come from coal-fired power plants, vehicle exhaust fumes, and industrial emissions.

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Heat: This is a water pollutant because it decreases the capacity of water to hold dissolved oxygen and increases the rates of metabolism in aquatic organisms. Increased water temperatures result into low amount of dissolved oxygen in the water causing deaths of many aquatic organisms. The increase in temperature is often caused by discharge of heated industrial effluents such as cooling water by factories and power plants.

Noise: Many marine organisms such as whales, sea turtles, and fish use sound to communicate, navigate, and hunt. Noise from ship engines and sonars has negative effects on such organisms. Some of the organisms may find it hard to hunt or detect predators, and others will be unable to navigate properly.

Microplastics: Microplastics are small plastic particles with a length of 5 mm or less, that occur in the environment as a consequence of plastic pollution. Microplastics have been found in different environmental matrices such as soil, atmosphere, and water bodies. They are also found in beaches, shelves, surface and deep water sediments. Microplastic ingestion has been observed in many aquatic species including fish and invertebrates. The negative impacts of microplastics ingestion in fish include clogging of the alimentary appendages and inflammation of the digestive system.

Effects of water pollution

Polluted water is harmful to organisms including plants, humans and animals, and the environment in general. Water pollution affects the ecosystems and has the following consequences:

1. Some infectious diseases are due to the effects of water pollution. Waterborne diseases occur when parasites or pathogens are transmitted through contaminated water. Some of the diseases include typhoid, cholera, and dysentery. Contaminated water can facilitate the spread of intestinal parasites such as roundworms and hookworms. Polluted water can also cause rashes, respiratory infections, diarrhoea, vomiting, and stomach aches.
2. Excessive growth of waterweeds as a result of nutrient pollution reduces water clarity, which makes it hard for aquatic organisms to find food. The weeds also block the sunlight needed by sea grasses which serve as nurseries for many aquatic organisms. The decomposition of dead waterweeds uses oxygen from water, thus reducing the capability of the water to support aquatic lives. Water weeds also compete for oxygen with aquatic organisms during the night. Such areas with low oxygen contents become coastal dead zones. Nutrient pollution can also trigger outbreaks of diseases such as methemoglobinaemia to aquatic organisms and children.

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3. Severe chemical spills and leaks into water bodies kill aquatic organisms such as fish. Presence of pesticides in drinking water and in the food chain can damage the nervous, endocrine and reproductive systems, kidney, and the liver. Some pesticides cause cancer and other diseases.

4. Exposure to oil or its constituent chemicals can alter the ecology of aquatic habitats and the physiology of marine organisms. The oil (or its components) can seep into marsh and sub-tidal sediments and remain there for many years. This negatively affects marsh grasses, marine worms, and other aquatic life forms that live in, on or near the sediment.

5. Mercury has serious effects on human health, especially young children and unborn babies. Exposure to mercury in unborn babies can result in delayed or incomplete mental development, autism, and brain damage. Mercury can also cause serious nervous system problems in adults. These include Parkinson's disease, multiple sclerosis, and Alzheimer's disease. Animals in the food chain that are affected by accumulation of mercury can also suffer the effects of mercury pollution. Possible effects include death, reduced reproduction, and slow growth rate and development.

6. In some cases, marine animals swallow debris mistaking them for prey. For example, sea turtles eat plastic bags mistaking them for jellyfish. The bags cause intestinal blockage leading to death of the turtles. Discarded or lost fishing gears (line, rope, nets) and other trash items can get wrapped around the marine animals, their fins or flippers, causing drown or injury to their limbs. Marine debris can also degrade coral reefs, sea grass beds, and other aquatic habitats.

7. Aquatic organisms are adapted to a particular temperature range. Rise in water temperature can kill the organisms through thermal shock. Excessive heat may disrupt spawning or kill young fish. Warm water lowers the amount of dissolved oxygen in the water causing stress to aquatic life.

8. Lead poison is another serious health problem in human beings that affects the nervous system. High doses of lead may result into headache, mental dullness, attention difficulties, and memory loss.

9. Chromium(VI) exposure has been associated with increased risks of lung, nasal, and sinus cancers. It can also cause severe dermatitis.

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Methods of preventing water pollution

Different sectors should work together to prevent water pollution. The following are some of the ways that can be utilised to prevent water contamination:

Reducing the use of fertilisers and pesticides: This can be achieved by adopting environmental friendly agricultural practices. These include the use of organic fertilisers (manures) and biological pest control methods.

Treating sewage and industrial waste: Pollution of water by sewage can be controlled by treating raw sewage before releasing it into the water bodies. The treatment plants should be well maintained to ensure that they are functioning properly all the time. Wastewater from industries should be cooled and detoxified before being released into water bodies.

Stopping deforestation: Most forests are catchment areas of different water bodies such as rivers and streams. Thus, clearing forests affects the biological cycles. Deforested areas allow surface run off directly into streams which eventually carry sediments into nearby water bodies. Stopping deforestation therefore reduces sedimentation into water bodies.

Controlling coastal development: Building structures near the shores contributes greatly to water pollution. Most of the wastes from these establishments are disposed off into the nearby water bodies. Governments should put in place laws that prohibit building of structures near the water bodies.

Reducing pollution from oil spills: The following are some of the ways that can be used to reduce frequencies and impacts of oil spills:

(a) Enforcing regulations that govern maintenance and inspection of commercial ships and motorboats that can leak oil and fuel into the water.

(b) Cleaning oil spills as quickly as they occur.

(c) Converting oil tankers into double-hull ships. A double-hull ship has two complete layers of watertight hull surface. The outer layer forms the normal hull of the ship and the second inner hull forms a protective barrier to seawater in case the outer hull is damaged and leaks.

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Reducing the use of mercury: The use of mercury is being phased out in many industrial processes. However, some industries continue to use mercury on a large scale. Such industries should develop methods of recovering the mercury instead of releasing it into the environment. Where alternatives exist, the use of mercury should be stopped completely.

Cleaning up existing and abandoned mines: The following are some of the ways through which water pollution due to mines can be controlled:

(a) Mining companies should clean up abandoned mines which continue to release pollutants.

(b) New mines should not be established in areas where they are likely to cause water pollution.

(c) Mining practices which cause water pollution should be banned.

Cleaning up chemical pollutants: Chemical pollutants on land should be treated accordingly before they find their way into water bodies. In case of chemical spills in water bodies, appropriate measures should be taken for remediation. As with land pollution, appropriate laws should be put in place to control water pollution. Awareness should also be created so that people are informed on the importance of clean environment.

Banning the use of lead pipes: Lead leaching from pipes into the water supply is a serious public health problem occurring in areas where water supply use lead pipes. Replacing led pipes with durable plastic pipes will reduce contamination of domestic water supplies.

Task 4.1

Visit a sewage treatment plant or stabilisation ponds in your area and carefully observe how sewage is treated before being disposed off. Write a brief report on the process.

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Project 4.1

Study one among the following sources of water and land contamination in your local environment, and propose appropriate sustainable intervention.

(a) Mining

(b) Household and yard wastes

(c) Pulp and paper mills

(d) Sewage

(e) Agriculture

(f) Construction

(g) Plastics

(h) Coal or natural gas power plants

Exercise 4.2

1. (a) Explain the difference between point source pollution and non-point source pollution.

   (b) How does eutrophication affect the quality of water?

   (c) Explain any ten causes of water pollution.

2. (a) What are the major effects of water pollution?

   (b) Give examples of diseases or health disorders which are caused by pesticide contamination in water.

3. Explain the effects of pollution by toxic metals and pesticides in the soil.

4. Briefly explain three ways in which water pollution can be prevented.

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Air pollution

Air pollution is the introduction of substances into the air which have harmful effects to the organisms and the environment. It occurs when gases, dust particles, fumes (or smoke) or odour are introduced into the atmosphere in a way that makes it harmful to organisms.

Sources of air pollution

The sources of pollutants in the air can be divided into natural sources and artificial sources. Natural sources include volcanic eruptions, hot springs and fumaroles. Artificial sources that contribute to air pollution include industries, combustion of fuels, deforestation, and chemical substances. The natural and artificial sources of air pollution may be described as follows:

Carbon dioxide: Carbon dioxide (CO_2) is one of the major air pollutants. The primary sources of carbon dioxide are burning of fossil fuels and biomass, deforestation, and industrial processes. The natural sources of carbon dioxide include out gassing from the ocean, decomposing vegetation and other biomass, volcanic eruption, naturally occurring wildfires, and belches from ruminant animals. Carbon dioxide is one of the greenhouse gases, that contributes to global warming.

Oxides of nitrogen: The oxides of nitrogen include nitrogen monoxide (NO), nitrogen dioxide (NO_2), and dinitrogen oxide (N_2O). Nitrogen monoxide and nitrogen dioxide are natural components of the atmosphere produced from various sources such as volcanic eruption, decay of organic matter and lightning. During lightning storms, nitrogen and oxygen in the atmosphere react to form nitrogen monoxide which is further oxidised by oxygen to produce nitrogen dioxide.

$$N_2(g) + O_2(g) \longrightarrow 2NO(g)$$

$$2NO(g) + O_2(g) \longrightarrow 2NO_2(g)$$

The oxides can also be produced from the burning of biomass and fossil fuels. For example, NO and NO_2 are among the gases produced when fuels are burned at high temperatures such as in coal-fired power plants and in automobile engines (Figure 4.8).

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Figure 4.8: *Exhaust fumes from a vehicle*

Nitrogen monoxide and nitrogen dioxide play great roles in the formation of both *acid rain* and *photochemical smog*. Acid rain refers to any form of precipitation with dissolved acidic gases such as sulphur dioxide acid and nitrogen dioxide fall to the ground from atmosphere. Unpolluted rain is normally slightly acidic (pH = 5.6) due to dissolved carbon dioxide which forms carbonic acid. Acid rain has harmful effects on plants, aquatic animals, and buildings.

Photochemical smog is a reddish-brown haze that is formed when oxides of nitrogen and volatile organic compounds (hydrocarbons, such as methane, propane, and benzene) react in the presence of sunlight. It tends to occur more often in summer, since it is when there is most sunlight. Photochemical smog is commonly observed in most of the world's heavy industrialised cities. Dinitrogen oxide is a natural component of the atmosphere which is also produced from nitrogen-based fertilisers, deforestation, and burning of vegetation. It is a greenhouse gas, and hence contributes to the greenhouse effect and global warming.

Compounds of sulphur: The compounds of sulphur that pollute the air include sulphur dioxide (SO_2), sulphur trioxide (SO_3) and hydrogen sulphide (H_2S). Sulphur dioxide is a major air pollutant that is produced by combustion of sulphur-containing fuels such as coal and oil. The gas is also produced during preparation of sulphuric acid and in metallurgical processes that involve ores containing sulphur. Sulphur oxides can cause health problems to people and

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damage plants and materials. At high concentrations, sulphur dioxide irritates the upper respiratory tract of human beings, making breathing difficult. Sulphur dioxide also causes acid rain.

Chlorofluorocarbons (CFCs): Chlorofluorocarbons, commonly referred to as CFCs, are organic compounds made up of carbon, chlorine and fluorine atoms. These compounds are widely used as solvents in cleaners, coolants in refrigeration and air conditioning systems, blowing agents in the production of foam, and as propellants in aerosols. They are also the main causes of ozone layer depletion in the stratosphere. It is estimated that, one chlorine atom released by CFCs can result in the loss of 100,000 ozone molecules. The lifetime of CFCs is about 20 to 100 years, and can therefore continue to destroy the ozone layer for a long period. In addition, CFCs are greenhouse gases that contribute to global warming.

Smog: The word 'smog' is derived from the words 'smoke' and 'fog' caused by vehicle exhaust gases and industrial smoke. It is the air pollution that reduces visibility, commonly observed in urban areas (Figure 4.9). The two main components of smog are ground-level ozone and particulate matter (such as pollen and dust). Other pollutants include nitrogen oxides, volatile organic compounds, sulphur oxides, and carbon monoxide.



Figure 4.9: *Smog*

Source: *https://www.firstpost.com/tech/science/delhis-air-pollution-problem-7711081.html Accessed on March, 2022.*

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Effects of air pollution

The lives and health of humans and other organisms on planet are threatened by air pollution. Health problems, acid rain, reduced visibility, enhanced greenhouse effect, and global warming are examples of effects of air pollution.

Health problems: The health effects caused by air pollutants include difficulty in breathing, wheezing, and coughing. Prolonged exposure to air pollutants can lead to severe complications such as chronic respiratory problems, and heart conditions. Illnesses related to air pollution include asthma, bronchitis, emphysema, lung and heart diseases, and respiratory allergies.

Acid rain: When sulphur dioxide and nitrogen dioxide combine with water vapour in the atmosphere, they form dilute acidic solutions. These solutions reach the Earth in form of acid rain which has pH range from 3.5 to 5.6. Acid rain damages forests and corrodes many buildings and sculptures made of marble.

Formation of acid rain

The major gases responsible for acid rain are nitrogen monoxide (NO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and sulphur trioxide (SO_3).

The acid rain caused by the presence of oxides of nitrogen in the atmosphere occurs when NO_2 combines with water to form nitric acid (HNO_3) which falls as rain.

$$2NO_2(g) + H_2O(l) \longrightarrow HNO_3(aq) + HNO_2(aq)$$

This acid dissociates in water to yield hydrogen ions (H^+) and nitrate ions (NO_3^-) which lower the pH of water bodies.

$$HNO_3(aq) \longrightarrow H^+(aq) + NO_3^-(aq)$$

The acid rain caused by oxides of sulphur present in the polluted air, occurs when SO_2 combines with rain water to form sulphurous acid (H_2SO_3).

$$SO_2(g) + H_2O(l) \rightleftharpoons H_2SO_3(aq)$$

The acid ionises to give hydrogen ions (H^+) and hydrogensulphite ions (HSO_3^-).

$$H_2SO_3(aq) \rightleftharpoons H^+(aq) + HSO_3^-(aq)$$

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On the other hand, SO_2 gas can be oxidised to SO_3 gas which reacts with water to produce H_2SO_4.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$
$$SO_3(g) + H_2O(l) \rightleftharpoons H_2SO_4(aq)$$

This can also be shown by the equation:

$$2SO_2(g) + 2H_2O(l) + O_2(g) \rightleftharpoons 2H_2SO_4(aq)$$

Sulphuric acid is a strong acid which readily dissociates in water to give H^+ and HSO_4^- that may dissociate further to give H^+ and SO_4^{2-} hence reducing the pH of the rainwater to a harmful level.

$$H_2SO_4(aq) \longrightarrow H^+(aq) + HSO_4^-(aq)$$
$$HSO_4^-(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$$

Reduced visibility: Smog reduces visibility making activities such as driving difficult.

The enhanced greenhouse effect: The greenhouse effect is caused by the *greenhouse gases*. A greenhouse gas is a gas that has the ability to absorb and release radiant energy in the thermal infrared spectrum. Examples of greenhouse gases include carbon dioxide, nitrous oxide, methane, water vapour, ozone, and chlorofluorocarbons (CFCs). The molecules from CFCs are extremely effective greenhouse gases in trapping heat. One molecule of CFC is about 10,000 times more effective than a single carbon dioxide molecule. The gases function in a similar manner as a greenhouse (Figure 4.10) in which short wave length visible light is transmitted through a translucent material like glass, absorbed by the components of the greenhouse such as plants and the floor, and converted into heat. This makes the inside of the greenhouse warmer than the outside air temperature. The greenhouse effect occurs when gases in the atmosphere trap the thermal energy and warm the Earth's surface.

When solar energy reaches the Earth's surface, most of it is absorbed, and the remaining portion is reflected back to space. The warmed earth's surface then releases some of the absorbed energy as long wave infrared radiations. The

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greenhouse gases in the atmosphere absorb and re-radiate these infrared radiations in all directions. The energy that is re-radiated back to the earth's surface warms the planet.

The greenhouse effect is actually important because it aids in heating the Earth's surface and atmosphere; without it, the Earth would be too cold for the survival of soil organisms. However, an enhanced greenhouse effect, which is caused by the presence of high levels of greenhouse gases in the atmosphere, can result in a drastic increase in temperature which may have detrimental effects on humans and other organisms.



Figure 4.10: *Greenhouse*

Methods of controlling air pollution

To mitigate the negative consequences and guarantee that environmental quality criteria are met, governments have established regulatory and other policy measures. The following are some measures that would help to control air pollution:

Reducing over-dependence on fossil fuels: Fossil fuels contribute greatly to air pollution. There is an urgent need to shift from dependence on fossil fuels to usage of 'clean' sources of energy. Clean sources of energy are those sources that do not produce harmful substances during production as well as during their uses. Clean sources of energy include solar energy, wind energy, and hydroelectric power. The use of biofuels which produce less emission is also encouraged.

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Using fuel-efficient systems: Reducing energy consumption by manufacturing and using energy-saving appliances such as energy-saving bulbs, refrigerators, and smart thermostat will help to reduce harmful emissions.

Modifications and replacement of industrial systems: Industrial systems should be modified in order to reduce emissions. The modifications include installation of recycling devices which can help to recover harmful gaseous by-products of industrial processes. In cases where it is not possible to modify the systems, total replacement should be done.

Use of air pollution control devices: Air pollution control devices include precipitators, cyclones, scrubbers, absorbers, reduction systems, filters, and oxidisers. These should be installed in industrial plants, motor vehicles, and any other place where air pollutants are produced in large quantities.

Enforcement of laws: Environmental laws that ensure chemical wastes, whether in solid, gaseous or liquid forms are disposed safely, should be enforced. Policies should also be put in place to govern the uses of polluting devices such as motor vehicles. Vehicles and industries which emit pollutants above the acceptable limits should not be allowed to operate.

Safety measures to protect industrial workers from gaseous pollution

Industrial workers face major health risks from exposure to gaseous pollutants emitted from industrial processes. These chemicals cause various illnesses and disorders when get in contact with the skin or get into the body. Chemicals can get into the workers' bodies through inhalation, skin contact, and ingestion. The following are proposed measures to protect industrial workers from gaseous pollution:

Eliminate or substitute hazardous chemicals: The most effective way of controlling hazards caused by chemicals is by eliminating hazardous chemicals from the industrial processes or by substituting them with non-hazardous substances.

Shield processes that release harmful products: Processes that involve highly toxic materials should be carried out in sealed chambers which are leak-proof. This will prevent poisonous substances from escaping into the environment.

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Use of protective equipment: The use of personal protective equipment is the cheapest method of ensuring personal safety at work places. Personal protective equipment include safety glasses, earmuffs and plugs, respirators, gloves, safety shoes, helmets, aprons, and overalls. Workers should be provided with the correct types of protective equipment for the specific hazards and given proper training on their correct uses. If possible, workers should wash their clothes or shower at work places before going home.

Exercise 4.3

1. Explain three sources of air pollutants and their effects on human health.
2. Explain the hazards posed by the oxides of nitrogen and sulphur in the environment.
3. (a) Describe any two methods of controlling air pollution.
   (b) Suggest two ways different from those described in 3(a) on how air pollution can be controlled at your school environment.

Task 4.2

(a) Visit a nearby factory or industry and find out:
   (i) If the industrial wastes and effluents are properly disposed and treated.
   (ii) If smoke and toxic gases are produced.
   (iii) If workers are protected from hazardous chemicals and toxic gases.

(b) Write a visit report and present it to the class.

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Noise pollution

Noise pollution is among the problems in cities around the world. Noise is any disturbing or unwanted sound that affects the health and well-being of organisms. Noise pollution can occur in different components of the environment such as land, water, and air.

Causes of noise pollution

Extensive sounds in the environment lead to noise pollution that pose serious threats to the lives of humans and other organisms. Noise pollution can be caused by a number of factors including the following:

Road traffic noise: Noise from cars, motorcycles, and ambulance sirens are few examples that may affect the hearing of humans and other organisms around.

Construction activities: During construction of structures such as roads, buildings, and bridges, high levels of noise are usually produced by drilling machines or other heavy machinery in operation.

Air traffics noise: Airports with constant traffics produce elevated noises from planes during taking off and landing. The noises produced at airports may be hazardous to the hearing of the people and other organisms around the airport.

Workplace noise: Some work offices are found in open spaces, and their activities produce high noises. For example, garage and welding areas, where most of the activities such as cutting and hammering metals are conducted, produce loud noises.

Commercial noise: Recreational areas such as clubs and other commercial areas play music and provide announcements at loud volumes as part of their services. Furthermore, powerful amplifiers placed in different areas such as theatres, fitness classes, concerts, restaurants, market places, bars, and sports arenas produce loud volume which interferes with hearing.

Industrial noise: Industries are important in processing goods such as food, clothes and building materials. However, their activities produce loud sounds due to fans, generators, compressors, mills, and many other operating tools which produce loud noices.

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Residential noise: In households, there are different machines and tools or equipment used for various reasons including simplifying work or for recreation. Televisions, radios, computers, vacuum cleaners, fans, coolers, washing machines, and dishwashers are examples of the machines and equipment. All these produce loud noises that may have adverse effects to the hearing process and ability.

Events involving fireworks or firecrackers: Military activities may produce loud noises during trials of new inventions of weapons. Mining activities also involve fireworks and firecrackers when dynamites and other machines are used to break hard rocks. The loud noises produced from these activities may lead to hearing loss.

Effects of noise pollution

Noise presents a public health problem that can lead to hearing loss, sleep disturbances, children diseases and dysfunctions, hypertension and cardiovascular dysfunctions, and disturbances on marine organisms and wildlife. Some of the effects of noise pollution are described as follows:

Hearing loss: The level of noise and the time a person listens to the noise can result into the risks of hearing loss. Noise levels less than 70 decibels (dB) are not damaging to organisms, regardless of how long or consistent the exposure is. Exposure for more than 8 hours to constant noise beyond 85 dB may be hazardous. Noise levels reach dangerous intervals around 140 dB for adults and 120 dB for children. One can develop hearing loss when listening to loud music using headphones or by being exposed to loud drilling noises, heavy air traffic or land traffic, or other incidents in which noises reach dangerous levels. Hearing loss can result from a single loud noise (like firecrackers) near the ear, or more often, hearing loss develops over time due to repeated exposures to loud noises. The louder the noise, the shorter the time it takes for hearing loss to occur.

Sleep disturbances: Loud noise at night or when a person is asleep can affect every day performance and can lead to serious diseases. Apart from affecting the individual's work performance during the day, it leads to costs on the health systems and it negatively affects school performance to children.

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Children diseases and dysfunctions: Children appear to be more sensitive to noise pollution, and a number of noise pollution related diseases and dysfunctions are known to affect children. These range from hearing impairments to psychological and physical effects.

Cardiovascular diseases: Exposure to noise pollution for a longer period of time, especially during the night can lead to high blood pressure levels, cardiovascular diseases, and stress-related heart problems. Studies suggest that high-intensity noise causes high blood pressure and increases heartbeat rate as it disrupts the normal blood flow.

Disturbances on marine organisms and wildlife: Oceanic activities such as oil drills, sonars, seismic survey devices, coastal recreational watercraft, and shipping vessels populating waters cause noise pollution to marine lives. For example, noise pollution interferes with whales and dolphins feeding habits, reproductive patterns, and migration routes, and can even cause haemorrhage and death. Other than marine organisms, land animals are also affected by traffic and firecrackers noise pollution.

Measures to control noise pollution

Strict legislative measures need to be enforced to curb the effects of noise pollution. Some of the measures could be wearing of ear plugs, maintaining low noise levels, residential areas be away from noisy sources, avoiding prolonged uses of earphones, and avoiding jobs with regular exposure to high noise levels. The following are some of the measures to be taken in order to control noise pollution.

Wearing of ear plugs: People working in areas with loud noises should wear ear plugs to protect them from hearing loss. For example, people working in industries or in high sound producing project firms should wear ear plugs to keep them safe from hazardous sounds.

Maintain low noise levels: Maintain noise levels less than 70 dB that are not damaging to organisms.

Residential areas be away from noise sources: If possible, choose residential areas far from traffic and other sources of noises.

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Avoid prolonged use of earphones: People should avoid prolonged use of earphones, especially at elevated sound. Music from smartphones and other devices, particularly when the volume is set close to the maximum levels can lead to hearing loss.

Using machines or equipments with soundproofs: Machines which produce high noise such as standby generators can be protected by mounting with soundproofs to reduce the noise.

Exercise 4.4

1. Identify the sources of noise pollution in your environment.
2. Explain the effects of noise pollution on human health and other organisms.
3. Describe different methods used to control noise pollution in the environment.

Global warming

Global warming is an increase of the Earth's average temperature as a result of the increase of the greenhouse gases levels in the atmosphere. The greenhouse gases in the atmosphere absorb the infrared radiation emitted from the earth's surface which would otherwise be dispersed into space. Global warming may result in the melting of ice caps, thus causing an increase in water levels in the oceans. In humid regions, extreme precipitation increases with global warming, and may result into floods as shown in Figure 4.11.



Figure 4.11: *Flooded settlements*

Source: *https://floodlist.com/africa/tanzania-daressalaam-floods-october-2020*
Accessed on March 2022

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Causes of global warming

Global warming is mainly caused by greenhouse gases which include carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFCs), halons, and dinitrogen oxide (N_2O). The main greenhouse gases are described as follows:

Carbon dioxide: This is the major contributor to the greenhouse effect. The following are some of the sources of carbon dioxide in the atmosphere:

Clearing and burning of vegetation and biomass: Green plants, especially woody plants absorb carbon dioxide from the atmosphere as they grow. When the woody plants die and decompose, the carbon dioxide is released back into the atmosphere. Clearing of forests (deforestation) and burning vegetation result in the release of carbon dioxide to the atmosphere. In addition, deforestation decreases the number of trees that would absorb carbon dioxide (carbon dioxide sinks) from the atmosphere. Burning of biomass produces carbon dioxide.

Burning of fossil fuels: Carbon dioxide is a by-product in the combustion of fossil fuels such as coal and petroleum. These fossil fuels are burned in cars, power plants, and industries.

Methane: The main sources of methane are agricultural activities. It is released from wetlands such as rice fields, and from animals, particularly cud-chewing animals like cows. The emissions of methane gas therefore increase with the increase in agricultural activities. Methane is also produced during coal and oil mining, burning of vegetation, and from animal manures. Methane molecules have a lifetime of about 12-15 years in the atmosphere.

Dinitrogen oxide: This is produced from both natural and human-made processes. Human activities which produce dinitrogen oxide include combustion of fossil fuels in vehicles and power stations, use of nitrogenous fertilisers, and the burning of vegetation and animal waste. Natural sources include the denitrification process by anaerobic bacteria.

Chlorofluorocarbons (CFCs): The sources of CFCs in the atmosphere include fridges, air conditioners, and aerosols.

Halons: These are haloalkanes derived from hydrocarbons where one or more hydrogens are replaced by halogens mainly bromine. The main source of halons in the atmosphere are fire extinguishers.

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Effects of global warming

Global warming can result in many serious alterations to the environment, eventually making life difficult or impossible for some organisms. Global warming has a variety of negative consequences, some of which are described as follows:

Increased temperature in water bodies: Increased water temperature reduces levels of dissolved oxygen causing suffocation in aquatic organisms. It also causes bleaching of corals which is the loss of pigments and microscopic plant cells from coral tissues. Loss of pigments results into whitening of the coral reefs.

Rise in sea levels: Sea levels are rising due to thermal expansion caused by warming of the oceans (since water expands as it warms) and increased melting of land-based ice, such as glaciers and ice sheets. These may eventually lead to flooding of the coastal lands.

Changes in the world's climatic patterns: The climatic patterns in most parts of the world have changed making it hard to forecast the weather accurately. Rain seasons are no longer maintained as expected. Rains are heavier than expected, leading to flooding and sometimes they are far less than expected, leading to drought. The extent of the Earth's surface to desertification is also increasing.

Extreme weather events: These include floods, droughts, heat waves, hurricanes, and tornadoes. They are often the results of global warming. Other effects of global warming include:

(a) increased or decreased agricultural yields due to extreme or unfavourable weather.

(b) melting of ice caps such as the ice losses from Greenland, Antarctica, Mount Kilimanjaro, and melting of glaciers (Figure 4.12).

(c) extinction of some animal and plant species, and

(d) increase in the range of disease pathogens and vectors.

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February 17, 1993 February 21, 2000

Figure 4.12: *Ice loss at Mount Kilimanjaro due to increase of global temperature*

Source: *https://earthobservatory.nasa.gov/images/3054 Accessed on March 2022*

Solutions to global warming

The effects of greenhouse gases in the atmosphere will continue to be felt for a long time. This is due to the fact that greenhouse gases remain in the atmosphere for long periods of time. This implies that global warming may continue even if we were to cut down on the emission of the greenhouse gases. However, it is important to reduce the amounts of the emissions before they reach alarming levels. The following are some of the measures that can be taken to reduce greenhouse gases emissions into the atmosphere:

1. Put in place energy conservation measures to reduce the use of fossil fuels. These measures include the use of public transport to minimise the number of vehicles on the roads and the use of fuel-efficient cars.
2. Use of cleaner alternative sources of energy such as solar energy and wind.
3. Controlling deforestation while emphasizing afforestation (planting of trees) that would absorb carbon dioxide.
4. Commit in minimising emissions of the greenhouse gases into the atmosphere. This is being done through agreements such as the Kyoto Protocol.

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Ultraviolet radiation protection and ozone layer depletion

The ozone layer is a belt of naturally occurring ozone gas (O_3) that is located in the stratosphere (around 15 km to 30 km above the Earth's surface) (Figure 4.13). Over 90% of the ozone in the earth's atmosphere is within the ozone layer. The stratosphere is the second layer of the earth's atmosphere. The *troposphere*, *mesosphere*, and *thermosphere* are other regions of the atmosphere. The troposphere is the lowest layer of the atmosphere, the mesosphere is located above the stratosphere, and the thermosphere is above the mesosphere.

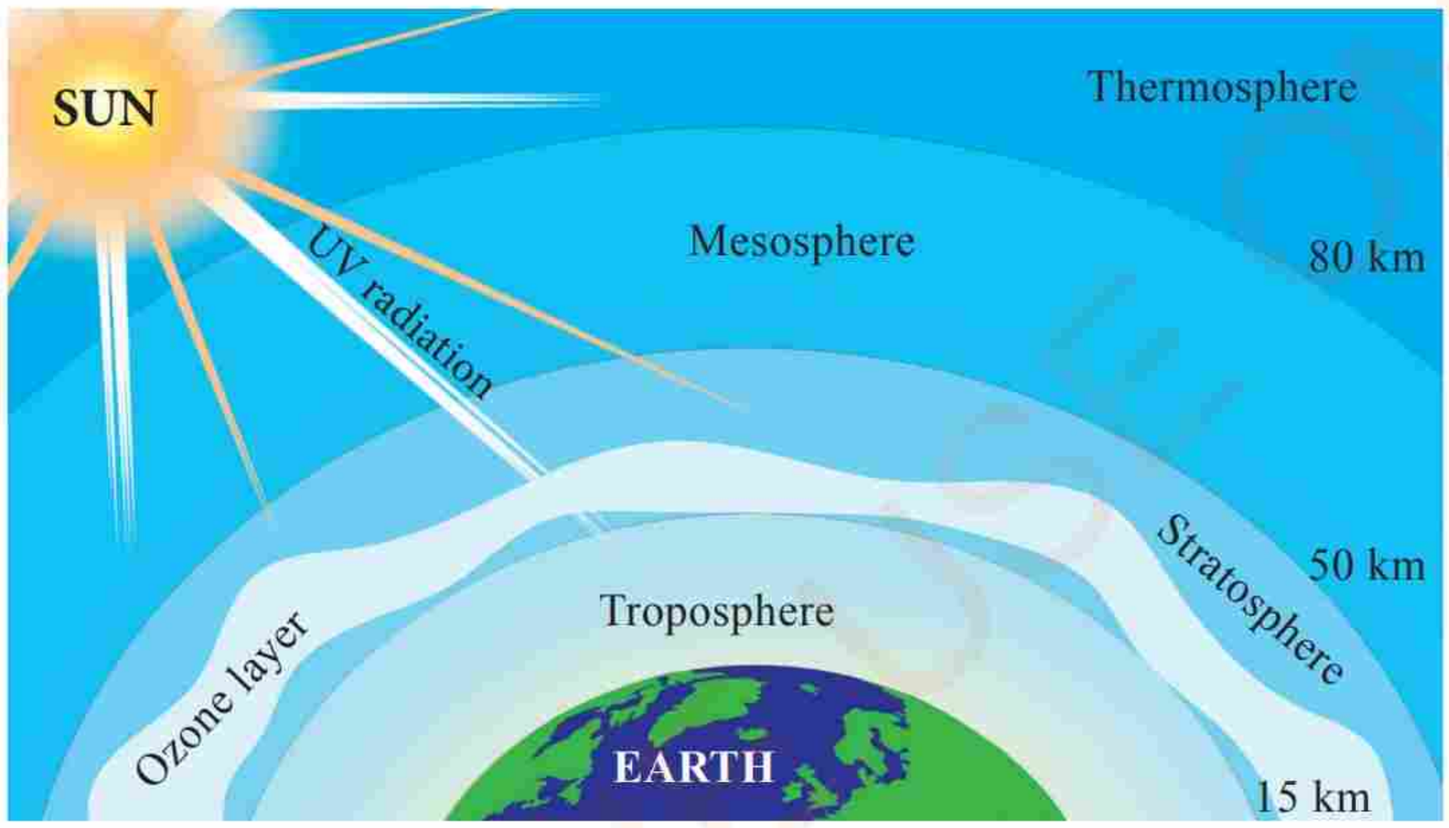


Figure 4.13: *Location of the ozone layer*

Ultraviolet radiation protection to the Earth's surface

The Earth's surface is protected from UV radiations by the ozone layer. The process occurs by breaking and reforming the ozone gas. The ozone layer absorbs between 97% and 99% of the sun's high frequency ultraviolet light which is harmful to life on Earth. Ultraviolet radiations cause skin cancer in human beings.

The amounts of ozone within the stratosphere vary according to altitudes. Ozone concentration is highest between 19 km and 23 km above sea level, but there is significant amount up to 30 km. The ozone layer protects the Earth from harmful radiations by filtering out harmful ultraviolet radiations from the sun. Upon absorption of solar radiations in wave lengths between 240 nm and 290 nm, ozone is decomposed to oxygen gas and oxygen atom.

$$O_3(g) \xrightarrow{\text{UV light}} O_2(g) + O(g)$$

The dissociated oxygen molecules and oxygen atoms recombine to form ozone.

$$O_2(g) + O(g) \longrightarrow O_3(g)$$

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Therefore, in the presence of UV radiations, ozone is constantly being formed and broken down. This is how the ozone layer serves as a shield to protect the Earth from harmful UV radiations emitted by the sun.

Ozone layer depletion

The permanent ozone layer depletion is mainly caused by chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methylbromide, and halons. These compounds are the main sources of bromine and chlorine radicals. The atoms are the main substances that deplete the ozone layer. They are produced from some industrial processes, and are also present in some products. The following are the main sources of bromine and chlorine atoms in the atmosphere:

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs): The CFCs and HCFCs differ in that HCFCs contain hydrogen in addition to chlorine and fluorine. The CFCs and HCFCs are used in refrigeration and air conditioning systems, and in aerosols. Some of the common CFCs include trichlorofluoromethane (CCl_3F), dichlorodifluoromethane (CCl_2F_2) and chlorotrifluoromethane ($CClF_3$), whereas the common HCFCs include chlorofluoromethane (CH_2ClF), dichlorofluoromethane ($CHCl_2F$), and chlorodifluoromethane ($CHClF_2$). The CFCs and HCFCs have low toxicity, reactivity, and flammability. Due to their low reactivity, the gases eventually reach the stratosphere, where they are broken down by the UV light to release ozone-depleting chlorine free radical ($\dot{C}l$). For example, CF_2Cl_2 is broken down by strong ultraviolet radiation to produce $CF_2\dot{C}l$ and $\dot{C}l$ as shown in the following equation.

$$CF_2Cl_2(g) \xrightarrow{\text{UV light}} \dot{C}l(g) + \dot{C}F_2Cl(g)$$

The chlorine free radical reacts with ozone to form chlorine monoxide radical ($Cl\dot{O}$) and molecular oxygen (O_2).

$$\dot{C}l(g) + O_3(g) \longrightarrow Cl\dot{O}(g) + O_2(g)$$

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The reaction of the chlorine monoxide radical with atomic oxygen produces more chlorine radical which repeats the cycle over and over again.

$$\dot{Cl}O(g) + O(g) \longrightarrow \dot{Cl}(g) + O_2(g)$$

The entire process of ozone layer depletion is summarised in Figure 4.14.
Before being removed from the stratosphere, a single chlorine atom is estimated to deplete over a hundred thousand (100,000) ozone molecules.

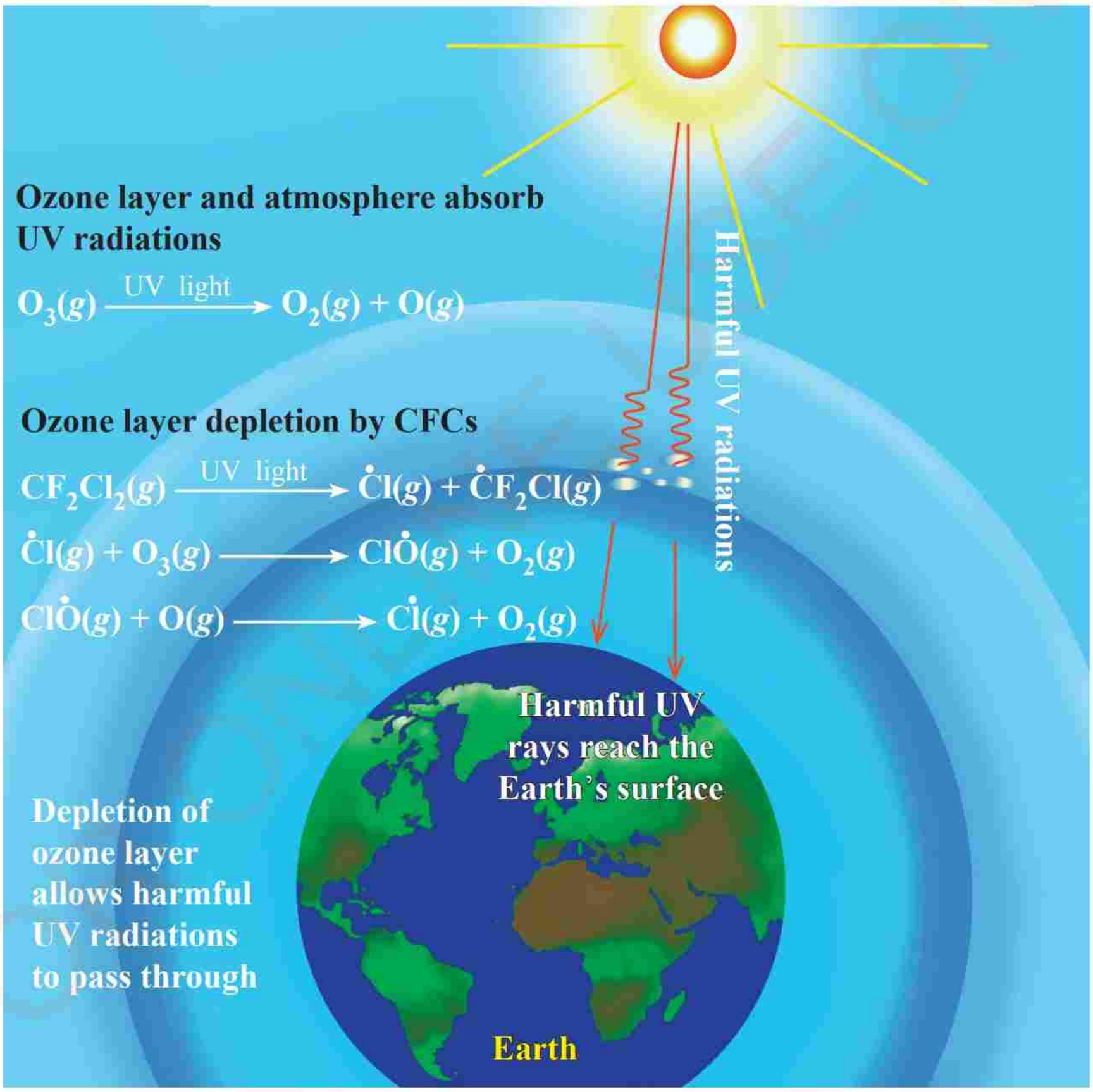


Figure 4.14: *Reactions and processes in ozone layer depletion*

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Methyl bromide: Methyl bromide is an odourless, colourless gas commonly used as an agricultural fumigant. In the stratosphere, methyl bromide is decomposed photochemically to produce atomic bromine which contributes to the ozone layer depletion.

$$CH_3Br(g) \xrightarrow{\text{UV light}} \dot{C}H_3(g) + \dot{B}r(g)$$

Like in chlorine free radical, a bromine radical ($\dot{B}r$) reacts with ozone to produce bromine monoxide and molecular oxygen.

$$\dot{B}r(g) + O_3(g) \longrightarrow Br\dot{O}(g) + O_2(g)$$

The bromine free radical is regenerated from the reaction of $BrO^{\bullet}$ with atomic oxygen and can further react with ozone. The circle repeats over and over again.

$$Br\dot{O}(g) + O(g) \longrightarrow \dot{B}r(g) + O_2(g)$$

Halons: These are organic compounds derived from hydrocarbons. Halons have some or all of the hydrogen atoms in hydrocarbons replaced with halogen atoms such as bromine, chlorine, and fluorine. Examples include bromochloromethane (CH_2BrCl), bromochlorofluoromethane (CF_2ClBr), and bromotrifluoromethane ($CBrF_3$). The presence of halogens makes halons effective in depleting the ozone layer. Halons are more potent than chlorofluorocarbons (CFCs), and they also act as greenhouse agents more potent than carbon dioxide. Halons are mainly used in fire extinguishers and in explosion suppression systems.

Apart from chlorine and bromine radicals, the ozone layer can also be depleted by nitrogen monoxide and hydroxyl radicals.

Control of ozone layer depletion

The most effective way of controlling the depletion of ozone layer is to ban the production and use of all ozone-depleting substances. However, other methods used to protect the ozone layer are as follows:

Cutting down the use of ozone depleting substances: This can be achieved by

(a) replacing the use of CFCs and HCFCs in refrigerators, automobile, air conditioners, aerosol sprays, solvents, and electronics with none-ozone depleting substances such as hydrofluorocarbons (HFCs).

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(b) replacing the use of methylbromide as a fumigant with other alternatives such as phosphine, sulphuryl fluoride, carbonyl sulphide, and botanicals (plant essential oils and their components).

(c) replacing the use of halons in fire extinguishers.

Minimising the use of fuel-based vehicles: Nitrogen monoxide is one of the gases emitted when fuels in vehicles are burnt. Minimising the use of such vehicles or using public transport can reduce the concentration of nitrogen monoxide in the atmosphere.

Establishment and implementation of protocols on ozone layer protection: Protocols for the ozone layer protection have been established. This includes the Montreal Protocol which was signed in 1987 with the aim of cutting back the production of CFCs. The protocol has contributed to the ongoing efforts on the control of ozone layer depletion.

Environmental conservation

Environmental conservation is the protection and preservation of natural resources from destruction, wastage or loss. Natural resources include soil, minerals, water, aquatic life, air, forests, and animals (domestic and wild).

Importance of environmental conservation

Working for environmental conservation has become increasingly important in recent years. The critical need to save the environment from further degradation are explained by the following factors:

Sustenance of human lives: The environment contains the resources which sustain human lives. These include soil, water, and air. Therefore, environmental conservation seeks to protect and preserve these resources for the continued sustenance of human lives on Earth.

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Protection of animal and plant species: Animals and plants play important roles in the environment. These include maintenance of ecological balances in the ecosystem. Ecological balance is a state in which the number of plants and animals in an area are enough to ensure their continued existence. Human activities such as hunting, agriculture, settlements, mining, and trade have led to some destruction of wildlife. Environmental conservation aims at protecting animals and plants from further destruction.

Economic values: Most economic activities depend on natural resources. For economic development to take place, natural resources must be protected and preserved to ensure their continued availability.

Future generations: Environmental conservation aims at making natural resources available to future generations.

Beauty and attractions: The natural resources give the environment a sense of beauty. For example, forests are beautiful and attractive to look at. Environmental conservation aims at protecting and preserving the beauty and attractions.

Environmental conservation measures

Environmental conservation is the entire process of ensuring that the quality of the environment does not deteriorate, and the environment that has deteriorated is restored. The following are some of the measures taken to conserve the environment:

Setting up organisations and institutions: Many organisations have been set up for the purposes of environmental conservation efforts. These organisations include both national and international organisations, government ministries, agencies, and non-governmental organisations. The government ministries and agencies include the National Environment Management Council (NEMC). The International agencies include the United Nations Environment Programme (UNEP), Global Environment Facility (GEF), and UN-Habitat.

Legislation: Making and enforcing laws that govern environmental conservation play great roles in environmental conservation efforts, including preventing pollution and protecting certain species of organisms, areas or resources.

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Education: Communities are educated on the importance of environmental conservation. Environmental education is continually offered in schools, colleges, universities, local communities, and even in organisations. This creates awareness and promotes the involvement of stakeholders in environmental conservation efforts.

Research: Researches are carried out on best practices to protect and conserve the natural resources and other environment. Some of the areas of research include; alternative sources of energy, methods of preventing and controlling pollution, and sustainable uses of natural resources.

Pollution prevention and control

Efforts are directed towards preventing and controlling pollution. This is done in a number of ways such as setting up recycling factories, rehabilitating polluted areas, and establishing laws and policies to control pollution. Pollution prevention and control can be implemented through international agreements and personal involvements.

International agreements: International bodies, such as the United Nations (UN) and regional blocks such as the European Union, have put in place agreements which help in the conservation of the environment. Member nations commit themselves by signing the agreements. Such agreements include the Kyoto Protocol which aimed to reduce the onset of global warming by reducing greenhouse gas concentrations in the atmosphere. The protocol was agreed upon in Kyoto, Japan on December 11, 1997. The Paris Agreement or the Paris Climate Accords is another international treaty on climatic changes adopted in 2015. It covers climate change, mitigation, adaptation, and financing. Furthermore, the 26th conference of the Parties (COP 26) for the United Nations Framework Convention on Climate Change was held in Glasgow, Scotland, UK from 31st October to 12th November, 2021. This meeting is also part of the evaluations on climate changes after the Paris Agreement.

Personal involvements: It is important that everyone is involved in environmental conservation efforts because the impacts of destroying the environment affect everyone. For example, many organisms will be affected when the ocean levels rise and floods cover the coastal areas. Livestock will not be spared when droughts sweep across the entire islands.

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The following are some of the approaches towards environmental conservation.

(a) Planting more trees and avoiding unnecessary cutting down of trees.

(b) Avoiding littering the environment. Dispose wastes in designated areas or in disposal bins.

(c) Avoiding setting fires near forested areas. Any fire lit should be monitored until it goes out or is put off.

(d) Avoiding harming animals, both domestic and wild. Be kind to animals.

(e) Educating people on the importance of environmental conservation.

(f) Participating in environmental conservation programs and tasks. These include the World Environment Day which is observed on June 5 of every year where conservation activities and cleanliness activities in local areas are practised.

Task 4.3

With the guide of your teacher, organise a cleanliness exercise within your local area. This can be the local market, street or even the school compound. Remember to put on protective gears such as dust masks, gloves, and gumboots. Do not handle rubbish with bare hands. Use sharp pointed sticks and shovels.

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Chapter summary

1. Pollution is the introduction of harmful or unwanted substances into the environment.
2. Pollution can be divided into three main categories depending on where it occurs. These are land (terrestrial) pollution, water (aquatic) pollution, and air pollution.
3. Land pollution is the introduction of harmful or unwanted substances on the land.
4. Water pollution occurs when harmful or unwanted substances are introduced in water bodies such as rivers, streams, lakes, oceans, ponds, dams, and groundwater.
5. Air pollution is the introduction of harmful or unwanted substances into the air. These substances include harmful gases and dust particles.
6. Global warming is the increase of the average temperature on the surface of the earth as a result of enhanced greenhouse effect which is attributed to the increase in the levels of the greenhouse gases levels in the atmosphere. Carbon dioxide, methane, dinitrogen oxide, halons, and chlorofluorocarbons (CFCs) are examples of greenhouse gases.
7. The effects of global warming include rise in sea levels, climate changes, and extreme weather events such as floods, droughts, heat waves, hurricanes, and tornadoes.
8. The ozone layer is a layer on the Earth's atmosphere which contains relatively high concentrations of ozone. The ozone layer absorbs most of the sun's harmful ultraviolet radiations.
9. The ozone layer is being destroyed by ozone-depleting substances. These include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl bromide, halons, nitrogen monoxide radical, and hydroxyl radical.
10. The uses of chemicals containing ozone-depleting substances should be stopped in order to save the ozone layer.
11. Environmental conservation is the protection and preservation of natural resources from destruction, wastage or loss. The natural resources include soil, minerals, water sheds, catchment areas, air, plants, and animals.

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Revision exercise 4

Choose the correct answer in items 1 – 4.

1. One of the following is a major component of photochemical smog:
   (a) Ozone and nitrogen dioxide
   (b) Particulate matter and ozone
   (c) Carbon monoxide and particulate matter
   (d) Nitrogen dioxide and carbon dioxide

2. Which of the following statements explains the effects of increase in temperature in water pollution?
   (a) Heat decreases dissolved oxygen in the water.
   (b) Heat promotes microbes that prey on fish.
   (c) Heat promotes dissolved oxygen in water.
   (d) Heat releases unpleasant odours from the water.

3. Which region of the atmosphere contains the ozone layer?
   (a) Mesosphere (b) Troposphere
   (c) Stratosphere (d) Thermosphere

4. The following family of organic compounds have some or all of the hydrogen atoms replaced with halogen atoms and is involved in the depletion of the ozone layer:
   (a) Dichloromethane. (b) Halides.
   (c) Halogens. (d) Halons.

5. The following table shows some sources of solid wastes in the environment and some examples of the wastes produced by the sources. Match each of the sources with the waste it produces. One waste may be used more than once.

Sources	Wastes
Mining	NPK
Industries	Ashes
Agriculture	Manure
Solid fuels	Nuclear waste
Nuclear plants	Chemical waste
Sewage treatment plants	Biomass sludge
	Waste rocks and tailings

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6. Answer the following questions by using the correct words or phrases provided in the box. More than one word or phrase may be used for the same question.

Chlorine	Ozone	Chlorofluorocarbons
Halons	Sunlight	Hydrofluorocarbons
Bromine	Methyl bromide	Ultraviolet radiation

(a) The substance contained in high concentrations in the ozone layer.
(b) Harmful light from the sun which is absorbed by ozone.
(c) Ozone-depleting substances.
(d) Substances used in refrigerators and air conditioning systems.
(e) A chemical substance used as an agricultural fumigant.

7. For each of the following statements, write TRUE for the correct statement and FALSE for an incorrect statement. For the incorrect statements, give reasons for your answer.
(a) Soil pollution is beneficial because it adds nutrients to the soil.
(b) Chlorine and bromine atoms are the two main substances that cause ozone layer depletion.
(c) The Earth would have been a better place to live in without the presence of the greenhouse effect.
(d) CFCs are more potent than halons.

8. (a) Explain any four causes of global warming.
(b) Describe any five effects of global warming.

9. (a) Explain the possible sources of water pollution.
(b) Write short notes on microplastics pollution.

10. (a) Explain the causes of eutrophication.
(b) Examine the effects of eutrophication.
(c) Explain the ways in which mining contributes to water pollution.

11. Industries are among the leading sources of air pollutants.
(a) Explain four substances that are released from industries which contribute to air pollution.
(b) Explain two other sources of air pollutants apart from (a).

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(c) Give three effects of air pollution.

(d) Explain how industrial workers can be protected against harmful chemicals.

12. The following figure shows a certain type of pollution.



(a) What type of pollution is shown in the figure?

(b) Give any four causes of this type of pollution.

(c) Explain the effects of this type of pollution.

(d) What measures can be taken to prevent this type of pollution?

13. (a) Explain the concept of environmental conservation.

(b) Explain the measures that can be (or have been) taken to conserve the environment.

14. (a) What is ozone layer?

(b) Explain the meaning of ozone layer depletion.

(c) With the aid of chemical equations, explain how CFCs and methyl bromide cause ozone layer depletion.

15. What are the sources of solid non-biodegradable wastes found in the environment? Give any five examples of such wastes and the problems they cause in the environment.

16. What features are associated with biodegradable wastes? Explain.

17. There are various environmental plans to be used in controlling the liquid and solid wastes in municipalities. Advise accordingly the effective plans to be taken in order to achieve such activities.

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Chapter Five

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Qualitative analysis

Introduction

Incidences related to fraud in food business, drinks, medicine, and cosmetics have been reported widely. In some cases, you might have heard about some occasions involving land, water and air pollution as a result of human activities such as mining, agriculture, and industrial process. Chemists have always been involved in investigating the levels of hazards due to those phenomena. You might have asked yourself what chemists do to address those cases. In fact, what they do is qualitative analysis of samples under investigation. This can be done through procedural identification of the characteristics of chemical species contained in the substances. In this chapter, you will learn about the concept of qualitative analysis, qualitative analysis procedure, and qualitative analysis report writing. The competencies developed will enable you to identify cations and anions present in different salts. You will also be able to use various reagents to separate and identify unknown components of different substances for different purposes in daily life.

The concept of qualitative analysis

Qualitative analysis is concerned with the investigations and identification of chemical species which make substances. It involves a set of analytical procedures that provide non numerical data about analytes. Qualitative analysis involves identifying the chemical species present in a given sample. It involves a set of analytical procedures that provide non numerical data about an analyte. Thus, qualitative analysis can indicate whether an atom, ion, functional group, or compound is present or absent in a sample. Qualitative analysis can be categorised into *qualitative organic analysis* which deals with identification of functional groups, chemical bonds, or molecules in the samples, and *qualitative inorganic analysis* which deals with the determination of ionic or elemental composition of samples. The chemical species in substances are identified by following various procedures which include physical observations and chemical reactions.

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Importance of qualitative analysis

Qualitative analysis has several applications in real life as described in the following areas:

Determination of ions present in a chemical substance: This is achieved through carrying out analytical tests in a sequence of appropriate steps involving identifying the physical and chemical properties of the unknown substance.

Determination of gases produced in a chemical reaction: Qualitative analysis involves procedures which are useful in identifying gases evolved in a chemical reaction.

Identification of chemical compounds: Chemical compounds can display different properties including solubility, characteristic smell, flame colour, and reaction products. These properties can be utilised to identify the chemical substances under investigation.

Determination of the pH and types of nutrients in a soil sample: The procedure for determining soil pH and its mineral composition is purely qualitative. For soil pH, the determination involves observation of the colour changes of the indicator when subjected into a solution of soil sample. Different tests for cations and anions employed in qualitative analysis help to identify the ions (such as K^+, Ca^{2+}, SO_4^{2-}, NO_3^-, and PO_4^{3-}) present in the soil. The knowledge of the ions present in the soil is beneficial for deciding the types of fertilisers to be applied to the particular soil.

Identification of environmental pollutants: Environmental scientists utilise qualitative analytical tests to determine the chemical composition of a specific contaminant.

Application in medical and forensic analysis: Numerous tests are carried out in the medical and forensic professions using qualitative analytical techniques. The tests are used to identify a wide range of diseases, medical conditions, and criminal evidences. For example, when a reagent is dipped in urine, it reacts with the substances present, causing a precise colour or physical changes that indicate a particular medical condition such as pregnancy. Qualitative analysis can also be applied in blood grouping which involves adding antibodies to the

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blood sample to determine the blood groups. When antibodies are introduced in blood corpuscles, they agglutinate, and aids in the detection of the blood group. Qualitative chemical analysis may further be used by forensic scientists to identify the nature of the compounds at crime scenes for convicting a suspected criminal.

Application in chemical industries: Products in chemical industries are frequently contaminated with chemical pollutants such as toxic metals. To detect contaminants, qualitative tests are used, followed by quantitative analysis that determines the quantities (amounts) of the contaminants present.

Qualitative analysis techniques

Qualitative analysis needs to be carried out carefully because even small errors may cause misinterpretation of the contents of the tested sample. The following are some important aspects that should be observed when performing qualitative analysis experiments:

Adding the test reagent: The reagents should be added carefully since some of them may lead to vigorous reactions. Initially, the reagent must be added in small amount, and then added in excess. After adding a reagent, some of the mixture may require thorough stirring before making any observations and conclusions.

Avoiding contamination: Contamination of apparatus, samples, and chemicals, lead to inaccurate results. For example, the presence of a contaminant that contains a cation with similar chemical properties with test analyte may lead to false positive results. The following are some precautions that should be taken to avoid contamination of chemicals, apparatus, and samples:

(a) All glassware should be thoroughly cleaned, rinsed with distilled water, and dried before use.

(b) Do not lay a glass rod on a laboratory bench as this can lead to contamination; instead, put it in a clean beaker or any other clean container.

(c) Do not touch the sides of the test tube with the tip of a dropper as this can cause contaminants to be picked up and transferred to another solution.

(d) Distilled water should be used for qualitative analysis procedure.

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(e) Use tap water for normal cleaning and not for rinsing apparatus or dissolving chemicals.

(f) Use separate glassware or apparatus for preparation of standard solutions and samples.

Heating a solution below its boiling point: Direct heating of solution should be avoided. Use a water bath when heating the solution.

Evaporating a solution: Evaporation should always be done in an evaporating dish. The dish can be held using a pair of tongs and waved through a flame. It may also be placed on a wire gauze and heated using a burner over a tripod stand. Alternatively, the sample may be placed in an evaporating dish or a filter paper and exposed to sunlight to allow evaporation.

Testing the pH of a solution: A strip of litmus paper is placed on a clean and dry surface. Using a clean glass rod, a drop of the test solution is placed on the litmus paper. The colour change of the paper is noted while it is still wet.

Format of the qualitative analysis report

The report of qualitative analysis experiments is usually organised in tabular form for easy follow up. Normally, the table has three columns showing a brief explanation of the experimental procedure or tests performed, observations, and inferences made. Each column has particular information to be filled in, as explained in the following paragraphs:

Experiment column: Tests carried out on an unknown sample should be written in the "Experiments" column. Experiments should be reported in simple past tense (in most cases in "passive voice") to explain what was performed. For example, "A small amount of a sample was picked using a clean nichrome wire and heated on a flame".

Observation column: The appearance of the sample and changes which have been observed or identified when a chemical substance is subjected to the tests are written in the "Observations" column. The observations include colour, texture, formation of precipitates, evolution of gas, flame colour, and production of special sound.

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Inference column: The deductions or what can be inferred from the observations are written in the "Inferences" column. Inferences are the ones which lead to systematic identification of the unknown salt under investigation. It should be noted that, not all tests will give detectable changes. Sometimes if no obvious changes are observed, it can infer the presence or absence of a particular ion. For example, the addition of barium chloride solution in an unknown solution may or may not give observable changes. If no reaction, it implies the absence of sulphate ion. The formation of white precipitates indicates the presence of sulphate ion in the sample. Table 5.1 shows the format for a report of a qualitative analysis.

Table 5.1: *Report format for qualitative analysis experiments*

Experiments	Observations	Inferences

Qualitative analysis procedure for some selected ions

The qualitative analysis methods prepared in this chapter will be used in determining the identity of samples containing the following ions:

Cations: NH_4^+, Na^+, Ca^{2+}, Pb^{2+}, Fe^{2+}, Fe^{3+}, Zn^{2+}, and Cu^{2+}

Anions: NO_3^-, SO_4^{2-}, Cl^-, CO_3^{2-}, and HCO_3^-

The qualitative analysis procedure involves three sets of experiments as follows:

(a) Preliminary tests

(b) Tests in aqueous solutions

(c) Confirmatory tests

Preliminary tests

The preliminary tests are generally for solid samples. Preliminary tests of solid samples involve the following:

1. Appearance: Colour, texture, deliquescence, and odour.
2. Action of heat.
3. Flame test.
4. Solubility in water.
5. Action of dilute hydrochloric acid or dilute sulphuric acid.
6. Action of concentrated sulphuric acid.

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Appearance of a compound

The appearance of a compound can help its identification. This involves the colour, texture, deliquescence, and odour of the compounds in solid forms. Table 5.2 shows preliminary tests applicable to the appearance of solid samples.

Caution: Avoid direct smelling of the chemicals in the laboratory.

Table 5.2: *Appearance of solid samples*

Experiments	Observations	Inferences
Appearance of a solid sample (i) Colour	White	NH_4^+, Na^+, Ca^{2+}, Zn^{2+}, Pb^{2+} may be present, or Transition metals Fe^{2+}, Fe^{3+}, Cu^{2+} may be absent.
	Blue or green	Cu^{2+} may be present.
	Pale green (light green)	Fe^{2+} may be present.
	Yellowish-brown	Fe^{3+} may be present.
(ii) Texture	Crystalline form	NO_3^-, SO_4^{2-}, Cl^- may be present.
	Powder form	CO_3^{2-}, HCO_3^- may be present.
(iii) Odour	Choking smell	NH_4^+ may be present.
(iv) Deliquescence	Absorbs water from the atmosphere to form a solution	NO_3^-, Cl^-, SO_4^{2-} may be present.

Ionic compounds derive their colours from the colours of their ions. Most ions are colourless. Ions of most transition elements tend to be coloured. However, Table 5.3 provides colours of some common anhydrous salts.

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Table 5.3: *Colours of some common anhydrous salts*

Types of substances	Names of salts and their formulae	Colour
Carbonates	Silver carbonate, Ag_2CO_3	Yellow
	Copper(II) carbonate, $CuCO_3$	Green
	Barium carbonate, $BaCO_3$	White
	Calcium carbonate, $CaCO_3$	White
Chlorides	Silver chloride, AgCl	White
	Lead(II) chloride, $PbCl_2$	White
	Copper(II) chloride, $CuCl_2$	Yellowish brown
	Barium chloride, $BaCl_2$	White
Hydroxides	Silver hydroxide, AgOH	Greyish-brown
	Copper(II) hydroxide, $Cu(OH)_2$	Pale blue
	Iron(II) hydroxide, $Fe(OH)_2$	Dirty green
	Iron(III) hydroxide, $Fe(OH)_3$	Reddish-brown
	Lead(II) hydroxide, $Pb(OH)_2$	White
	Zinc hydroxide, $Zn(OH)_2$	White
Sulphates	Barium sulphate, $BaSO_4$	White
	Zinc sulphate, $ZnSO_4$	White
	Copper(II) sulphate, $CuSO_4$	White
	Lead(II) sulphate, $PbSO_4$	Bright white
	Iron(II) sulphate, $FeSO_4$	Green

Note that, copper(II) sulphate and copper(II) carbonate contain the same type of cation (Cu^{2+}) but have different colours. Anhydrous copper(II) sulphate is white and crystalline, while copper(II) carbonate is a green powder. Copper(II) carbonate and iron(II) sulphate have the same colour, but copper(II) carbonate is a powder, while iron(II) sulphate is crystalline. Therefore, colour and texture are not accurate determinants of the cations and anions present in salts but give prior information to describe a chemical substance.

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Flame test

A flame test involves dipping a clean nichrome wire (or glass rod or a base of a test tube) in concentrated hydrochloric acid then in the unknown substance, followed by heating the mixture over a non-luminous flame. The flame changes to a characteristic colour of the element. Table 5.4 shows the characteristic flame colours of some metal ions.

Table 5.4: *Flame colours of some metal ions*

Experiments	Observations	Inferences
Flame test Dip a clean nichrome wire (or a clean glass rod or the base of the test tube) in concentrated HCl to allow a small sample to adhere on it, then pick up a small amount of the sample using the wet wire (or glass rod or the base of the test tube) and heat it on a flame	Golden yellow flame	Na^+ may be present.
	Brick red flame	Ca^{2+} may be present.
	Bluish-green flame	Cu^{2+} may be present.
	Blue-white (pale-blue) flame	Pb^{2+} may be present.
	Yellow (orange) sparks	Fe^{2+}, Fe^{3+} may be present.
	No definite flame colour	Zn^{2+}, NH_4^+ may be present.

Effects of heat on solid samples

Different substances decompose on heating to give different products. If a compound is heated and a colourless liquid condenses on the inner cooler part of the test tube, the compound is most likely to be a hydrate and the liquid is probably water. A test to confirm the presence of water can be performed using a cobalt chloride paper or anhydrous copper(II) sulphate. If a gas is given off, note its colour and odour. The observations include the following:

(a) If a brown gas is given off, the compound is most likely to be a nitrate, and the brown gas is most likely to be nitrogen dioxide. For example, lead nitrate decomposes upon heating to produce lead oxide, oxygen gas, and brown fumes of nitrogen dioxide.

$$2Pb(NO_3)_2(s) \xrightarrow{\text{heat}} 2PbO(s) + O_2(g) + 4NO_2(g)$$
Brown

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(b) Sulphites decompose to give a colourless gas (sulphur dioxide), which has a choking smell. For example, calcium sulphite decomposes to give calcium oxide and a colourless sulphur dioxide gas.

$$CaSO_3(s) \xrightarrow{\text{heat}} CaO(s) + SO_2(g)$$
Colourless

Smell and colour alone are not sufficient to conclude that the gas produced is sulphur dioxide. A confirmatory test for sulphur dioxide is required.

(c) Some carbonates decompose when heated to give a colourless and odourless gas (carbon dioxide) that forms white precipitates with limewater. For instance, calcium carbonate decomposes to give calcium oxide, and carbon dioxide gas which forms white precipitates of calcium carbonate when bubbled through limewater.

$$CaCO_3(s) \xrightarrow{\text{heat}} CaO(s) + CO_2(g)$$

Note: The residues of some salts, such as lead, iron, copper, and zinc salts, have a distinctive colour that can be used to confirm the identities of the cations present. Some anions such as nitrate and carbonate can be confirmed through decomposition experiments as they produce gases with characteristics different from other gases. Generally, the characteristics of the gases evolved infer anion(s) present in the sample(s), whereas the colours of residues infer the cations present. The procedure for testing the effects of heat on solid samples is shown in Table 5.5.

Caution: Hold the test tube in a slanting position and away from observers and neighbours when heating.

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Table 5.5: *Effects of heat on solid samples*

Experiments	Observations	Inferences
Action of heat on a solid sample Transfer about 0.5 g of the solid sample in a dry test tube. Heat gently and then strongly until no further change is observed. Test for any gas evolved and observe the appearance of the residues	White sublimate and a colourless gas with a chocking smell which turns moist red litmus paper blue and forms dense white fumes with HCl	NH_4^+ may be present.
	Reddish-brown fumes evolve which turn moist blue litmus paper red and a gas which relights a glowing splint	NO_3^- may be present, except that of Na^+.
	Colourless gas evolves, which relights a glowing splint	NO_3^- of Na^+ may be present.
	Colourless gas evolves, which turns limewater milky and moist litmus paper from blue to red	CO_3^{2-}, HCO_3^- may be present.
	Colourless gas with pungent smell evolves, which turns moist blue litmus paper red or filter paper dipped in acidified potassium dichromate solution from yellow to green or decolourises the solution of potassium permanganate	SO_4^{2-} may be present, except that of Na^+.
	Colourless gas with a pungent smell evolves, which gives dense white fumes with ammonia gas and turns moist blue litmus paper red	Cl^- of hydrated Ca^{2+}, Zn^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+} salts may be present.

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Experiments	Observations	Inferences
	No gas evolves	SO_4^{2-} of Na^+, Ca^{2+}, Pb^{2+} may be present.
		Cl^- of Na^+, Pb^{2+} may be present.
		CO_3^{2-} of Na^+ may be present.
	Colourless droplets forming on the cooler parts of the test tube, that turns anhydrous $CuSO_4$ blue or $CoCl_2$ pink	Hydrated salt, HCO_3^- may be present.
	Cracking sound and brown gas	NO_3^- of Pb^{2+} may be present.
	White sublimate and a colourless gas with chocking smell which turns moist red litmus paper blue	NH_4^+ may be present.
	Cracking sound with no evolution of gas	Cl^- of Na^+ may be present.
	Yellow residue when hot and white when cold	Zn^{2+} may be present.
	Reddish-brown residue when hot and yellow when cold	Pb^{2+} may be present.
	Black residue	Cu^{2+} may be present.
	Reddish-brown residue	Fe^{2+}, Fe^{3+} may be present.
	White residue	Ca^{2+}, Na^+ may be present.
	Blue crystals turn white	SO_4^{2-} of hydrated Cu^{2+} may be present.

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Action of dilute HCl or H_2SO_4 on solid samples

Dilute hydrochloric acid is added dropwise to the test sample until its solution is acidic. A cation that generates an insoluble chloride will form a precipitate. For example:

$$Pb^{2+}(aq) + 2Cl^{-}(aq) \longrightarrow PbCl_2(s)$$

The action of dilute HCl on solid sample is summarised in Table 5.6.

Table 5.6: *Action of dilute HCl or dilute H_2SO_4 on solid samples*

Experiments	Observations	Inferences
Action of dilute HCl or H_2SO_4 on a solid sample Transfer about 0.5 g of the solid sample in a test tube followed by addition of 3 to 5 drops of HCl or dilute H_2SO_4	Effervescence of a colourless gas evolves, which turns limewater milky and moist blue litmus paper red	CO_3^{2-}, HCO_3^{-} may be present.
	No gas evolves	SO_4^{2-}, NO_3^{-}, Cl^{-} may be present.
	White precipitate	Pb^{2+} may be present.

Action of concentrated H_2SO_4 on solid sample

Concentrated sulphuric acid is added dropwise to the test sample until its solution is acidic. Table 5.7 presents tests for the action of concentrated H_2SO_4 on solid samples. A cation that generates an insoluble sulphate will form a precipitate. For example:

$$Ba^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow BaSO_4(s)$$

Caution: Concentrated H_2SO_4 is corrosive, handle it with caution, and do not boil it. Keep the test tube slanted and away from observers and neighbours.

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Table 5.7: *Action of concentrated H_2SO_4 on solid samples*

Experiments	Observations	Inferences
Action of concentrated H_2SO_4 on a solid sample Transfer about 0.5 g of the sample in a clean and dry test tube. Add 3 to 5 drops of concentrated H_2SO_4. If no reaction, warm the contents gently	Effervescence occurs, and a colourless gas evolves. The gas turns limewater milky and moist blue litmus paper red	CO_3^{2-}, HCO_3^- may be present.
	Colourless gas with irritating smell evolves. The gas turns moist blue litmus paper red and forms dense white fumes with ammonia gas	Cl^- may be present.
	Blue crystals which turn white even without warming	SO_4^{2-} of hydrated Cu^{2+} may be present.
	Brown fumes evolve, which turn moist blue litmus paper red and intensify on addition of copper turnings	NO_3^- may be present.
	No gas evolves	SO_4^{2-} may be present.

Solubility of solid samples

The solubility of different substances in water can be used in their identification. It is therefore important to know the solubility of different substances. To test the solubility of a substance, one spatulaful of the test substance is put in 1 cm^3 of distilled water and stirred. If the compound is soluble, this amount will dissolve. If it is sparingly soluble, some of this amount will dissolve; but if the compound is insoluble, none of this amount will dissolve.

The following are some general trends on the solubility of different compounds in water:

1. All nitrates are soluble.
2. All salts of sodium, potassium, and ammonium are soluble.
3. All chlorides, bromides, and iodides are soluble, except those of silver, mercury(I), and lead(II).
4. All sulphates are soluble, except those of barium and lead(II). The sulphates of calcium and silver are sparingly soluble.

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5. All carbonates, sulphites, and phosphates are insoluble, except those of sodium, potassium, and ammonium.

6. All sulphides are insoluble, except those of the alkali metals, the alkaline earth metals, and ammonium.

7. All hydroxides are insoluble, except those of the alkali metals. The hydroxides of calcium and barium are sparingly soluble. Ammonium hydroxide exists as aqueous ammonia, $NH_3(aq)$. The tests for the solubility of solid samples are outlined in Table 5.8.

Table 5.8: *Solubility of solid samples*

Experiments	Observations	Inferences
Solubility of a solid sample Transfer about 0.5 g of the solid sample into the test tube and add enough cold distilled water to dissolve the solid sample. If the sample does not dissolve warm it	Soluble and forming a colourless solution	NO_3^- of Na^+, NH_4^+, may be present.
		CO_3^{2-}, HCO_3^- of Na^+, NH_4^+ may be present.
		Cl^- of Zn^{2+} or Ca^{2+} may be present.
		SO_4^{2-} of Zn^{2+} may be present.
	Soluble and forming a blue or green solution	Cu^{2+} may be present.
	Soluble and forming a pale green solution	Fe^{2+} may be present.
	Soluble and forming a yellowish-brown solution	Fe^{3+} may be present.
	White crystals is formed, insoluble in cold water but soluble in hot water; crystals reappear on cooling	Cl^- of Pb^{2+} may be present.
	Insoluble	CO_3^{2-} of Ca^{2+}, Pb^{2+}, Zn^{2+}, Fe^{2+}, Fe^{3+}, Cu^{2+} may be present.
		SO_4^{2-} of Ca^{2+} and Pb^{2+} may be present.

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Tests in solution

Tests on a sample solution include the following:

1. Action of NaOH solution.
2. Action of NH_3 solution.

Preparation of the stock solution of the sample

Transfer about 1 g of the solid sample into a test tube. Add about 15 cm^3 to 20 cm^3 of distilled water and shake thoroughly. If the sample is insoluble in cold water, warm it. If the sample is insoluble in hot water, transfer about 1 g of the original solid sample in a test tube and then dissolve it in dilute nitric acid to make about 15 cm^3 to 20 cm^3 of the final solution.

Action of NaOH solution on sample solutions

Dilute sodium hydroxide solution is added dropwise to the test solution. The mixture is stirred or shaken and observations are made. If a precipitate forms, more sodium hydroxide solution is added. If no precipitate form, the mixture is warmed. Table 5.9 shows the action of NaOH solution on a sample solution.

Table 5.9: *Tests in solution using NaOH*

Experiments	Observations	Inferences
Action of NaOH solution on a sample solution Add sodium hydroxide solution to about 1 cm^3 of the original sample solution, dropwise until in excess	White precipitate is formed, soluble in excess	Zn^{2+}, Pb^{2+}, Al^{3+} may be present.
	White precipitate is formed, insoluble in excess	Ca^{2+} may be present.
	Blue precipitate is formed, insoluble in excess	Cu^{2+} may be present.
	Green precipitate is formed, insoluble in excess; turns brown on standing	Fe^{2+} may be present.
	Reddish-brown precipitate is formed; insoluble in excess	Fe^{3+} may be present.
	No precipitate is formed on warming; a colourless gas with a choking smell which turns moist red litmus paper blue evolves	NH_4^+ may be present.
	No precipitate is formed even on warming	Na^+ may be present.

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Action of NH_3 solution on sample solutions

Add dilute aqueous ammonia dropwise to the test solution. Stir or shake the mixture and observe any changes. If a precipitate forms, continue adding the aqueous ammonia solution. Table 5.10, shows the action of NH_3 solution on sample solutions.

Table 5.10: *Tests in solution using NH_3 solution*

Action of NH_3 solution on a sample solution Add ammonia solution to about 1 cm^3 of the original sample solution, dropwise until in excess	White precipitate is formed, insoluble in excess	Pb^{2+} may be present.
	White gelatinous precipitate is formed, soluble in excess.	Zn^{2+} may be present.
	No precipitate is formed	Ca^{2+}, Na^+, NH_4^+ may be present.
	Pale blue precipitate is formed, soluble in excess forming a deep blue solution	Cu^{2+} may be present.
	Green precipitate is formed, insoluble in excess	Fe^{2+} may be present.
	Reddish-brown precipitate is formed, insoluble in excess	Fe^{3+} may be present.

Confirmatory tests

After performing preliminary tests in solution on the sample of unknown composition, it is important to make conclusions about the ions present in the sample by performing confirmatory tests for every deduced ion. This can be obtained by combining the inferences made in the successive tests. Confirmatory tests are divided into two categories; *confirmatory tests for cations* and *confirmatory tests for anions*.

Confirmatory tests of some cations

The confirmatory tests that can be performed to confirm the presence of selected cations are summarised in Table 5.11.

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Table 5.11: *Confirmatory tests for selected cations*

Experiments	Observations	Inferences
1. Confirmatory tests for Ca^{2+} (i) To about 1 cm^3 of the original sample solution, add ammonia solution followed by ammonium oxalate solution	White precipitate is formed	Ca^{2+} confirmed.
(ii) Dip a nichrome wire (or glass rod or the base of a test tube) into concentrated hydrochloric acid, then to the sample. Heat the wire (glass rod or the base of test tube) over a non-luminous flame	Burns with a brick red flame	Ca^{2+} confirmed.
2. Confirmatory tests for Pb^{2+} (i) Add K_2CrO_4 solution to about 1 cm^3 of the sample solution	Yellow precipitate is formed	Pb^{2+} confirmed.
(ii) Add KI solution to about 1 cm^3 of the sample solution. Warm and cool the mixture	Yellow precipitate which disappears on warming but re-appears on cooling	Pb^{2+} confirmed.
3. Confirmatory tests for Zn^{2+} (i) Add potassium hexacyanoferrate (II) solution to about 1 cm^3 of the sample solution, followed by few drops of dilute HCl	Whitish-blue precipitate insoluble in dilute HCl	Zn^{2+} confirmed.
(ii) To about 1 cm^3 of the sample solution,d add ammonia solution until in excess	White gelatinous precipitate, soluble in excess	Zn^{2+} confirmed.

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Experiments	Observations	Inferences
4. Confirmatory test for NH_4^+ Transfer about 0.2 g of the original solid sample into a test tube, add sodium hydroxide solution just to cover the whole solid, then warm gently. Dip a glass rod in concentrated HCl and pass it to the mouth of the test tube containing the mixture. Test the gas evolved with moist red litmus paper	Colourless gas evolves which turns moist red litmus paper blue and forms white fumes with concentrated HCl	NH_4^+ confirmed.
5. Confirmatory test for Na^+ Perform the flame test	Golden yellow flame	Na^+ confirmed.
6. Confirmatory tests for Cu^{2+} (i) Add ammonia solution to about 1 cm^3 of the original sample solution, dropwise until in excess	Pale blue precipitate formed, soluble in excess aqueous ammonia forming a deep blue solution	Cu^{2+} confirmed.
(ii) Add few drops of potassium hexacyanoferrate(II) to about 1 cm^3 of the original sample solution	Reddish-brown precipitate	Cu^{2+} confirmed.
7. Confirmatory tests for Fe^{2+}, Fe^{3+} (i) Add few drops of potassium hexacyanoferrate(III) to about 1 cm^3 of the sample solution	Deep blue precipitate	Fe^{2+} confirmed.
(ii) Add few drops of potassium hexacyanoferrate(II) to about 1 cm^3 of the sample solution	Light blue precipitate	Fe^{2+} confirmed.

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Experiments	Observations	Inferences
	Deep blue precipitate	Fe^{3+} confirmed.
(iii) Add few drops of potassium or ammonium thiocyanate solution to about 1 cm^3 of the sample solution	Deep blood- red solution	Fe^{3+} confirmed.

Confirmatory tests for some anions

Table 5.12 summarises confirmatory tests for selected anions and the procedure followed after preparation of stock solution of the test sample.

Table 5.12: *Confirmatory tests for selected anions*

Experiments	Observations	Inferences
1. Confirmatory tests for SO_4^{2-} (i) To about 1 cm^3 of the sample solution in the test tube, add barium chloride followed by dilute HCl or barium nitrate followed by dilute HNO_3	White precipitate, insoluble in dilute HCl or dilute HNO_3	SO_4^{2-} confirmed.
(ii) To about 1 cm^3 of the sample solution in the test tube, add ethanoic acid followed by lead ethanoate solution. Divide the resulting mixture into two portions. In one portion, add dilute HCl and in another portion add ammonium ethanoate solution	White precipitate insoluble in dilute HCl but soluble in ammonium ethanoate solution	SO_4^{2-} confirmed.

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Experiments	Observations	Inferences
2. Confirmatory tests for NO_3^- (i) Transfer about 1 cm^3 of the sample solution into a test tube. Add freshly prepared $FeSO_4$ solution followed by slowly addition of concentrated H_2SO_4 along the side of the test tube	A brown ring is formed at the junction of the liquids	NO_3^- confirmed.
(ii) Transfer about 0.5 g of the original solid sample into a test tube. Add copper turnings followed by concentrated H_2SO_4, then warm	Brown fumes evolve	NO_3^- confirmed.
3. Confirmatory tests for soluble CO_3^{2-} and HCO_3^- (i) Transfer about 1 cm^3 of the sample solution into a test tube. Add few drops of $MgSO_4$ solution. If no precipitate is formed, warm the contents	White precipitate is formed before warming the contents	CO_3^{2-} confirmed.
	White precipitate is formed after warming the contents	HCO_3^- confirmed.
(ii) Transfer about 1 cm^3 of the sample solution into a test tube. Add $BaCl_2$ solution. If a precipitate forms, add dilute HCl	White precipitate soluble in dilute HCl is formed	CO_3^{2-} confirmed.

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Experiments	Observations	Inferences
(iii) Transfer about 1 cm^3 of the sample solution into a test tube. Add few drops of $CaCl_2$ solution. If no precipitate is formed, warm the contents	White precipitate is formed before warming the contents	CO_3^{2-} confirmed.
	White precipitate is formed after warming the contents	HCO_3^- confirmed.
4. Confirmatory test for insoluble CO_3^{2-} Transfer about 0.5 g of a water insoluble solid sample into a test tube. Add a small volume of dilute nitric acid	Effervescence of a colourless gas, which turns limewater milky	CO_3^{2-} confirmed.
5. Confirmatory tests for Cl^- (i) To about 1 cm^3 of the sample solution, add about 3 drops of dilute nitric acid followed by about 3 drops of silver nitrate solution then excess ammonia solution	White precipitate soluble in excess ammonia solution is formed	Cl^- confirmed.
(ii) Transfer about 0.5 g of the original solid sample into a test tube. Add an equal amount of solid MnO_2 followed by concentrated H_2SO_4	Greenish-yellow gas evolves which bleaches moist red litmus paper	Cl^- confirmed.
(iii) Transfer about 0.5 g of the original solid sample into a test tube. Add potassium dichromate solution followed by concentrated H_2SO_4	Red orange vapour is observed	Cl^- confirmed.

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Report summary

The qualitative analysis report is written in simple past tense (in most cases in "passive voice") to explain what was performed, observed or inferred. Table 5.13 summarises the steps that should be followed in writing a qualitative analysis report.

Table 5.13: *Report summary for qualitative analysis procedure*

Experiments	Observations	Inferences
Preliminary tests		
Appearance: texture, colour, smell and deliquescence		
Action of heat on a solid sample		
Flame test		
Solubility in water		
Action of dilute HCl or H_2SO_4 on a solid sample		
Action of concentrated H_2SO_4 on a solid sample		
Tests on a sample solution		
Action of NaOH solution		
Action of NH_3 solution		
Confirmatory tests		
Confirmatory tests of the cation		
Confirmatory tests of the anion		

Conclusion: The cation contained in the sample was_____ .

The anion in the sample was_____ .

The chemical formula of the compound is _____ .

The IUPAC name of th compound is _____ .

Table 5.14 outlines a sample report for a particular experiment to identify the ions present in the sample of unknown substances which contains one cation and one anion.

Table 5.14: *Report for analysis of sample of unknown*

S/N	Experiments	Observations	Inferences
(a)	Appearance of the sample	White powdery solid	CO_3^{2-}, HCO_3^- may be present.

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S/N	Experiments	Observations	Inferences
(b)	Enough water was added to a dry sample and warmed	Insoluble in cold and hot water	CO_3^{2-} of Pb^{2+}, Zn^{2+}, Ca^{2+} may be present. SO_4^{2-} of Ca^{2+}, and Pb^{2+} may be present.
(c)	Concentrated sulphuric acid was added to a small portion of a dry sample	Effervescence of a colourless gas evolved, which turned a moist blue litmus paper red	CO_3^{2-} may be present.
(d)	A small portion of a dry sample was placed in a test tube and heated gently then strongly	A colourless gas evolved. The gas turned limewater milky and moist blue litmus paper red.	CO_3^{2-} may be present.
		The residue turned yellow when hot and white when cooled	Zn^{2+} may be present.
(e)	Dilute HCl was added in a small portion of a dry sample then divided into three portions	Effervescence of a colourless gas evolved, which turned a moist blue litmus paper red	CO_3^{2-} may be present.
	(i) To one portion NaOH solution was added dropwise till in excess	White precipitate formed, soluble in excess NaOH solution	Pb^{2+}, Zn^{2+}, Al^{3+} may be present.
	(ii) To the second portion NH_3 solution was added till in excess	White gelatinous precipitates formed, soluble in excess NH_3 solution	Zn^{2+} confirmed.
(f)	Dilute nitric acid was added to a small amount of dry sample in the test tube	Effervescence of a colourless gas evolved, which turned limewater milky	CO_3^{2-} confirmed.

Conclusion

1. The cation in the sample of the unknown was Zn^{2+} and the anion was CO_3^{2-}
2. The chemical formula of the compound of unknown is $ZnCO_3$
3. The IUPAC name of the compound is zinc carbonate.

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Revision exercise 5

Choose the correct answer in items 1–6.

1. One of the following processes is not part of qualitative analysis:
   (a) Heat test
   (b) Flame test
   (c) Ductility test
   (d) Solubility test

2. What does the colour of a residue indicate after heating a sample of an unknown salt?
   (a) Type of cation
   (b) Type of anion
   (c) Solubility of salt
   (d) Type of both cation and anion

3. What does the gas collected after heating a solid sample of an unknown salt indicate about the salt?
   (a) Type of cation
   (b) Type of anion
   (c) Volatility
   (d) Reactivity with oxygen

4. The following reagents can be used to differentiate iron(II) ions from iron(III) ions:
   (a) Sulphuric acid
   (b) Potassium thiocyanate solution
   (c) Potassium iodide solution
   (d) Sodium sulphate solution

5. When aqueous sodium hydroxide is added dropwise until in excess to the solution of unknown salt, green precipitates which are insoluble in excess sodium hydroxide solution are formed. The precipitates slowly turn brown. Which of the following is present in the solution of the unknown salt?
   (a) Copper(II) sulphate
   (b) Iron(II) sulphate
   (c) Iron(III) sulphate
   (d) Lead(II) sulphate

6. One of the following statements does not give the correct information about the colour of the respective compound(s):
   (a) Aqueous $CuSO_4$ is blue.
   (b) Anhydrous Na_2CO_3 is white.
   (c) Aqueous $FeCl_2$ is brown.
   (d) Both $PbCl_2$ and AgCl are white solids.

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7. Explain the role(s) of preliminary tests in qualitative analysis.

8. How does qualitative analysis differ from quantitative analysis?

9. A river water sample M is suspected to contain high levels of the cations Na^+, NH_4^+, Cu^{2+}, Fe^{2+}, Fe^{3+}, Zn^{2+}, Pb^{2+}, and Ca^{2+}. An environmentalist is concerned about the possible health impacts of the contaminants to organisms in the area. Develop a qualitative analysis scheme to confirm the identity of all the cations.

10. Briefly describe a simple physical test or chemical test which would distinguish ions in each of the following pairs. Give the test results in each case.

    (a) $Zn^{2+}(aq)$ and $Pb^{2+}(aq)$
    (b) $Fe^{2+}(aq)$ and $Fe^{3+}(aq)$
    (c) $NH_4^+(aq)$ and $Ca^{2+}(aq)$
    (d) $CO_3^{2-}(aq)$ and $SO_4^{2-}(aq)$
    (e) $NO_3^-(aq)$ and $Cl^-(aq)$

11. (a) Identify the name of analyte X with the following characteristics:
    Appearance: Yellow/brown solid
    Action of heat: No reaction
    Flame test: No specific colour
    Solubility in water: Soluble
    Reaction with excess sodium hydroxide solution: Insoluble reddish brown precipitate
    Reaction with excess ammonia solution: Insoluble reddish brown precipitate
    Reaction with hydrochloric acid: No reaction
    Reaction with acidified NH_4SCN solution: Blood-red colouration
    Reaction with silver nitrate solution: Insoluble white precipitate
    Reaction with acidified $AgNO_3$ solution followed by concentrated ammonia solution: White precipitates, soluble in excess ammonia.

    (b) Give the chemical equations for every property or characteristic displayed by sample X.

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12. On heating, a green solid A gave off gas B which turned limewater milky, and a black solid C. When dissolved in warm dilute sulphuric acid, solid C formed a blue solution D. Identify substances A to D, and write their corresponding reaction equations.

13. A sample salt which was brought in the laboratory for analysis had the following characteristics:

Appearance: White crystalline

Action of heat: Brown gas evolved

Flame test: No identified colour

Solubility in water: Soluble

Reaction with excess sodium hydroxide solution: White precipitate soluble in excess

Reaction with excess ammonia solution: White precipitate soluble in excess

Reaction with hydrochloric acid: White precipitate

(a) Identify the cation and anion of the salt, and write its chemical formula.

(b) Write an equation for the reaction of the salt with
   (i) nitric acid.
   (ii) ammonia.
   (iii) hydrochloric acid.

14. Devise a scheme for separating and identifying any four possible cations in a sample of an unknown substance. Your scheme should show the solubility of the salts, action of hydroxide solutions, and the confirmatory tests.

15. One of the confirmatory tests for HCO_3^- involves warming the sample solution with a few drops of $MgSO_4$ to form white precipitates. Write a balanced chemical equation for the reaction taking place in the process.

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Appendix

Periodic Table

	Group I	Group II										Group III	Group IV	Group V	Group VI	Group VII	Group VIII/0
Period 1	1 H Hydrogen																4 He Helium
Period 2	6.9 Li Lithium	9 Be Beryllium										10.8 B Boron	12 C Carbon	14 N Nitrogen	16 O Oxygen	19 F Fluorine	20.2 Ne Neon
Period 3	23 Na Sodium	24.3 Mg Magnesium										27 Al Aluminium	28.4 Si Silicon	31 P Phosphorus	32.1 S Sulphur	35.5 Cl Chlorine	39.9 Ar Argon
Period 4	39.1 K Potassium	40.1 Ca Calcium	45 Sc Scandium	47.9 Ti Titanium	50.9 V Vanadium	52 Cr Chromium	54.9 Mn Manganese	55.9 Fe Iron	58.9 Co Cobalt	58.7 Ni Nickel	63.5 Cu Copper	65.4 Zn Zinc	69.7 Ga Gallium	72.6 Ge Germanium	74.9 As Arsenic	79 Se Selenium	79.9 Br Bromine	83.8 Kr Krypton
Period 5	85.5 Rb Rubidium	87.6 Sr Strontium	88.9 Y Yttrium	91.2 Zr Zirconium	92.9 Nb Niobium	95.9 Mo Molybdenum	98.0 Te Technetium	101.1 Ru Ruthenium	102.9 Rh Rhodium	106.1 Pd Palladium	107.6 Ag Silver	112.4 Cd Cadmium	115 In Indium	119 Sn Tin	122 Sb Antimony	126 Te Tellurium	127 I Iodine	131 Xe Xenon
Period 6	133 Cs Caesium	137.3 Ba Barium	57-71 Lanthanide series	178.5 Hf Hafnium	180.9 Ta Tantalum	183.9 W Tungsten	186.2 Re Rhenium	190.2 Os Osmium	192.2 Ir Iridium	195.1 Pt Platnum	197.0 Au Gold	200.6 Hg Mercury	203 Tl Thallium	207 Pb Lead	209 Bi Bismuth	210 Po Polonium	210 At Astatine	222 Rn Radon
Period 7	223 Fr Francium	226 Ra Radium	89 - 103 Actinide series	267 Rf Rutherfordium	262 Db Dubnium	271 Sg Seaborgium	270 Bh Bohrium	277 Hs Hassium	278 Mt Meitherium	281 Ds Francium	282 Rg Francium	285 Cn Francium	286 Nh Nihonium	289 Fl Flerovium	289 Mc Moscovium	293 Lv Livermorium	294 Ts Tennessine	294 Og Oganesson

Alkali metals
Alkaline earth metals
Transition metals
Poor metals
Metalloids
Non-metals
Noble gases
Rare earth metals

Transition metals

Lanthanide series	138.9 La Lanthanum	140.1 Ce Cerium	140.9 Pr Praseodymium	144.2 Nd Neodymium	145 Pm Promethium	150.4 Sm Samarium	152 Eu Europium	157.3 Gd Gadolium	158.9 Tb Terbium	162.5 Dy Dysprosium	164.9 Ho Holmium	167.3 Er Erbium	168.9 Tm Thulium	173 Yb Ytterbium	175 Lu Lutetium
Actinide series	227 Ac Actinium	232 Th Thorium	231 Pa Protactinium	238 U Uranium	237 Np Neptunium	244 Pu Plutonium	243 Am Americium	247 Cm Curium	247 Bk Berkelium	251 Cf Californium	252 Es Einsteinium	257 Fm Fermium	258 Md Mendelevium	259 No Nobelium	262 Lr Lawrencium

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Glossary

Acid rain — any foam of precipitation with dissolved acidic gases such as sulphur dioxide and nitrogen oxide that fall to the ground from the atmosphere.

Agrochemicals — are chemical products comprised of fertilisers, plant-protection chemicals or pesticides, and plant-growth hormones used in agriculture.

Alkanes — hydrocarbons that contain single covalent bond between the carbon atoms.

Alkenes — hydrocarbons that contain at least one double covalent bond between the carbon atoms.

Alkynes — hydrocarbons that contain at least one triple covalent bond between the carbon atoms.

Allotropy — the existence of an element in two or more different forms in the same physical state. In each allotrope, the atoms of elements are bonded together in a different manner.

Amalgam — an alloy of mercury with another metal.

Anhydrous — the substance without water of crystallisation.

Basicity — the number of hydrogen atoms that can be replaced by a base in a particular acid.

Biodegradable — the property of a substance that allows it to be broken down by bacteria and other microorganisms into simple, and stable products that will not harm the environment.

Biotechnology — the use of organisms such as bacteria, fungi, plants, and animals, for industrial and scientific purposes to make products. Examples of such products are drugs, hormones and variety of chemicals.

Carbohydrates — organic compounds made up of carbon, hydrogen and oxygen, and are important sources of energy. Carbohydrates include starch, cellulose and sugars.

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Coagulation	the process in which colloidal particles come together irreversibly to form larger masses.
Coal	a combustible black or brownish sedimentary rock mainly made of organic compounds.
Concentration	the amount of solute contained per unit volume of solution.
Contaminant	any potentially harmful substance in the environment.
Cracking	the breaking of larger hydrocarbon molecules into smaller hydrocarbon molecules by heating them at high temperature.
Dehydration	removal of water from a substance.
Dimer	a molecule resulting from the combination of two identical molecules.
Dissociation	the process by which ionic compounds separate or split into smaller molecules, ions or radicals.
Double salt	a complex salt formed from the reaction of two salt solutions.
Ecological balance	a state of dynamic equilibrium within a community of organisms in which genetic, species, and ecosystem diversity remain relatively stable, subject to gradual changes through natural succession.
Eutrophication	the process in which excess nutrients in water bodies stimulate excessive growth of various algae and water plants in large quantities.
Feminisation	the process in which a male person develops female characteristics, for example loss of facial hair or breast enlargement, because of hormonal disorders.
Fermentation	the anaerobic process through which enzymes act on sugars to produce simpler substances such as ethanol and carbon dioxide.
Flocculation	the process in which particles in a colloid aggregate forms larger clumps.

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Force positive results	is when something is determined to be true or present when it is actually false or absent.
Forensic science	the applications of scientific methods and techniques to the investigations of crime.
Fractional distillation	a process of separating liquids based on their different boiling points.
Greenhouse effect	a heating effect resulting from the trapping of infrared radiations of long wavelengths by greenhouse gases such as carbon dioxide and methane.
Greenhouse gases	are gases such as carbon dioxide, halons, methane, chlorofluorocarbons, oxides of nitrogen, ozone, and water vapour that slow the passage of re-radiated heat through the Earth's atmosphere by absorbing infrared radiations.
Hydrogen bond	attractive interaction of a hydrogen atom and a more electronegative atom such as nitrogen, oxygen and fluorine.
Halogenation	the reaction of a halogen element with an organic compound by direct addition or by substitution with a hydrogen atom.
Hormones	chemical substances secreted by the endocrine glands in the body. Hormones are carried through the blood stream to have effects on other parts of the body away from where they are produced.
Humus	a complex organic substance resulting from the breakdown of plant and animal materials in a process called humification.
Hydrated	containing water molecules.
Hydrocarbons	are compounds made up of carbon and hydrogen only.
Irreversible reaction	a reaction that can proceed in one direction.
Isomerism	the existence of two or more compounds (isomers) having the same molecular formula but different structural formulae.

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Leaching	the loss of water soluble chemicals or plant nutrients from the soil due to excessive rain, irrigation, and floods whereby chemical substances or plant nutrients are taken away in solution form.
Lipids	a class of water-insoluble compounds that encompass molecules such as fatty acids or their derivatives. They include natural oils, waxes, and steroids. Some of them are essential for structures and functions of living cells.
Marine waste	debris, garbage, trash, and litter that float on water in the ocean or sea.
Oxidising agent	a substance that adds oxygen to, removes hydrogen from, or accepts electron(s) from another substance.
Ozone	a form of oxygen that has three atoms per molecule (O_3).
pH value	a value that indicates the degree or level of acidity or alkalinity due to hydrogen ions concentrations in a solution.
Pollutant	a contaminant introduced into the environment.
Precipitation	water that falls to the ground in the form of rain, snow or hail.
Precipitation reaction	a reaction that involves production of water-insoluble species.
Products	the chemical substances formed during a chemical reaction.
Proteins	large molecules made up of amino acids that play many major roles in the body, including forming the basis of body structures such as skin and hair, and important biological chemicals such as enzymes and hormones.
Reducing agent	a substance that removes oxygen from, gives hydrogen to, or donates electron(s) to another substance.
Reduction	the process of losing oxygen, gaining hydrogen or electrons.

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Salt	the compound formed when the hydrogen of an acid is replaced, directly or indirectly, by a metal or ammonium ion.
Sedimentation	the process in which soil, debris, and other materials are deposited on the ground surface or in water bodies and waterways.
Soil catena	a sequence of different soil profiles that occurs down a slope as a result of changes in slope gradient.
Solubility	the maximum amount of substance (solute) that can dissolve in a given amount of solvent at a given temperature.
Steam reforming	the production of hydrogen gas from organic compounds at high temperature using steam.
Stoichiometry	the relationship between the quantities of substances that take part in a reaction or form a compound.

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