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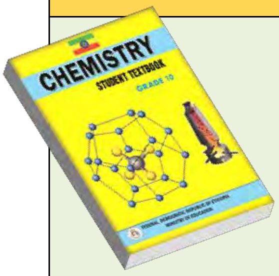

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CHEMISTRY

STUDENT TEXTBOOK

GRADE 10

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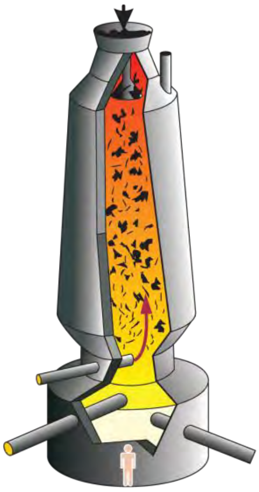
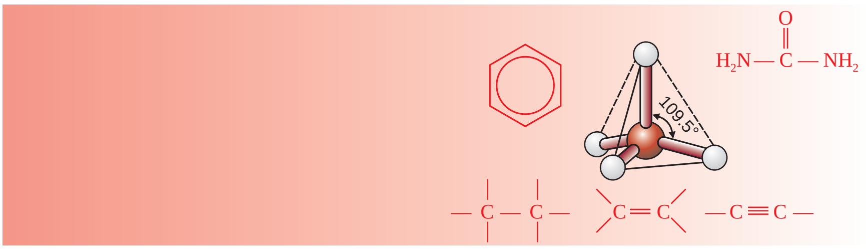


UNIT 1



Introduction to Organic Chemistry

Unit Outcomes

After completing this unit, you will be able to:

- *know the historical development of organic chemistry and the classification of organic compounds;*
- *know the general formulas of alkanes, alkenes, alkynes, alcohols, aldehydes, ketones, carboxylic acids and esters;*
- *develop skills in naming and writing the molecular and structural formulas of simple alkanes, branched-chain alkanes, simple alkenes, branched-chain alkenes, simple alkynes, alcohols, aldehydes, ketones, carboxylic acids and esters;*
- *understand isomerism and know possible isomers of alkanes, alkenes and alkynes;*
- *know the major natural sources of hydrocarbons;*
- *understand the physical and chemical properties and the general methods of preparation of alkanes, alkenes, alkynes, benzene and alcohols;*
- *know the uses of organic compounds in the manufacture of plastics, beverages, pharmaceuticals, soaps and detergents, dry cleaning chemicals, fuels, pesticides, and herbicides; and*
- *demonstrate scientific inquiry skills: observing, classifying, communicating, measuring, asking questions, interpreting data, drawing conclusions, applying concepts, predicting and problem solving.*

MAIN CONTENTS

1.1 INTRODUCTION

Competencies

By the end of this section, you will be able to:

- narrate the historical development of organic compounds;
- define the term functional group;
- classify organic compounds based on their functional groups.

Historical Notes

Friedrich Wöhler

Friedrich Wöhler

In 1828 German chemist, **Friedrich Wöhler** converted ammonium cyanate, an inorganic compound, into the organic substance urea. **Wöhler's** discovery revolutionized the study of chemistry by redefining the manner in which chemists distinguished between inorganic and organic compounds. He is also credited for his work in isolating the elements aluminium and beryllium.

Activity 1.1

1. Do you agree with the notion that says: "carbon compounds can be synthesized only by animals and plants"?
2. Draw diagrams to show how carbon atoms can link to one another in different ways to form a variety of compounds by considering only four carbon atoms.

   Discuss with your group and present it to the class.

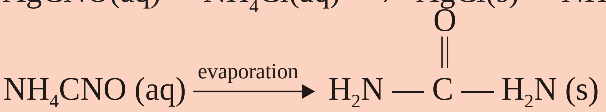
History of Organic Chemistry

Before the beginning of the nineteenth century, chemists classified compounds into two classes; organic and inorganic. Those derived from living things (*plants* and *animals*) were classified as organic compounds, while those that came from mineral constituents of the earth or were found with non-living things are classified as inorganic compounds.

What was the basis of this classification? Early chemists believed that organic compounds differed from inorganic compounds because living things had a special 'life force' within them, which was invisible and hard to detect. According to the theory of 'life force', the only source of organic compounds was nature itself (*plants* and *animals*). It was thought impossible to synthesize them in the laboratory. This was because man could not add or create the 'life force' within them.

The belief in the 'life force' theory continued until Friedrich Wöhler synthesized urea for the first time in 1828. In attempting to prepare ammonium cyanate, NH_4CNO, from the reaction of silver cyanate, $AgCNO$, and ammonium chloride, NH_4Cl, he accidentally and surprisingly obtained urea, $(NH_2)_2CO$:

$$AgCNO(aq) + NH_4Cl(aq) \rightarrow AgCl(s) + NH_4CNO(aq)$$



$$NH_4CNO\ (aq) \xrightarrow{\text{evaporation}} H_2N - \overset{\overset{\displaystyle O}{\|}}{C} - H_2N\ (s)$$

Urea

Urea was the first organic compound synthesized in the laboratory. The synthesis of urea by Friedrich Wöhler and subsequent synthesis of other organic compounds marked the downfall of the 'life force' theory.

How do you explain organic compounds at present and define organic chemistry?

The common feature of organic compounds is that they all contain the element carbon. Organic compounds are the compounds of carbon found in and derived from plants and animals. They also include those substances synthesized in laboratories except the oxides of carbon, carbonates, hydrogen carbonates, cyanides and cyanates.

Besides carbon, these compounds contain a few other elements such as hydrogen, oxygen, nitrogen, sulphur, halogens and phosphorus. The branch of chemistry that studies carbon compounds is called organic chemistry. This branch of chemistry was developed, starting from the theory of 'life force' to the era in which synthetic organic compounds are used in our daily lives. The number of inorganic compounds discovered and prepared may be in the region of some hundred thousand. At present, millions of organic compounds have been discovered, synthesized, and used.

The main reason for the presence of millions of carbon compounds is the unique property of carbon called catenation. Catenation is the ability of atoms of the same element to join together forming short or long chains and rings. A few other elements like sulphur, silicon and boron show this behaviour, but to a much lesser extent.

Classification of Organic Compounds

Activity 1.2

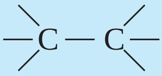
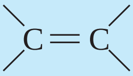
CH_3CH_2CHO and CH_3COCH_3 have the same chemical formula C_3H_6O. Write their detailed structures and observe their difference? Why do these compounds have different properties? Discuss with your group and present it to the class.

Organic compounds are generally classified based on their functional group.

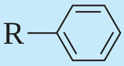
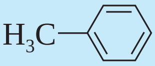
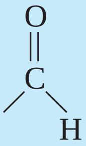
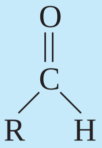
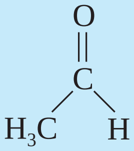
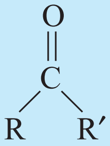
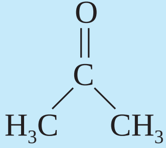
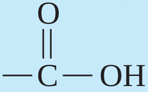
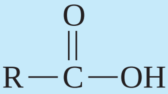
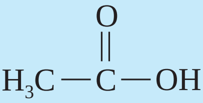
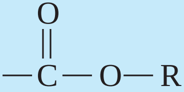
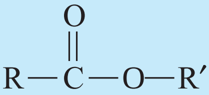
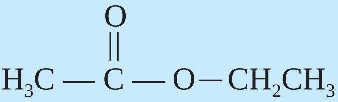
What are functional groups and what groups of organic compounds are known on the basis of this classification?

The functional group is the part of a molecule or a compound that determines the chemical properties of that molecule or compound. This group also determines some of the physical properties of a compound. Based on the functional groups they possess, the most common classification of organic compounds including alkanes, alkenes, alkynes, aromatics, alcohols, aldehydes, ketones, carboxylic acids and esters. The common functional groups of some organic compounds are given in Table 1.1.

Table 1.1 Some classes of organic compounds, their functional groups, general structural formula with typical examples (R = alkyl or H).

Organic Compound	Functional Group	General Structure	Example
Alkane	 (single bond)	$R-CH_2-CH_3$	$H_3C-CH_2-CH_3$ Propane
Alkene	 (double bond)	$R-CH=CH_2$	$H_2C=CH_2$ Ethene
Alkyne	$-C\equiv C-$ (triple bond)	$R-C\equiv C-R$	$H-C\equiv C-H$ Ethyne

Continued next page

Organic Compound	Functional Group	General Structure	Example
Aromatic	 (benzene ring)		 Toluene
Alcohols	— OH	R — OH	CH_3CH_2-OH Ethanol
Aldehydes	— CHO group 	R — CHO 	CH_3-CHO  Ethanal
Ketone	— CO — group 	RCOR′ 	CH_3COCH_3  Propanone
Carboxylic Acid	— COOH group  $-\overset{\overset{O}{\Vert}}{C}-OH$	R — COOH  $R-\overset{\overset{O}{\Vert}}{C}-OH$	 $H_3C-\overset{\overset{O}{\Vert}}{C}-OH$ Ethanoic acid
Ester	— COOR group  $-\overset{\overset{O}{\Vert}}{C}-O-R$	RCOOR′  $R-\overset{\overset{O}{\Vert}}{C}-O-R'$	 $H_3C-\overset{\overset{O}{\Vert}}{C}-O-CH_2CH_3$ Ethyl ethanoate

Exercise 1.1

1. Which compounds were classified as organic compounds, according to the early chemists?
2. According to the belief of early chemists, which class of compounds has a special ‘life force’ within them?
3. What are the differences between organic and inorganic compounds, according to early chemists?
4. What is the main concept of the theory of ‘life force’?

5. Who disproved the 'life force' theory; and how?
6. What was the first organic compound synthesized in the laboratory?
7. Identify the functional groups in each of the following compounds?

   a $CH_3CH_2COCH_2CH_2CH_3$ c $CH_3CH_2CH_2COOH$
   b $CH_3CH_2COOCH_2CH_3$ d $CH_3CH_2CH_2CH_2OH$
8. Define the following terms.

   a Organic chemistry b Catenation c Functional group
9. Why is it necessary to assign organic chemistry exclusively to the study of carbon compounds?
10. What is the basis for the classification of organic compounds?
11. Write the general structures of:

   a alkanes b alkenes c alkynes
   d aromatics e alcohols

1.2 SATURATED HYDROCARBONS

Competencies

At the end of this topic, you will be able to:

- define hydrocarbons;
- define saturated hydrocarbons;
- define homologous series;
- write the general formula of alkanes;
- write the first ten members of alkanes;
- write the molecular formulas of alkanes from the given number of carbon atoms;
- explain the physical properties of alkanes;
- write the structural formulas of the first ten alkanes;
- apply IUPAC rules to name straight and branched chain alkanes;
- define isomerism as the way compounds having the same formula differ in the way their atoms are arranged;
- define structural isomerism;
- write possible structural isomers for C_4H_{10}, C_5H_{12} and C_6H_{14};
- describe the general method for the preparation of alkanes in the laboratory;

- prepare methane in a laboratory by the decarboxylation method;
- carry out a project to produce biogas from cow dung; and
- explain the chemical properties of alkanes.

Activity 1.3

1. Draw the Lewis structure of carbon ($Z = 6$) and hydrogen ($Z = 1$) atoms. How many valence electrons are there in an atom of carbon and hydrogen respectively?
2. Consider three organic compounds containing two carbon atoms each. The two carbon atoms contributed one electron each in the first, two electrons each in the second and three electrons each in the third for the bond they form between them by sharing the electrons. The remaining valence electrons of each carbon atom in all the three compounds were used to form bonds with hydrogen atoms.
   - a What type of covalent bond do the two-carbon atoms form between themselves in the first, the second and the third compound, respectively?
   - b How many hydrogen atoms can form bonds with each carbon atom in the first, the second and the third compound, respectively?
   - c Draw line or dot formula to show the formation of the bonds between the carbon atoms and carbon and the hydrogen atoms in the first, the second and the third compound, respectively.
   - d If the three compounds mentioned above are hydrocarbons, define hydrocarbons?
   - f If the first compound is a saturated hydrocarbon, the second and the third are unsaturated, what is the basis for such a classification of hydrocarbons?

Discuss with your group and present it to the class.

What are hydrocarbons and on what basis do we categorize them?

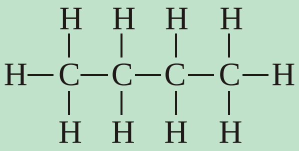
Hydrocarbons are organic compounds composed of the elements carbon and hydrogen only. Hydrocarbons are subdivided into two groups, based on the type of bonding between carbon atoms, as saturated hydrocarbons and unsaturated hydrocarbons.

Saturated Hydrocarbons are those compounds of carbon and hydrogen containing only carbon-carbon single bonds. Methane, ethane, and propane are typical examples of this group. Unsaturated Hydrocarbons are those compounds of carbon and hydrogen possessing one or more multiple bonds (*double or triple bonds*) between carbon atoms. Alkenes, alkynes and aromatic hydrocarbons are examples of unsaturated hydrocarbons.

A formula that shows all the bonds and atoms is called a detailed structure. The shorter structure is called condensed structure.

Example

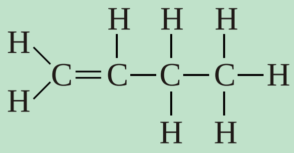
Condensed structure



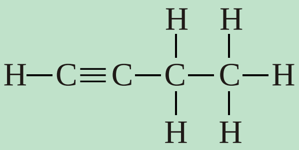
$$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H$$

or $H_3C-CH_2-CH_2-CH_3$

Saturated Hydrocarbons (Detailed structure)



or $H_2C{=}CH-CH_2-CH_3$



$$H-C{\equiv}C-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-H$$

or $HC{\equiv}C-CH_2-CH_3$

Unsaturated Hydrocarbons

1.2.1 Alkanes or Paraffins

Activity 1.4

Draw a graph using the information in Table 1.2 by plotting the number of carbon atoms of each compound on one axis, and hydrogen atoms on the other. Predict the formulas of the saturated hydrocarbons containing 8, 9 and 10 carbon atoms and complete Table 1.2. Discuss with your group and present it to the class.

Alkanes are saturated hydrocarbons. They contain chains of carbon atoms linked by single bonds only. Every carbon atom in the molecule forms four single covalent bonds with other atoms. Alkanes have the general formula C_nH_{2n+2}, where, $n = 1, 2, 3 \ldots$ Using this general formula, we can write the molecular formula of any alkane containing a specific number of carbon atoms. For example, the chemical formulas of alkanes containing one, two and three carbon atoms are $C_1H_{2\times1+2} = CH_4$, $C_2H_{2\times2+2} = C_2H_6$, and $C_3H_{2\times3+2} = C_3H_8$, respectively.

When we compare the formulas of CH_4 and C_2H_6 or C_2H_6 and C_3H_8, they differ by one carbon and two hydrogen atoms or $-CH_2-$ group called the methylene group. A group of compounds in which each member of the group differs from the next member by a $-CH_2$, is called a homologous series. Compounds in the same homologous series can be represented by the same general formula. The individual members of the group are called homologues.

Alkanes contain carbon-carbon single bonds (— C — C —) as their functional group. The first ten members of the homologous series of straight-chain alkanes are given in Table 1.2.

Table 1.2 Homologous series and physical constants of the first ten straight chain alkanes

Name	Formula	Physical state (at room temp.)	M.P (°C)	B.P (°C)	Density at 20°C	No. of isomers
Methane	CH_4	gas	–183	–162	0.717 g/L	1
Ethane	C_2H_6	gas	–172	–89	1.35 g/L	1
Propane	C_3H_8	gas	–187	–42	2.02 g/L	1
n-Butane	C_4H_{10}	gas	–135	–0.5	2.48 g/L	2
n-Pentane	C_5H_{12}	liquid	–130	36	0.63 g/mL	3
n-Hexane	C_6H_{14}	liquid	–94	68	0.66 g/mL	5
n-Heptane	C_7H_{16}	liquid	–91	98	0.68 g/mL	9
n-Octane	?	liquid	–57	126	0.70 g/mL	18
n-Nonane	?	liquid	–54	151	0.71 g/mL	35
n-Decane	?	liquid	–30	174	0.73 g/mL	75

Activity 1.5

1. What happens to the percentage by mass of hydrogen and the physical state of alkanes as the number of carbon atoms increase?
2. Categorize the petroleum related products you encounter everyday as solids, liquids and gases? Discuss in your group and present it to the class.

1.2.2 Physical Properties of Alkanes

Do you know which alkanes exist in the liquid, solid or gaseous state at room temperature? What types of intermolecular forces of attraction exist between the molecules of alkanes? Explain why the boiling points and melting points of alkanes increase with increasing number of carbon atoms.

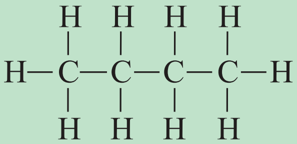
At room temperature, the first four alkanes, methane to butane, are gases; whereas pentane (C_5H_{12}) to heptadecane ($C_{17}H_{36}$) are liquids, and the alkanes containing eighteen and more carbon atoms are solids.

Alkanes are nonpolar organic compounds. Weak intermolecular forces called Van der Waal's forces hold their molecules together. The strength of these forces increases with the increasing surface area (*molecular mass*) of the alkanes. Since alkanes are non-polar, they are almost insoluble in polar solvents like water, but, they are soluble in non-polar solvents like benzene, toluene, ether and carbon tetrachloride.

The density, melting point, and boiling point of the homologous series of alkanes increase as the carbon number increases. For alkanes of the same carbon number, branched-chain isomers have lower boiling points than the straight-chain (*normal*) alkanes. The reason is, as branching increases, there is a decrease in surface area and the strength of the intermolecular force, which, in turn, results in a decrease in boiling point; e.g., the boiling points of n-pentane, iso-pentane and neo-pentane are 36°C, 28°C and 9.5°C, respectively.

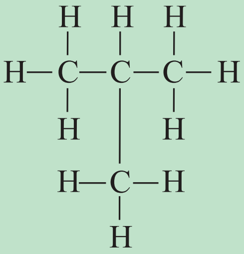
Alkanes containing all the carbon atoms in one continuous chain are called normal or straight-chain alkanes and those containing chains with branches are known as branched-chain alkanes.

Example



$$\begin{array}{ccccccccccc} & & H & & H & & H & & H & & \\ & & | & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & | & & \\ & & H & & H & & H & & H & & \end{array}$$

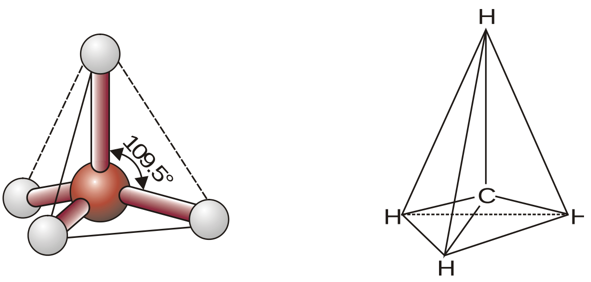
Straight-Chain Alkane



$$\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & \\ & & H & & | & & H & & \\ & & & & | & & & & \\ & & & H- & C & -H & & & \\ & & & & | & & & & \\ & & & & H & & & & \end{array}$$

Branched-Chain Alkane

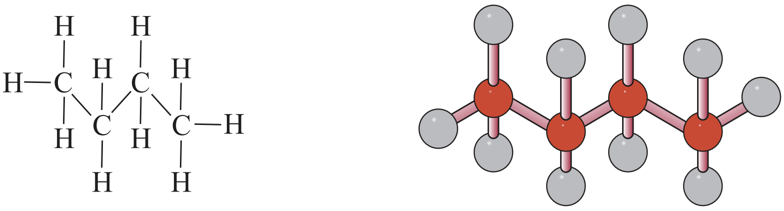
In alkanes (*branched* or *straight-chain*) each carbon atom is tetrahedrally bonded to four atoms with a bond angle of 109.5°.



a Ball and Stick Model of Methane b Tetrahedral structure of methane

Figure 1.1 Structure of methane.

In alkanes containing a continuous chain of carbon atoms, the carbon atoms are not linked in straight line but in zigzag chains to keep the tetrahedral distribution of atoms.



Zigzag chain in butane

Ball and stick model of butane

Figure 1.2 Zigzag chain and ball and stick model of butane.

Activity 1.6

1. Why rules are important for naming organic compounds? Discuss in your group some of the rules you know for naming organic compounds and present it to your class.
2. In mathematics, the names pentagon, hexagon, heptagon and octagon are used to describe polygons. What does each of the prefixes- pent, -hex, -hept and -oct indicate? What is the significance of these prefixes in chemistry? Discuss in groups and present it to the class.

1.2.3 Nomenclature (naming) of Alkanes

Organic chemistry uses a simplified and systematic way of naming organic compounds. The names of alkanes and most of the organic compounds are derived from:

i) a prefix- indicating the number of carbon atoms (listed in Table 1.3)and

*ii)*a -suffix indicating the type of the functional group present in the molecule.

The following table introduces the prefixes that are used to indicate the presence of one to ten carbon atoms in the longest continuous carbon chain.

Table 1.3 Prefixes commonly used to indicate one to ten carbon atoms.

Prefix	Number of carbon atoms	Prefix	Number of carbon atoms
Meth-	One	Hex-	Six
Eth-	Two	Hept-	Seven
Prop-	Three	Oct-	Eight
But-	Four	Non-	Nine
Pent-	Five	Dec-	Ten

From Table 1.2, you can note that the names of all alkanes contain the suffix '-ane', which indicates that their functional group is a carbon — carbon single bond. Thus, to name an alkane, you should use the appropriate prefix that indicates the number of carbon atoms and the suffix '-ane'. For example, to name the alkane C_6H_{14}, use the prefix 'Hex' that indicate the presence of six carbon atoms and add the suffix '-ane' so that the name becomes hexane.

Activity 1.7

Practice naming alkanes using first four prefixes mentioned in Table 1.3. In naming alkanes, why are number of carbon atoms used as prefixes? Discuss in groups.

Common Names of Alkanes

Lower members of the alkane homologous series have common names. The prefixes used in the common names are *n*- (*normal*), 'iso-' and 'neo-'. The prefix *n*- is used when all the carbon atoms form a continuous chain.

Example

$$H_3C-CH_2-CH_2-CH_2-CH_3$$

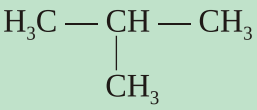
n-pentane

$$H_3C-CH_2-CH_2-CH_2-CH_2-CH_3$$

n-hexane

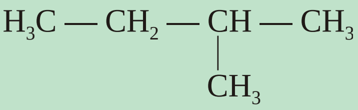
Iso- is used when all of the carbon atoms form a continuous chain, except for the one next to the last carbon.

Example



$$\begin{array}{c}H_3C-CH-CH_3\\ |\\ CH_3\end{array}$$

Isobutane

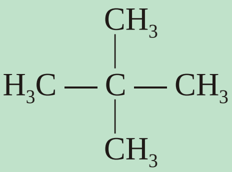


$$\begin{array}{c}H_3C-CH_2-CH-CH_3\\ \quad\quad\quad |\\ \quad\quad\quad CH_3\end{array}$$

Isopentane

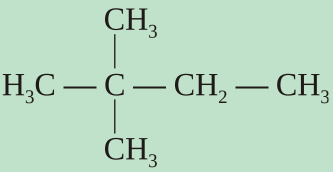
Neo- is used when the central carbon is bonded to four other carbon atoms.

Example



$$\begin{array}{c}CH_3\\ |\\ H_3C-C-CH_3\\ |\\ CH_3\end{array}$$

Neopentane



$$\begin{array}{l}\quad\quad\quad CH_3\\ \quad\quad\quad |\\ H_3C-C-CH_2-CH_3\\ \quad\quad\quad |\\ \quad\quad\quad CH_3\end{array}$$

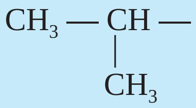
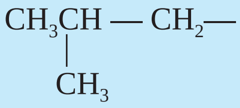
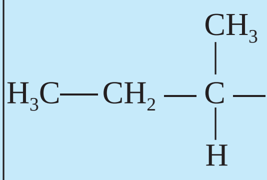
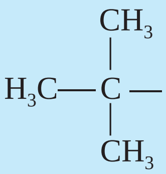
Neohexane

IUPAC System of Nomenclature of Alkanes

It is difficult to have common names for the more branched and complex alkanes. In naming such alkanes, the more systematic, convenient and appropriate one is the International Union of Pure and Applied Chemistry (IUPAC) system. In order to apply this system, it is very important to know the rules to be followed, what alkyl radicals are, and how they are named.

Alkyl radicals are obtained by removing one hydrogen atom from the corresponding alkanes. Their general formula is C_nH_{2n+1}, where $n = 1, 2, 3 \ldots.$ The names of alkyl radicals are derived from the names of the corresponding parent alkanes by changing the suffix -ane to -yl.

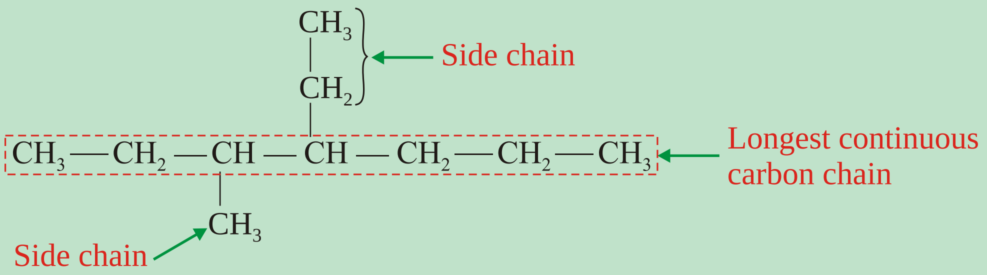
Table 1.4 Formulas, names and structures of some alkyl groups.

Formula of alkane	Formula of alkyl radical	Condensed structure of alkyl radical	Common name of alkyl radical
CH_4	CH_3-	CH_3-	Methyl
C_2H_6	C_2H_5-	CH_3CH_2-	Ethyl
C_3H_8	C_3H_7-	$CH_3CH_2CH_2-$  $CH_3-\underset{CH_3}{CH}-$	*n*-Propyl Isopropyl
C_4H_{10}	C_4H_9-	$CH_3CH_2CH_2CH_2-$  $CH_3\underset{CH_3}{CH}-CH_2-$  $H_3C-CH_2-\overset{CH_3}{\underset{H}{C}}-$  $H_3C-\overset{CH_3}{\underset{CH_3}{C}}-$	*n*-Butyl Isobutyl sec-Butyl (s-Butyl) tert-Butyl (t-Butyl)

The system of naming organic compounds is based on the recommendations of IUPAC. The following are the rules established by IUPAC to name branched-chain hydrocarbons.

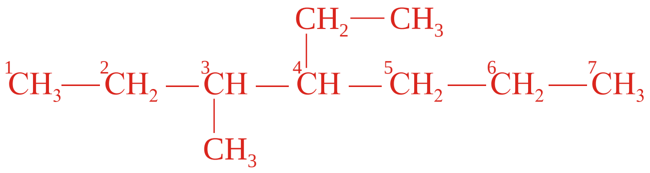
1. Select the longest continuous chain of carbon atoms in the molecule as the *parent structure*. The name of the straight-chain alkane possessing the same number of carbon atoms is used as the name of this longest chain. The groups attached to the parent structure are called side chains or substituents.

Example 1

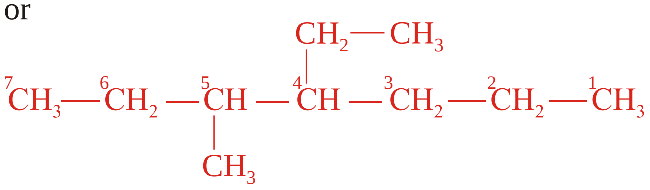

$$CH_3-CH_2-\underset{\begin{array}{c}|\\CH_3\end{array}}{CH}-\overset{\begin{array}{c}CH_3\\|\\CH_2\\|\end{array}}{CH}-CH_2-CH_2-CH_3$$

There are seven carbon atoms in the longest chain (*the parent structure*). Therefore, it gets the name "heptane".

2. Assign numbers to the carbon atoms of the longest chain starting from one end to the other so that the carbon atoms to which side chains are attached get the lowest possible number.


$${}^{1}CH_3-{}^{2}CH_2-\underset{\begin{array}{c}|\\CH_3\end{array}}{{}^{3}CH}-\overset{\begin{array}{l}CH_2-CH_3\\|\end{array}}{{}^{4}CH}-{}^{5}CH_2-{}^{6}CH_2-{}^{7}CH_3$$

or


$${}^{7}CH_3-{}^{6}CH_2-\underset{\begin{array}{c}|\\CH_3\end{array}}{{}^{5}CH}-\overset{\begin{array}{l}CH_2-CH_3\\|\end{array}}{{}^{4}CH}-{}^{3}CH_2-{}^{2}CH_2-{}^{1}CH_3$$

To check which direction of numbering is correct; add the locants (*numbers assigned to the carbon atoms to which substituents are attached*).

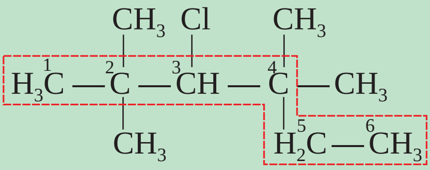
The sum of locants in the first case is $3 + 4 = 7$ and in the second case, $4 + 5 = 9$. So numbering should be done from left to right in this case. Thus, the first option is correct.

3. Indicate the position of the side chain by using the number assigned to the carbon atom to which it is attached. If the same substituents appear more than once, use the

prefix *di-*, *tri-*, *tetra-* etc. before the name of the substituent to show *two*, *three*, *four,* etc. substituents, respectively.

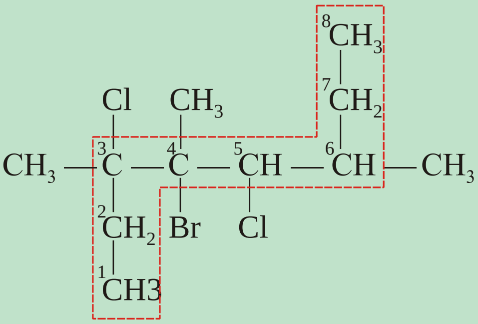
4. Numbers are separated from each other by commas while they are separated from substituent names by hyphens.
5. Arrange the names of the side chains before the parent name in alphabetical order. The complete name of the alkane given in the above example will then be 4-ethyl-3-methylheptane (substituents in *alphabetical order*).

Example 2



The longest chain has six carbon atoms and the parent name is hexane. There are two methyl groups at carbon-2 and another two methyl groups on carbon-4 and one chlorine atom at carbon-3. Therefore, the correct name of the compound is 3-chloro-2,2,4,4-tetramethylhexane.

Example 3

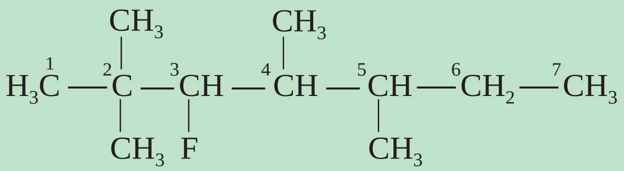


The longest chain contains eight carbon atoms. Hence, the parent name of the given molecule is octane. There are three methyl groups attached to carbon number 3, 4 and 6; one bromine atom is attached to carbon-4 and two chlorine atoms are attached to carbon-3 and carbon-5. Thus, the correct name of the compound is 4-bromo-3,5-dichloro-3,4,6-trimethyloctane.

Note:

When F, Cl, Br and I appear as substituents, change the names fluorine, chlorine, bromine and iodine to fluoro, chloro, bromo and iodo, respectively.

Example 4



$$\mathrm{H_3\overset{1}{C}-\overset{\substack{CH_3\\|}}{\underset{\substack{|\\CH_3}}{\overset{2}{C}}}-\underset{\substack{|\\F}}{\overset{3}{CH}}-\overset{\substack{CH_3\\|}}{\overset{4}{CH}}-\underset{\substack{|\\CH_3}}{\overset{5}{CH}}-\overset{6}{CH_2}-\overset{7}{CH_3}}$$

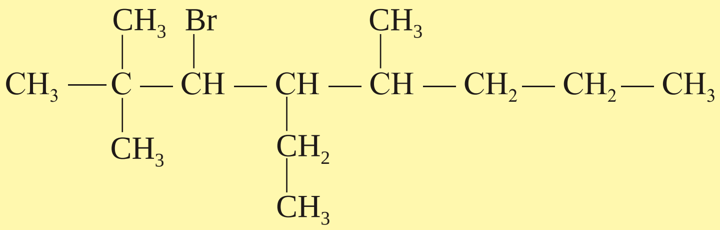
There are seven carbon atoms in the parent structure, so it takes the name heptane. There are two methyl groups at carbon-2 and two methyl groups at carbon-4 and carbon-5 and one fluorine at carbon-3. So the name of the compound is 3-fluoro-2,2,4,5-tetramethyl heptane.

Activity 1.8

Is there any scientific background for the IUPAC rules or is it just a convention? Why IUPAC recommendations are followed throughout the world. Present your opinion to the class.

Exercise 1.2

1. Write any three possible structures for octane, C_8H_{18}, and give their IUPAC names.
2. Give the IUPAC name of:



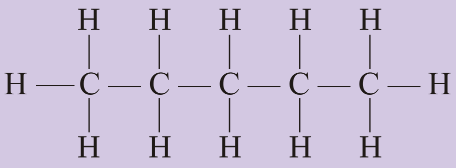
$$\mathrm{CH_3-\overset{\substack{CH_3\\|}}{\underset{\substack{|\\CH_3}}{C}}-\overset{\substack{Br\\|}}{CH}-\underset{\substack{|\\CH_2\\|\\CH_3}}{CH}-\overset{\substack{CH_3\\|}}{CH}-CH_2-CH_2-CH_3}$$

3. Write the structure of 2,2-dimethyl butane.
4. Write the structure of 2,3-dimethylpentane.
5. When F, Cl, Br and I appear as substituents in an organic compound, how are they named?

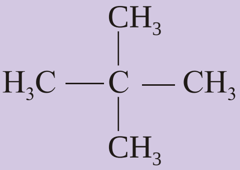
1.2.4 Isomerism

Activity 1.9

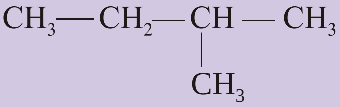
1. Write the molecular formula of the following compounds?



$$\begin{array}{ccccccccccccc} & & H & & H & & H & & H & & H & & \\ & & \mid & & \mid & & \mid & & \mid & & \mid & & \\ H & — & C & — & C & — & C & — & C & — & C & — & H \\ & & \mid & & \mid & & \mid & & \mid & & \mid & & \\ & & H & & H & & H & & H & & H & & \end{array}$$



$$\begin{array}{ccccc} & & CH_3 & & \\ & & \mid & & \\ H_3C & — & C & — & CH_3 \\ & & \mid & & \\ & & CH_3 & & \end{array}$$



$$\begin{array}{ccccccc} CH_3 & — & CH_2 & — & CH & — & CH_3 \\ & & & & \mid & & \\ & & & & CH_3 & & \end{array}$$

2. Do they have the same or different molecular formula? Do they have the same or different physical and chemical properties? Why? What do we call compounds of this type? Discuss the results in your group and present it to the class.

There is only one possible structure for each of the first three alkanes, namely, methane (CH_4), ethane (C_2H_6) and propane (C_3H_8). Those alkanes containing four or more carbon atoms have more than one structure. The existence of two or more chemical compounds with the same molecular formula but different structures is called isomerism.

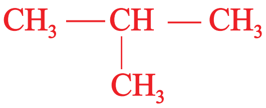
The compounds that have the same molecular formula but different structures are called isomers. Alkanes exhibit a type of structural isomerism called chain or skeletal isomerism. These structures differ in the arrangement of the carbon atoms and hydrogen atoms. To understand what isomers are, consider the isomers of butane (C_4H_{10}) and pentane (C_5H_{12}).

1. **Isomers of butane (C_4H_{10})**

   Butane has two isomers:

$CH_3 — CH_2 — CH_2 — CH_3$

n-butane



$$\begin{array}{ccccc} CH_3 & — & CH & — & CH_3 \\ & & \mid & & \\ & & CH_3 & & \end{array}$$

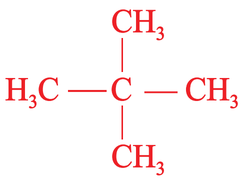
Isobutane or 2-methylpropane

2. **Isomers of pentane (C_5H_{12})**

   Pentane has three isomers.

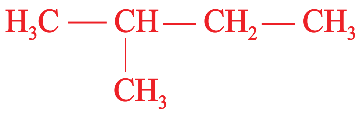
$CH_3-CH_2-CH_2-CH_2-CH_3$

n-pentane



$$H_3C-\underset{\displaystyle CH_3}{\overset{\displaystyle CH_3}{\underset{|}{\overset{|}{C}}}}-CH_3$$

Neopentane or 2, 2-dimethylpropane



$$H_3C-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_2-CH_3$$

Isopentane or 2-methylbutane

Exercise 1.3

1. Which of the following statements are true about isomers:
   - a They have the same molecular formula.
   - b They are different compounds.
   - c They have different boiling and melting points.
   - d They have similar chemical properties.
2. Draw all the possible structural isomers for hexane and name them.

1.2.5 Preparation of Alkanes

Alkanes are the major constituents of petroleum and natural gas. They are mainly obtained by fractional distillation of petroleum. Alkanes can also be prepared in the laboratory. Some methods of their preparation are as follows:

1. Hydrogenation of alkenes with a metal catalyst.

General Reaction: $R-CH=CH_2 + H_2 \xrightarrow[heat]{Pt} R-CH_2-CH_3$

Alkene Alkane

Example

$CH_2=CH_2 + H_2 \xrightarrow[heat]{Pt} CH_3-CH_3$

Ethene Ethane

2. **Wűrtz** Synthesis (*reaction*). This method involves the reaction of a halogenated alkane with sodium and the reaction is somewhat exothermic.

General Reaction:

$$2R-X \quad + \quad 2Na \longrightarrow R-R \quad + \quad 2NaX$$

Halogenated Alkane — Alkane — Sodium halide

Example

$$2CH_3I \quad + \quad 2Na \longrightarrow CH_3-CH_3 \quad + \quad 2NaI$$

Methyl iodide — Ethane — Sodium iodide

This reaction is named as Wűrtz reaction after the French chemist Charles-Adolphe Wűrtz (1817–1884).

3. Heating sodium salt of an organic acid with soda lime (*mixture of sodium hydroxide and calcium oxide*); the reaction brings about the removal of the carboxylate group from the sodium salt of the carboxylic acid. This type of reaction is called decarboxylation.

General Reaction:

$$RCOONa \quad + \quad 2NaOH \xrightarrow[\text{heat}]{\text{CaO}} R-H \quad + \quad Na_2CO_3\,(s)$$

Sodium salt of organic acid — Alkane

Example

$$CH_3COONa \quad + \quad 2NaOH \xrightarrow[\text{heat}]{\text{CaO}} CH_4\,(g) \quad + \quad Na_2CO_3\,(s)$$

Sodium acetate (Sodium ethanoate) — Methane

Methane

Methane is the main constituent (*about 90%*) of natural gas. It is obtained during fractional distillation of petroleum. Methane is also formed by the decay and decomposition of animal and plant remains in swampy or marshy lands.

Activity 1.10

Discuss the following points in groups, and present your ideas to the class.

1. Have you ever walked near a marshy or swampy area? Which characteristic smell do you observe?
2. In most parts of Ethiopia, the walls of houses are constructed from wood and mud. The mud for this purpose is usually prepared by mixing soil, water and hay or straw. After two or three weeks of decay and decomposition, an unusual smell is perceived. What do you think is the cause of this?
3. If Ethiopia introduces the technology of producing biogas to its residents, what benefits will be obtained by the country? What materials can be used to generate biogas? Which compound is the main constituent of biogas?

Experiment 1.1

Laboratory Preparation of Methane

Objective: To prepare methane and study its properties.

Materials required: Sodium acetate (CH_3COONa) and soda lime (CaO, $NaOH$), test tubes, delivery tube, stopper, gas jar and gas jar lid, pneumatic trough, stand, clamp, beehive shelf, Bunsen burner and balance.

Procedure:

Arrange the assembly as shown in Figure 1.3. Mix thoroughly 5 g powdered sodium acetate with 10 g of soda lime. Place the mixture in the test tube and heat it. Collect the gas by the downward displacement of water. Collect several jars of the gas.

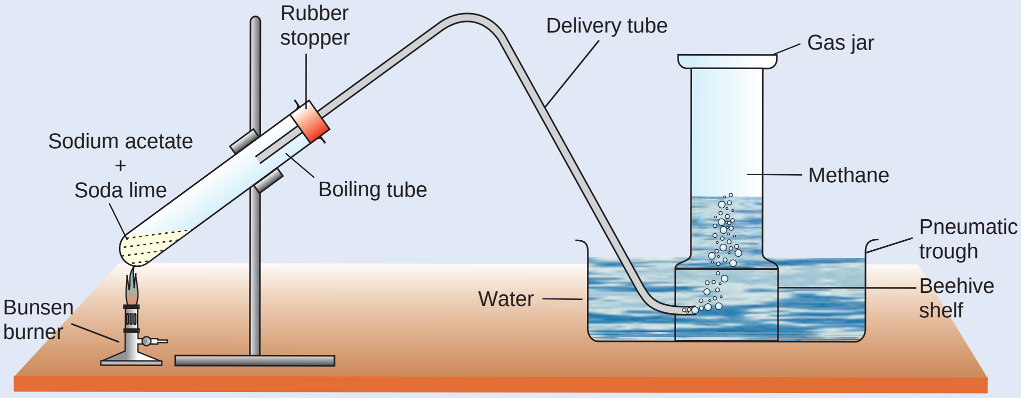


Figure 1.3 Preparation of methane.

Carry out the following activities with the collected gas:

Insert a burning splint into the jar full of the gas. Observe what happens in the jar. Add $Ca(OH)_2$ solution to the jar and observe. Add a few drops of bromine water to any one of the gas jars filled with methane. Cover the gas jar and shake well.

Observations and analysis:

a What is the colour of the gas? Is it soluble in water?

b Is the gas combustible? Write a balanced equation for the change.

c What change did you observe upon addition of $Ca(OH)_2$?

d Is there any change when bromine water is added?

Write a laboratory report on your observation and submit to your teacher.

Methane can be produced in a biogas plant. The biogas plant generates biogas, mainly consisting of methane by anaerobic fermentation of organic materials such as human excreta, animal dung and agricultural residue.

The conversion of organic materials into biogas involves a sequence of reactions and is graphically depicted in Figure 1.4.

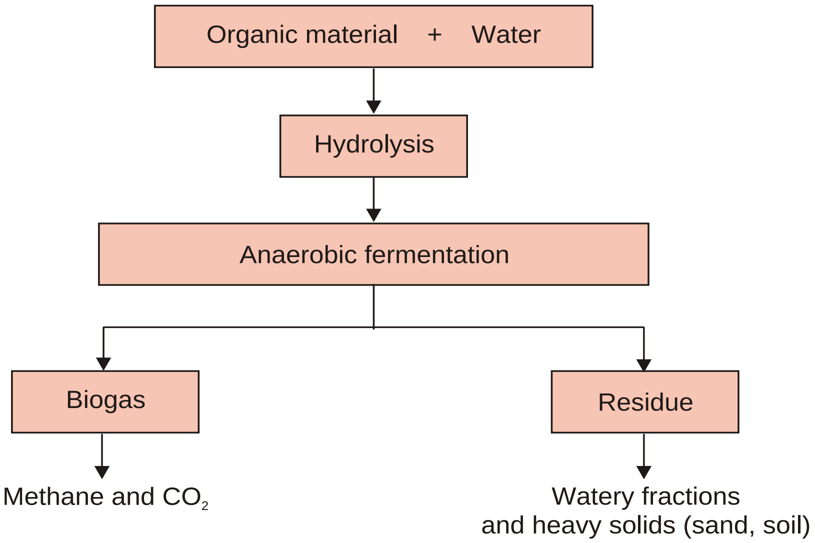


Figure 1.4 Reactions in the production of biogas.

The materials that can be used to produce biogas include dung from cattle, pigs, chickens, chopped green plants and plant wastes. The advantages of biogas technology include saving on fuel such as kerosene, wood and charcoal, and decrease in local deforestation. The residue obtained after preparing the biogas can be used as fertilizer.

Experiment 1.2

Production of Methane from Cow Dung

Objective: To prepare biogas from locally available materials.

Materials required: Conical flask, cow dung, water, delivery tube with tap and stopper with one hole.

Procedure:

1. Mix some cow dung with water and pour it in a conical flask.
2. Fit the conical flask with a stopper in which a delivery tube with a tap is inserted.
3. Cover the conical flask with a cotton wool and place it near a window and leave it there for 3 to 4 days.
4. Check the formation of methane after 4 days. (Bring a lighted splint closer to the outlet of the delivery tube and open the tap). See what happens.

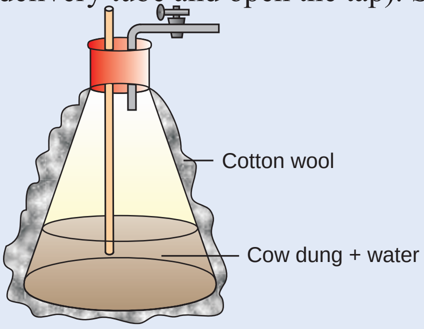


Figure 1.5 Preparation of methane gas from cow dung.

Observations and analysis:

a What is the importance of covering the conical flask with a cotton wool and placing it near the window?

b What is your observation when you bring a burning splint close to the outlet of the tube?

c What change do you think has occurred in the conical flask that leads to the formation of methane?

Write a laboratory report in group and present to the class.

PROJECT 1.1

Organize a trip to visit a biogas plant in your Kebele or neighbouring Kebeles if any and write a report on how it operates. Construct a small scale biogas plant in groups.

1.2.6 Chemical Properties of Alkanes

Activity 1.11

Discuss the following points in groups and present your opinions to the class.

1. Which chemical property of alkanes is responsible for generating electricity in diesel power stations or for moving motor vehicles? Name the major product formed when the fuel has been consumed in the diesel power station.
2. The reaction of methane with oxygen produces two different oxides of carbon, CO_2 and CO.
    1 What condition determines whether the product of the methane reaction is CO_2 or CO?
    b If a domestic heating system is fuelled by methane, what difference does it make if the combustion produces CO_2 or CO?

Alkanes are generally not considered to be very reactive organic compounds. The name paraffin for alkanes arose from two Latin words ‘parum’ meaning *little* and ‘affinis’ means *affinity*. Thus, paraffin means little affinity. This name was suggested because alkanes are inert towards many reagents like acids, bases, oxidizing and reducing agents. However, they undergo several reactions under suitable conditions.

The major reactions of alkanes are the following:

1. **Combustion Reactions:** If alkanes are burned with limited supply of oxygen, they will form water and carbon monoxide and will liberate lesser amounts of heat energy. Alkanes burn in excess oxygen to form carbon dioxide and water, liberating a greater amounts of heat. The general equation for the reaction is:

$$C_nH_{2n+2} \quad + \quad \left(\frac{3n+1}{2}\right)O_2 \quad \rightarrow \quad nCO_2 \quad + \quad (n+1)\ H_2O \quad + \quad \text{heat}$$

where n is the number of carbon atoms in the alkane molecule.

Example

$$C_3H_8 \quad + \quad 5O_2 \quad \rightarrow \quad 3CO_2 \quad + \quad 4H_2O \quad + \quad 2299\ \text{kJ}$$

The heat energy liberated is used to generate electricity, to move motor vehicles or to cook our food.

Activity 1.12

1. Write the general equation for the combustion of alkanes in a limited supply of oxygen that forms carbon monoxide, water and energy.
2. Why is a petroleum refinery is built in the open air? Present your opinion to the class.

2. **Substitution Reaction:** This is a reaction that involves the replacement of one atom or a group of atoms by another atom or group of atoms. Halogenation of alkanes is a very good example of substitution reaction. This reaction involves reacting alkanes with chlorine and bromine. The reaction of chlorine and bromine with alkanes proceeds in presence of heat or sunlight. This type of reaction is called photochemical reaction. The reaction of alkanes with chlorine and bromine proceeds in a sequence of steps. For example, let us consider the photochemical reaction of methane with chlorine (*chlorination*):

   i) **Chain Initiating Step:** This step involves absorption of energy to generate reactive particles known as free radicals. A free radical is an atom or a group of atoms possessing unpaired electron. A free radical is electrically neutral. A chlorine molecule absorbs light and decomposes into two chlorine atoms:

   $$Cl - Cl \xrightarrow{\text{light}} 2\,Cl\bullet$$

   ii) **Chain Propagating Step:** This is a step which consumes a reactive particle (*free radical*) produced in the chain initiation step and generates another free radical.

   $$Cl\bullet + CH_4 \longrightarrow HCl + CH_3\bullet$$

   iii) **Chain Terminating Step:** In the chain terminating step reactive particles (*free radicals*) are consumed but not generated.

   $$CH_3\bullet + Cl\bullet \longrightarrow CH_3Cl$$

   In this step, 'side reactions' that do not lead to the formation of the desired products often take place.

Examples

$$Cl\bullet + Cl\bullet \longrightarrow Cl_2$$

$$CH_3\bullet + CH_3\bullet \longrightarrow CH_3 - CH_3$$

Such a detailed step by step description of a chemical reaction is called a reaction mechanism.

Chlorination of methane may produce different products depending on the relative amounts of methane and chlorine.

$CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$

Methyl chloride

$CH_3Cl(g) + Cl_2(g) \rightarrow CH_2Cl_2(g) + HCl(g)$

Methylene chloride (*dichloromethane*)

$CH_2Cl_2(g) + Cl_2(g) \rightarrow CHCl_3(g) + HCl$

Chloroform (*trichloromethane*)

$CHCl_3(g) + Cl_2(g) \rightarrow CCl_4(g) + HCl(g)$

Carbontetrachloride (*tetrachloromethane*)

The chlorination of methane is an example of a chain reaction that involves a series of steps.

Activity 1.13

Alkanes do not react with chlorine and bromine in the dark but they do so in the presence of sunlight. Discuss the role of sunlight for the reaction in your group and present to the class.

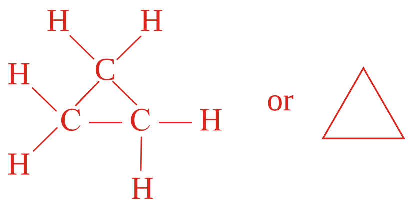
3. **Elimination reaction:** This type of reaction involves the removal of smaller molecules from a compound and leads to the formation of a compound containing a multiple bond (unsaturated compound). It can also involve the removal of hydrogen atoms from adjacent carbon atoms at relatively high temperatures.

$$\underset{\text{Ethane}}{CH_3CH_3} \xrightarrow{600\text{-}800^\circ C} \underset{\text{Ethene}}{CH_2{=}CH_2} + H_2$$

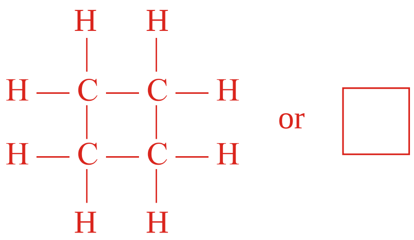
$$\underset{\text{Propane}}{CH_3CH_2{-}CH_3} \xrightarrow{400\text{-}600^\circ C} \underset{\text{Ethene}}{CH_2{=}CH_2} + \underset{\text{Methane}}{CH_4}$$

Cycloalkanes

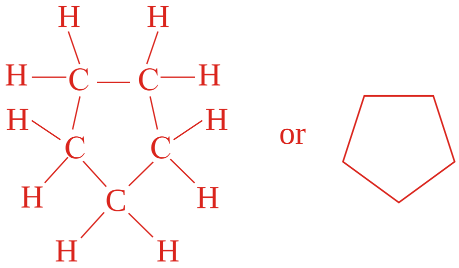
Cycloalkanes are saturated hydrocarbons in which the carbon atoms are linked in such a manner as to form closed chains or ring structures. They are represented by the general formula, C_nH_{2n}, where n ≥ 3. Cycloalkanes are isomeric with open-chain alkenes. Their names are obtained by prefixing "cyclo" to the name of an alkane containing the same number of carbon atoms. The following structures represent some examples of cycloalkanes.



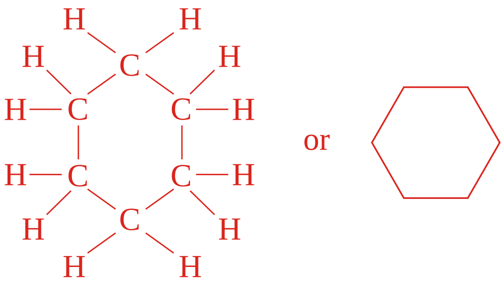
Cylopentane (C_3H_6)



Cylobutane (C_4H_8)



Cylopentane (C_5H_{10})



Cyclohexane (C_6H_{12})

Uses of Alkanes

Alkanes are primarily used as fuels. They are also used as solvents, raw materials for making alkenes, alcohols, soaps, detergents and plastics.

Exercise 1.4

1. Write the molecular formulas of alkanes containing the following number of carbon atoms.

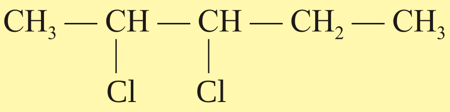
   a 5 b 8 c 15

2. Define the terms

   a Homologous series
   b Alkyl radical
   c Isomerism
   d Substitution reaction
   e Combustion reaction
   f Functional groups

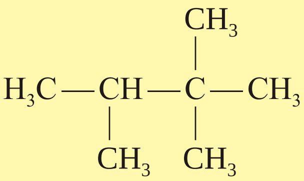
3. Write the balanced equation for the complete combustion of octane.
4. How many chain isomers are there for an alkane that contains 7 carbon atoms?
5. Give IUPAC names to each of the following.

   a



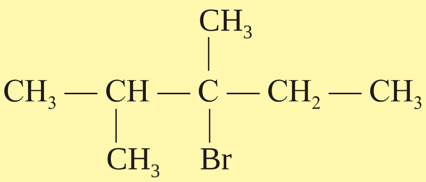
$$CH_3 - \underset{\displaystyle Cl}{\underset{|}{CH}} - \underset{\displaystyle Cl}{\underset{|}{CH}} - CH_2 - CH_3$$

b



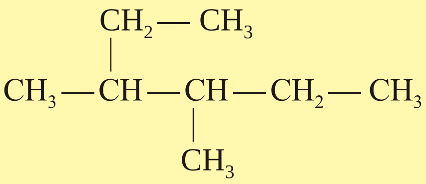
$$H_3C-\underset{CH_3}{CH}-\overset{CH_3}{\underset{CH_3}{C}}-CH_3$$

c



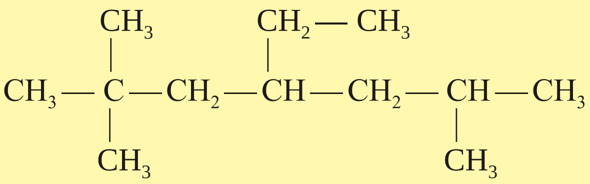
$$CH_3-\underset{CH_3}{CH}-\overset{CH_3}{\underset{Br}{C}}-CH_2-CH_3$$

d



$$CH_3-\overset{CH_2-CH_3}{CH}-\underset{CH_3}{CH}-CH_2-CH_3$$

e



$$CH_3-\overset{CH_3}{\underset{CH_3}{C}}-CH_2-\overset{CH_2-CH_3}{CH}-CH_2-\underset{CH_3}{CH}-CH_3$$

6. Write the structural formulas of the following compounds.
   - a 2,3-dimethylbutane
   - b 2-bromo-3,3,4,4-tetramethylhexane.
   - c 2-chloro-4-ethyl-2,3-dimethylhexane.
7. Complete and balance the following chemical reaction:

$$C_5H_{12} \quad + \quad O_2 \xrightarrow[\text{Combustion}]{\text{Complete}}$$

1.3 UNSATURATED HYDROCARBONS

Competencies

By the end of this section, you will be able to:

- define unsaturated hydrocarbons;
- define alkenes;
- write the general formula of alkenes;
- write the molecular formula for the first nine members in the homologous series of alkenes;
- define alkynes;
- write the general formula of alkynes;
- write the molecular formula for the first nine members in the homologous series of alkynes;
- write the molecular formulas of alkenes and alkynes from the given number of carbon atoms;
- describe the physical properties of alkenes and alkynes;
- apply IUPAC rules to name straight-and branched-chain alkenes and alkynes;
- write the structural formulas of alkenes and alkynes up to ten carbon atoms;
- write the possible structural isomers for C_4H_8 and C_5H_{10};
- define geometric (cis-trans) isomerism;
- give examples of molecules that show geometric isomerism;
- construct models that show cis-trans isomerism;
- describe the general methods for the preparation of alkenes in a laboratory;
- prepare ethylene in the laboratory by the dehydration of ethanol;
- describe the general method for preparation of alkynes in a laboratory;
- prepare acetylene in the laboratory by the reaction of CaC_2 with water;
- test for unsaturation of ethylene and ethyne;
- explain chemical properties of alkenes;
- explain chemical properties of alkynes;
- explain the uses of ethylene and acetylene;
- compare and contrast the properties of ethane, ethene and ethyne.

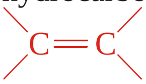
Unsaturated hydrocarbons are those compounds of carbon and hydrogen containing either double or triple bonds. These groups of hydrocarbons include alkenes and alkynes.

1.3.1 Alkenes or Olefins

Activity 1.14

1. The molecular formulas for the first three members of an alkene series are C_2H_4, C_3H_6 and C_4H_8. Derive the general formula for alkenes and compare it with that of alkanes. Is there a difference in the number of hydrogen atoms?
2. By referring to Table 1.5, what relationship do you observe between the number of carbon atoms and melting point, boiling point and density?

Discuss with your group and present it to the class.

Alkenes are unsaturated hydrocarbons containing a carbon-carbon double bond as their functional group: 

They are also known as olefins. They form a homologous series represented by the general formula C_nH_{2n}, where $n = 2, 3, 4\ldots.$

Table 1.5 The homologous series of alkenes and their physical constants.

Molecular	Condensed formula	IUPAC structure	Melting name	Boiling point (°C)	Density point (°C)
C_2H_4	$CH_2=CH_2$	Ethene	–169	–102	0.61 g/L
C_3H_6	$CH_2=CH-CH_3$	Propene	–185	–48	0.61 g/L
C_4H_8	$CH_2=CH-CH_2-CH_3$	1-butene	–130	–6.5	0.63 g/L
C_5H_{10}	$CH_2=CH-(CH_2)_2-CH_3$	1-pentene	–130.5	30	0.64 g/L
C_6H_{12}	$CH_2=CH-(CH_2)_3-CH_3$	1-hexene	–138	63	0.67 g/L
C_7H_{14}	$CH_2=CH-(CH_2)_4-CH_3$	1-heptene	–119	93	0.69 g/L
C_8H_{16}	$CH_2=CH-(CH_2)_5-CH_3$	1-octene	–104	122	0.72 g/L
C_9H_{18}	$CH_2=CH-(CH_2)_6-CH_3$	1-nonene	–95	146	0.73 g/L
$C_{10}H_{20}$	$CH_2=CH-(CH_2)_7-CH_3$	1-decene	–87	171	0.74 g/L

Physical Properties of Alkenes

Activity 1.15

1. Why some alkenes exist in gaseous and liquid states at room temperature?
2. The melting points, boiling points and densities of alkenes increase with increasing number of carbon atoms; why?
3. Are alkenes coloured compounds? Do they have smell?

Discuss with your group and present it to the class.

At room temperature, alkenes containing two to four carbon atoms are gases. Those containing five to seventeen carbon atoms are liquids, and those containing eighteen or more carbon atoms are solids.

Alkenes are non-polar. Therefore, their molecules are held together by weak intermolecular forces. Since they are non-polar, they are almost insoluble in polar solvents like water, but soluble in non-polar solvents like ether, benzene, toluene and carbon tetrachloride.

Nomenclature of Alkenes

Alkenes can have common names as well as IUPAC names. The common names of alkenes are obtained by using the prefixes in Table 1.3 and adding the suffix '-ylene':

Table 1.6 Common names of few alkenes.

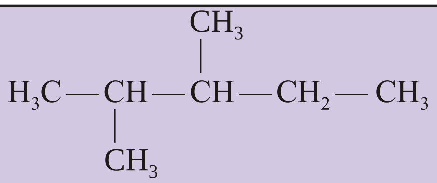
Formula of Alkene	Condensed Structure	Common Name
C_2H_4	$CH_2 = CH_2$	Ethylene
C_3H_6	$CH_2 = CH - CH_3$	Propylene
C_4H_8	$CH_2 = CH - CH_2 - CH_3$	Butylene
.	.	.
.	.	.
.	.	.

IUPAC System

Activity 1.16

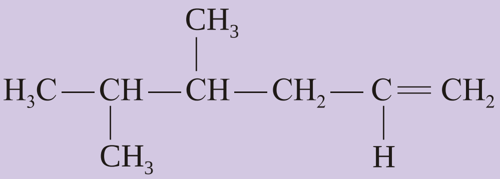
1. What difference do you expect in the IUPAC names of alkanes and alkenes?
2. If you are asked to name the following hydrocarbons:

i)



$$H_3C-\underset{\underset{CH_3}{|}}{CH}-\overset{\overset{CH_3}{|}}{CH}-CH_2-CH_3$$

ii)



$$H_3C-\underset{\underset{CH_3}{|}}{CH}-\overset{\overset{CH_3}{|}}{CH}-CH_2-\underset{\underset{H}{|}}{C}=CH_2$$

a How many carbon atoms are there in the longest chain of each hydrocarbon?

b From which end do you start numbering the carbon atoms of the longest chain of the hydrocarbon shown in structure i?

c From which end do you start numbering the carbon atoms of the longest chain of the hydrocarbon shown in structure ii?

d Is there any difference in how you assign number to the carbon atoms of the longest chain represented by structures i and ii? If so, why?

e Which name do you think is more appropriate for the longest chain of carbon atoms in structure ii? 5-hexene or 1-hexene or hexane? Discuss these questions in your group and present to the class.

The IUPAC names of alkenes are obtained by using the prefixes listed in Table 1.3 to indicate the number of carbon atoms in the molecule and adding the suffix '-ene'. The suffix '-ene' indicates the presence of a double bond. For example, the alkene having the formula C_8H_{16} is named as octene. The prefix oct- indicates that there are eight carbon atoms in the molecule and '-ene' signifies the presence of a double bond.

In the IUPAC system of naming alkenes, the rules we follow are similar to those rules we follow for naming alkanes with slight modifications. These are:

1. Select the longest continuous chain of carbon atoms in the molecule that includes the double bond as a parent structure. Its name will be the same as the alkene containing the same number of carbon atoms.

Activity 1.17

Why should the double bond(s) in alkenes be included in the longest continuous chain? Express your opinion to the class.

2. Number the carbon atoms starting from one end to the other in such a way that the carbon atom preceding the double bond takes the lowest possible number and indicate the position of the double bond by this number in the name.

Example 1

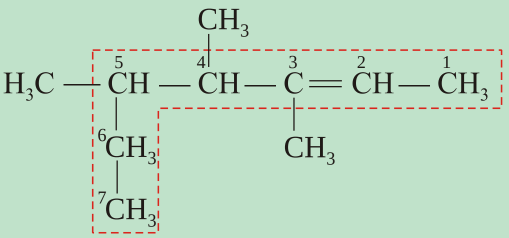
$$\overset{1}{\underset{6}{CH_3}}-\overset{2}{\underset{5}{CH}}=\overset{3}{\underset{4}{CH}}-\overset{4}{\underset{3}{CH_2}}-\overset{5}{\underset{2}{CH_2}}-\overset{6}{\underset{1}{CH_3}}$$

2-hexene or hex-2-ene
but not 4-hexene

$$\overset{1}{\underset{5}{CH_2}}=\overset{2}{\underset{4}{CH}}-\overset{3}{\underset{3}{CH_2}}-\overset{4}{\underset{2}{CH_2}}-\overset{5}{\underset{1}{CH_3}}$$

1-pentene or pent-1-ene
but not 4-pentene

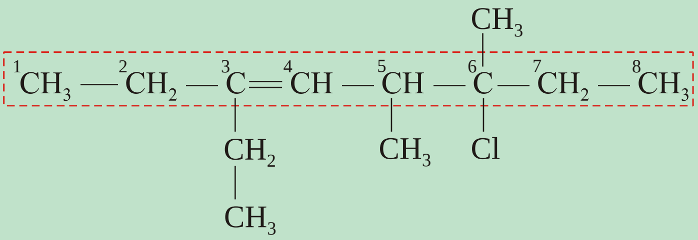
Example 2



The longest chain contains 7 carbon atoms and a double bond between the 2nd and 3rd carbon atoms. Therefore, it takes the name 2-heptene or hept-2-ene. There are three methyl groups at carbon number 3, 4 and 5. So the complete name of the compound is:

3, 4, 5-trimethyl-2-heptene or 3, 4, 5-trimethyl hept-2-ene

Example 3



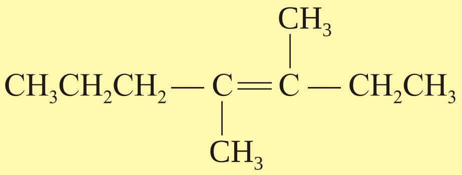
The parent structure contains 8 carbon atoms and a double bond between 3rd and 4th carbon atoms. Thus, it is named as 3-octene or oct-3-ene. The side chains attached are chlorine at the 6th, two methyl groups at 5th and 6th and an ethyl group at carbon number 3. Therefore, the complete name of the compound is:

6-chloro-3-ethyl-5,6-dimethyl-3-octene, or
6-chloro-3-ethyl-5,6-dimethyloct-3-ene.

Exercise 1.5

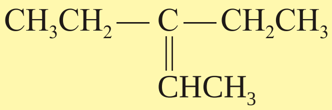
1. Write the names of the following compounds, using IUPAC rules:

a



$CH_3CH_2CH_2-\underset{CH_3}{C}=\overset{CH_3}{C}-CH_2CH_3$

b



$CH_3CH_2-\underset{\underset{CHCH_3}{\|}}{C}-CH_2CH_3$

2. Write the structure of each of the following compounds:

a 3-methyl-3-heptene b 3,4-diethyl-1-hexene

Isomerism in Alkenes

Alkenes containing two and three carbon atoms have only one possible structure. Alkenes containing four or more carbon atoms exhibit isomerism. Alkenes show the following three types of isomerism:

1. **Chain isomerism:** This is due to the difference in the arrangement of the carbon atoms in the longest continuous carbon chain.
2. **Position isomerism:** This is due to the difference in the position of the double bond in the carbon chain.

Example

Consider the following compounds with the same molecular formula (C_5H_{12}):

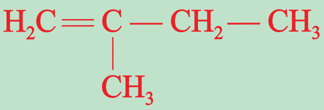
a $H_2C=CH-CH_2-CH_2-CH_3$

1-pentene

b $H_3C-CH=CH-CH_2-CH_3$

2-pentene

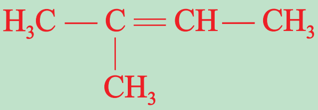
c



$H_2C=\underset{CH_3}{C}-CH_2-CH_3$

2-methyl-1-butene

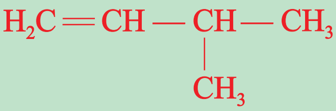
d



$H_3C-\underset{CH_3}{C}=CH-CH_3$

2-methyl-2-butene

e



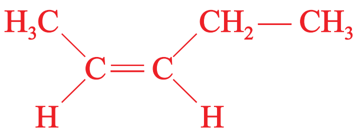
$H_2C=CH-\underset{CH_3}{CH}-CH_3$

3-methyl-1-butene

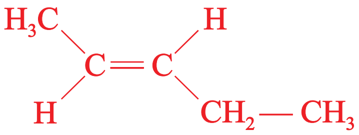
Compounds (a) and (b) represent the position isomers of pentene, (c) and (d) are position isomers of methylbutene, (a), (c) and (e) are the chain isomers, while all these compounds are the isomers of C_5H_{12}.

3. **Geometrical isomerism.** This results from the difference in the relative spatial arrangement of atoms or groups about the double bond. This isomerism exists because free rotation about the double bond is not possible. To differentiate geometrical isomers, we use the prefix '*cis*' if two similar groups are on the same side of the double bond and '*trans*' when the two similar groups are on opposite sides of it; '*cis*' means the same and '*trans*' means across.

   The geometrical isomers of 2-pentene are:



cis-2-pentene or *cis*-pent-2-ene



trans-2-pentene or *trans*-pent-2-ene

Alkenes have more isomers than the corresponding alkanes.

Exercise 1.6

Write three position isomers of hexene.

PROJECT 1.2

Prepare a model from locally available materials, to show the cis-trans isomers of 2-butene.

Preparation of Alkenes

Do you know the major source of alkenes and the process that leads to their formation? Alkenes are mainly obtained during fractional distillation of petroleum when the process called cracking is carried out.

In the laboratory, alkenes can be prepared by:

1. Dehydration of alcohols with concentrated sulphuric acid or alumina (Al_2O_3). Dehydration means removal of water.

General Reaction:

$$R-CH_2-CH_2-OH \xrightarrow[\text{heat}]{H_2SO_4} R-CH=CH_2 + H_2O$$

Alcohol Alkene

Example

$$CH_3 - CH_2 - OH \xrightarrow[\text{heat}]{H_2SO_4} CH_2 = CH_2 + H_2O$$

Ethanol   Ethene

2. Dehydrohalogenation of alkyl halides with a base (KOH). Dehydrohalogenation means removal of hydrogen and a halogen atom.

   Alkyl halides are compounds of an alkyl group and a halogen such as CH_3Cl and $CH_3 - CH_2 - Br$.

   General reaction:

$$R - CH_2 - CH_2 - X + KOH \longrightarrow R - CH = CH_2 + KX + H_2O$$

Alkylhalide   Alkene

Example

$$CH_3 - CH_2 - Cl + KOH \longrightarrow CH_2 = CH_2 + KCl + H_2O$$

Ethylchloride   Ethene

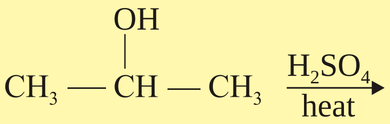
Activity 1.18

In the above two methods of preparations of alkenes, (a) what difference do you observe between the structures of the major reactant and the product? (b) What is the type of reaction? Share your findings with your group.

Exercise 1.7

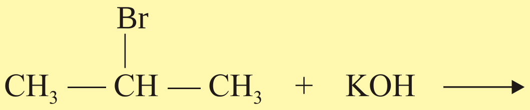
Write the complete and balanced chemical equations for each of the following reactions:

a



$$CH_3 - \overset{\overset{\large OH}{|}}{CH} - CH_3 \xrightarrow[\text{heat}]{H_2SO_4}$$

b



$$CH_3 - \overset{\overset{\large Br}{|}}{CH} - CH_3 + KOH \longrightarrow$$

Experiment 1.3

Laboratory preparation of Ethene

Objective: To prepare ethene and study some of its properties

Materials required: Ethanol, concentrated H_2SO_4, water, bromine water, basic $KMnO_4$. Round-bottomed flask, stopper, delivery tube, gas jar, pneumatic trough, thermometer, tripod, Bunsen burner, stand and clamp, beehive shelf and wire gauze.

Procedure:

1. Arrange the set-up as shown in Figure 1.6
2. Take ethanol in the flask and add concentrated H_2SO_4 through the thistle funnel; heat carefully until the temperature reaches about 170°C. Discard the initially formed gas as it might contain air; collect the ethene gas in three gas jars by downward displacement of water; perform the following activities.
    - a Insert a lighted splint into the jar containing the gas and see what happens.
    - b Add two drops of bromine water to the other gas jar, cover the jar and shake well.

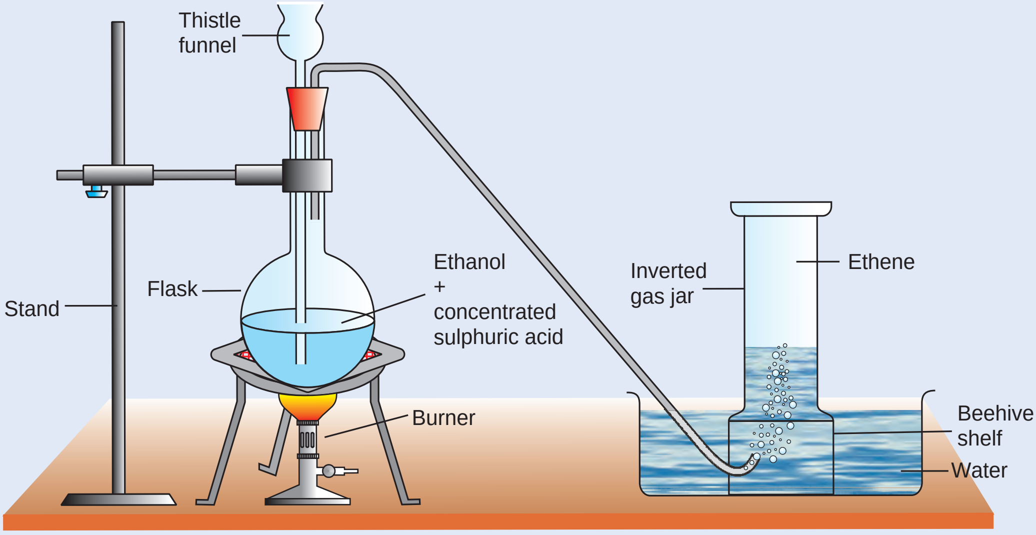


Figure 1.6 Preparation of Ethene.

c Add a few drops of alkaline $KMnO_4$ solution to another jar containing the gas and observe what happens.

Observations and analysis:

a What is the colour and odour of the gas?

b What is the substance left after combustion of the gas in the jar?

c What change is observed when the gas is shaken with bromine water or alkaline potassium permanganate? Write equations for the reactions?

d Name the dehydrating agent used in the experiment?

e Which method of preparation of an alkene is used in this experiment?

Write a laboratory report about the experiment and submit to your teacher.

Chemical properties of Alkenes

Alkenes are unsaturated hydrocarbons containing double bond (a strong bond and a weak bond) between the two carbon atoms. They are more reactive than alkanes, because the weak bond can be used for further reaction. They undergo several types of reactions.

1. **Combustion reaction.** Alkenes burn in oxygen with a luminous flame to form carbon dioxide and water.

General reaction: $C_nH_{2n} + \left(\frac{3n}{2}\right) O_2 \rightarrow nCO_2 + nH_2O + \text{heat}$

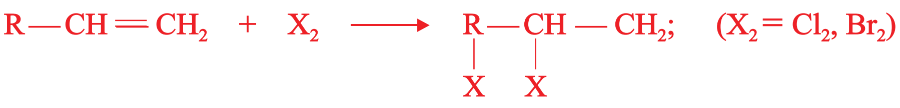
Example

$$C_4H_8(g) + 6O_2(g) \rightarrow 4CO_2(g) + 4H_2O(g) + \text{heat}$$

2. **Addition reaction.** Alkenes undergo mainly addition reactions. The addition occurs at the carbon-carbon double bond.

a **Addition of halogens (halogenation):** When a halogen molecule, X_2, (where, $X_2 = Cl_2$ or Br_2) is added to alkenes, the product is a dihaloalkane.

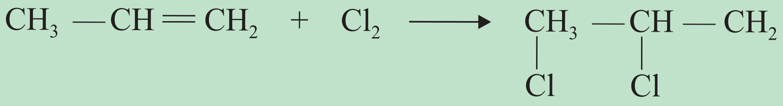
General reaction:



$$R-CH=CH_2 + X_2 \longrightarrow R-\underset{X}{\underset{|}{CH}}-\underset{X}{\underset{|}{CH_2}}; \quad (X_2 = Cl_2, Br_2)$$

Alkene Halogen Dihaloalkane

Example



$$CH_3-CH=CH_2 + Cl_2 \longrightarrow \underset{Cl}{CH_3}-\underset{Cl}{CH}-CH_2$$

Propene 1,2-dichloropropane

If bromine water (bromine in CCl_4) is added to alkenes, the reddish brown colour of Br_2 in CCl_4 will disappear. This is due to the addition of bromine (Br_2) across the double bond. So, Br_2 in CCl_4 is used to detect unsaturation (presence of multiple bond) in a compound.

b **Addition of hydrogen (Hydrogenation):** Addition of hydrogen molecule to alkenes in the presence of a nickel or platinum catalyst yields alkanes.

General reaction: $\underset{\text{Alkene}}{R-CH=CH_2} + H_2 \xrightarrow{Pt} \underset{\text{Alkane}}{R-CH_2-CH_3}$

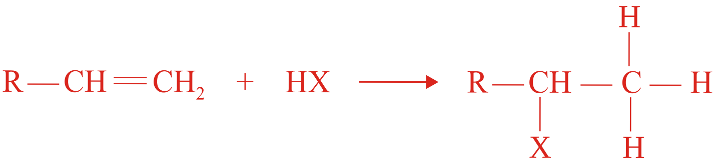
Example

$$\underset{\text{Ethene}}{CH_2=CH_2} + H_2 \xrightarrow{Pt} \underset{\text{Ethane}}{CH_3-CH_3}$$

c **Addition of hydrogen halides, HX (hydrohalogenation):** Addition of hydrogen halide (HCl, HBr or HI) to alkenes leads to the formation of alkyl halides. The product of the reaction can be predicted by Markovnikov's rule; which states that "when an alkene reacts with a hydrogen halide to give an alkyl halide, the hydrogen adds to the carbon atom of the double bond that has the greater number of hydrogen atoms, and the halogen to the carbon that has the fewer number of hydrogen atoms".

The same is true when an alkene reacts with water in an addition reaction to form an alcohol.

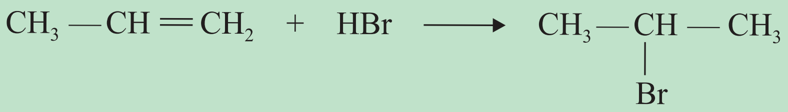
General reaction:



$$R-CH=CH_2 + HX \longrightarrow R-\underset{X}{CH}-\underset{H}{\overset{H}{C}}-H$$

Alkene Alkyl halide

Example



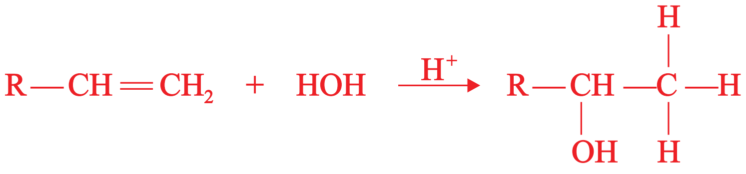
$$CH_3-CH=CH_2 \quad + \quad HBr \longrightarrow CH_3-\underset{\underset{\textstyle Br}{|}}{CH}-CH_3$$

Propene 2-bromopropane

Have you noticed the location where H and Br have formed bonds?

d **Addition of water (hydration):** When alkenes are hydrated in the presence of an acid catalyst, they produce alcohols, in accordance with Markovnikov's rule.

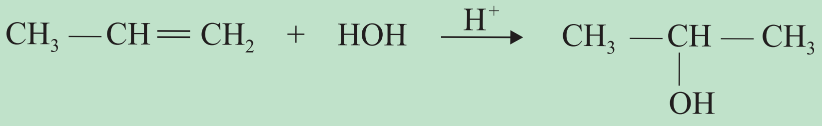
General reaction:



$$R-CH=CH_2 \quad + \quad HOH \xrightarrow{H^+} R-\underset{\underset{\textstyle OH}{|}}{CH}-\overset{\overset{\textstyle H}{|}}{\underset{\underset{\textstyle H}{|}}{C}}-H$$

Alkene Alcohol

Example

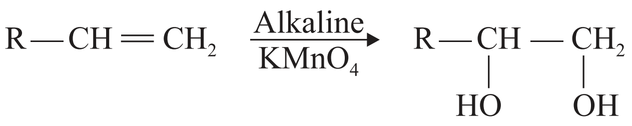


$$CH_3-CH=CH_2 \quad + \quad HOH \xrightarrow{H^+} CH_3-\underset{\underset{\textstyle OH}{|}}{CH}-CH_3$$

Propene 2-propanol

e **Oxidation of alkenes:** Oxidation of alkenes with cold alkaline potassium permanganate solution ($KMnO_4$) forms diols (compounds containing two hydroxyl groups).

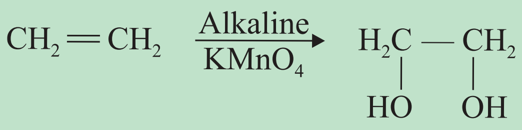
General reaction:



$$R-CH=CH_2 \xrightarrow[KMnO_4]{Alkaline} R-\underset{\underset{\textstyle HO}{|}}{CH}-\underset{\underset{\textstyle OH}{|}}{CH_2}$$

Alkene Diol

Example



$$CH_2=CH_2 \xrightarrow[KMnO_4]{Alkaline} \underset{\underset{\textstyle HO}{|}}{H_2C}-\underset{\underset{\textstyle OH}{|}}{CH_2}$$

Ethene 1,2-ethanediol

Alkaline $KMnO_4$ solution is also used as a qualitative test for the identification of unsaturation in a compound. The solution is called Baeyer's reagent. In the presence of unsaturated hydrocarbons, the purple colour of alkaline $KMnO_4$ solution fades and a brown precipitate is formed.

f **Polymerization (self-addition) of alkenes:** Polymerization is the union of small molecules called monomers to form a large molecule called a polymer.

Example

$$n(CH_2{=}CH_2) \xrightarrow[O_2\text{ (Catalyst)}]{1000\text{ atm, }473\text{K}} (\text{—}CH_2\text{—}CH_2\text{—})_n$$

Ethene Polyethene

Uses of Ethene (Ethylene)

Ethene is used in the production of ethanol, and polymers such as polyethene, polyvinylchloride (PVC), polystyrene and teflon. It is also used in the production of 1,2-ethanediol, which is used as an antifreeze material; and for the preservation as well as artificial ripening of fruits.

Activity 1.19

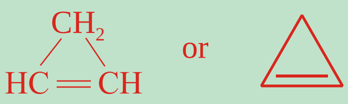
Take some green tomatoes in first basket and put a ripe banana in between them. In a second basket put only green tomatoes (but not a banana). Compare the tomatoes in the two baskets. Do the tomatoes ripen at the same rate in both baskets; if not, why? Share your opinion with your classmates.

Cycloalkenes

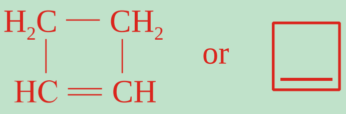
Cycloalkenes are unsaturated cyclic hydrocarbons. The carbon atoms are linked in such a manner as to form a closed chain or a ring structure. They contain a double bond between carbon atoms and are represented by the general formula C_nH_{2n-2}, where n should be equal to or greater than 3. They are isomeric with alkynes. They are named by prefixing "cyclo" to the name of alkenes containing the same number of carbon atoms. The given structures show some examples of cycloalkenes.

The IUPAC names for alkynes are obtained by using the prefixes listed in Table 1.3. The suffix '-yne' is added to the prefixes, which indicates the presence of a triple bond between a pair of adjacent carbon atoms. Alkynes are named in the same way as alkenes.

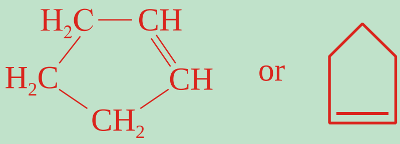
Examples



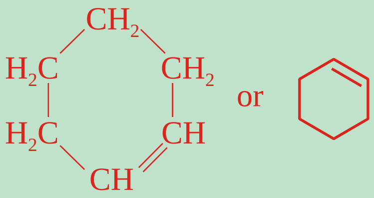
Cyclopropene



Cyclobutene



Cyclopentene



Cyclohexene

Exercise 1.8

Complete each of the following equations and name the products:

a $CH_3CH_2CH{=}CH_2 + HCl \rightarrow$

b $CH_3CH_2CH{=}CH_2 + Br_2 \rightarrow$

c $CH_3CH_2CH{=}CH_2 + H_2O \xrightarrow{H^+}$

d $CH_3CH_2CH{=}CH_2 \xrightarrow[KMnO_4]{Alkaline}$

1.3.2 Alkynes

Alkynes are another group of unsaturated hydrocarbons possessing a triple bond as their functional group. The homologous series of alkynes is represented by the general formula C_nH_{2n-2}, where $n \geq 2$. The first member of the group is commonly known as acetylene. The homologous series of alkynes is also called acetylene series.

Table 1.7 Homologous series of alkynes and their physical constants.

Formula of Alkyne	Condensed Structure	IUPAC Name	Melting Point (°C)	Boiling Point (°C)
C_2H_2	$CH \equiv CH$	Ethyne	– 82	–75
C_3H_4	$CH \equiv C - CH_3$	Propyne	–101.5	–23
C_4H_6	$CH \equiv C - CH_2$	1 - butyne	–122	9

Continued next page

Formula of Alkyne	Condensed Structure	IUPAC Name	Melting Point (°C)	Boiling Point (°C)
C_5H_8	$CH \equiv C-(CH_2)_2-CH_3$	1 - pentyne	–98	40
C_6H_{10}	$CH \equiv C-(CH_2)_3-CH_3$	1 - hexyne	–124	72
C_7H_{12}	$CH \equiv C-(CH_2)_4-CH_3$	1 - heptyne	–80	100
C_8H_{14}	$CH \equiv C-(CH_2)_5-CH_3$	1 - octyne	–70	126
		1- nonyne	–65	151
		1- decyne	–36	182

Physical Properties of Alkynes

Alkynes are non-polar compounds whose molecules are held together by weak intermolecular forces. The strength of the intermolecular forces increases with increasing molecular size. The physical properties of alkynes are almost similar to those of alkenes.

Activity 1.20

1. By looking at the trends for alkynes in **Table 1.7**, write the molecular formula and and the structures of the alkynes containing 9 and 10 carbon atoms.
2. Compare the physical state, melting points and boiling points of alkynes with alkenes and alkanes, as the number of carbon atoms increases. Discuss with your group and present to the class.

Nomenclature of Alkynes

Alkynes are commonly named as a derivative of acetylene.

Example

$CH \equiv CH$ acetylene

$CH \equiv C-CH_3$ methyl acetylene

$CH \equiv C-CH_2-CH_3$ ethyl acetylene

IUPAC System: The IUPAC names for alkynes are obtained by using the prefixes listed in Table 1.3. The suffix '-yne' is added to the prefixes. '-yne' indicate the presence of a triple bond between a pair of adjacent carbon atoms. Alkynes are named in the same way as alkenes.

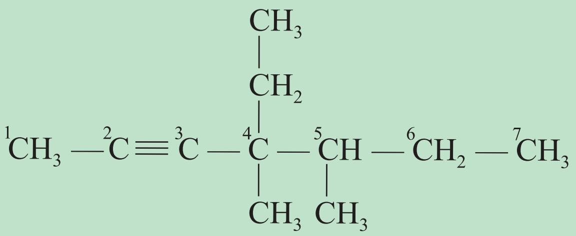
Example

$^{1}CH \equiv {}^{2}C - {}^{3}CH_2 - {}^{4}CH_2 - {}^{5}CH_3$

1-pentyne or pent-1-yne

$^{1}CH - {}^{2}C \equiv {}^{3}C - {}^{4}CH_2 - {}^{5}CH_3$

2-pentyne or pent-2-yne



$${}^{1}CH_3 - {}^{2}C \equiv {}^{3}C - \underset{\substack{|\\CH_3}}{\overset{\substack{CH_3\\|\\CH_2\\|}}{{}^{4}C}} - \underset{\substack{|\\CH_3}}{{}^{5}CH} - {}^{6}CH_2 - {}^{7}CH_3$$

4-ethyl-4,5-dimethyl-2-heptyne or 4-ethyl-4,5-dimethyl-hept-2-yne

Isomerism in Alkynes

Alkynes show both chain and position isomerism, but not geometrical isomerism.

Example

Isomers of butyne, C_4H_6

$HC \equiv C - CH_2 - CH_3$

1-butyne or but-1-yne

$H_3C - C \equiv C - CH_3$

2-butyne or but-2-yne

1-Butyne and 2-butyne are position isomers.

Activity 1.21

Write the structural formulas for pentane, pentene, and pentyne. Why are not these three hydrocarbons considered as isomers? Tell your idea to the class.

Exercise 1.9

1. Write the possible isomers of 1-pentyne and identify which isomers are:
   - a chain isomers?
   - b position isomers?
2. Write the structures of all isomers of 1-pentyne (C_5H_8) and name them.
3. How many isomers are possible for 1-hexyne?

Preparation of Alkynes

Alkynes can be prepared by several methods. Some of the general methods of preparation of alkynes are:

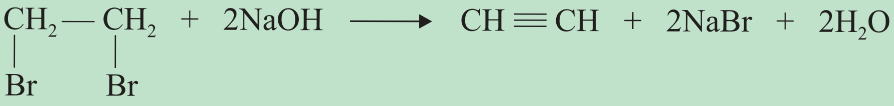
1. Dehydrohalogenation of vicinal (adjacent) dihalides with a base NaOH or KOH or $NaNH_2$.

General reaction:

$$R-\underset{X}{\underset{|}{CH}}-\underset{X}{\underset{|}{CH_2}} + 2NaOH \longrightarrow R-C\equiv CH + 2NaX + 2H_2O$$

Vicinal dihalide — Alkyne

Example



$$\underset{Br}{\underset{|}{CH_2}}-\underset{Br}{\underset{|}{CH_2}} + 2NaOH \longrightarrow CH\equiv CH + 2NaBr + 2H_2O$$

1, 2-dibromoethane — Ethyne

2. Alkylation of sodium acetylide (dicarbide) with a primary alkyl halide.

General reaction:

$$HC\equiv C^{-}Na^{+} + R-X \longrightarrow HC\equiv C-R + NaX$$

Sodium carbide — Primary Alkyl halide — Alkyne

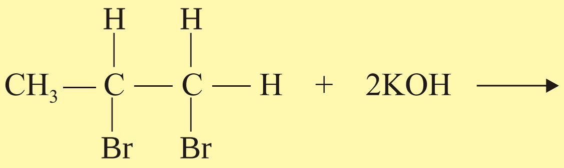
Example

$$HC\equiv C^{-}Na^{+} + CH_3CH_2Br \longrightarrow HC\equiv C-CH_2-CH_3 + NaBr$$

Sodium carbide — Ethyl bromide — But-1-yne (1-butyne)

Exercise 1.10

Write the major product of the following reactions:

a 

$$CH_3-\underset{Br}{\underset{|}{\overset{H}{\overset{|}{C}}}}-\underset{Br}{\underset{|}{\overset{H}{\overset{|}{C}}}}-H + 2KOH \longrightarrow$$

b $H-C\equiv C^{-}Na^{+} + CH_3Br \longrightarrow$

Experiment 1.4

Laboratory Preparation of Ethyne

Objective: To prepare ethyne from calcium carbide and water.

Materials required: CaC_2, H_2O, bromine water, round-bottomed flask, separating funnel, delivery tube, trough, beehive shelf and gas jar.

Procedure:

1. Arrange the set up as shown in Figure 1.7. Put a layer of sand in a conical flask and place calcium carbide on the sand.
2. Add water drop by drop from the separating funnel onto the calcium carbide. Watch carefully and record your observation. Touch the flask with the tip of your finger.
3. Collect several jars of the gas over water and carry out the following tests:
   a Burn the gas as you did with methane and ethene.
   b Add a few drops of bromine water to another jar filled with ethyne and note the changes.

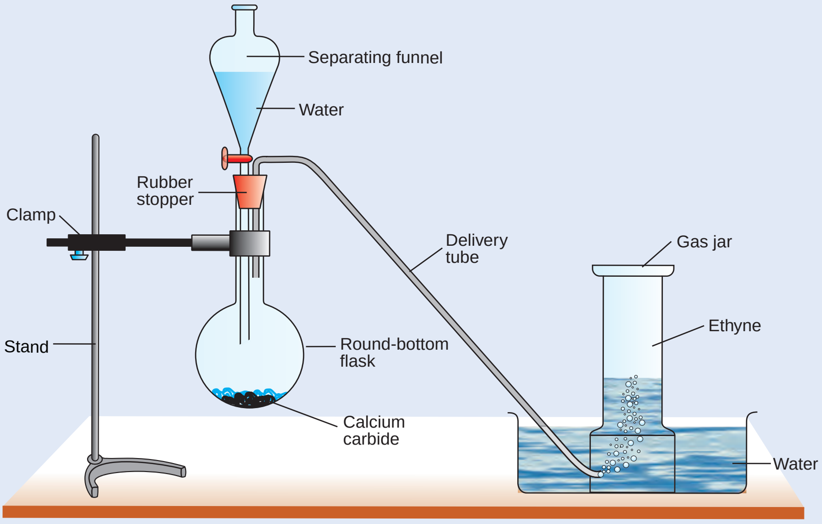


Figure 1.7 Laboratory Preparation of Ethyne.

Observations and analysis:

a What do you feel when you touch the flask? Is the reaction exothermic or endothermic?
b How do you compare the colour of the flame produced with that of methane and ethene?

Write a complete laboratory report and submit to your teacher.

Chemical Properties of Alkynes

Alkynes are more reactive than alkanes and alkenes. Why?

Alkynes are more unsaturated than alkanes and alkenes due to the presence of a carbon-carbon triple bond. They can undergo combustion and addition reactions.

Some of the common reactions of alkynes are:

1. **Combustion reaction:** Alkynes burn with a smoky luminous flame, forming CO_2 and water. Smoky luminous flames result from the combustion of alkynes due to their high carbon content.

General reaction: $C_nH_{2n-2} + \frac{3-1}{2} O_2 \rightarrow nCO_2 + (n-1)\,H_2O$

Example

$$C_3H_4 + 4O_2 \rightarrow 3CO_2 + 2H_2O + \text{heat}$$

2. **Addtion reaction:** Alkynes undergo addition reaction at the carbon-carbon triple bond. Some of the addition reactions of alkynes are the following:

   a **Addition of hydrogen (hydrogenation):** In the presence of nickel or palladium catalyst, alkynes produce alkanes.

General relation:

$$\underset{\text{Alkyne}}{C_nH_{2n-2}} + H_2 \xrightarrow[\text{heat}]{\text{Ni}} \underset{\text{Alkene}}{C_nH_{2n}} \xrightarrow[\text{Ni/heat}]{H_2} \underset{\text{Alkane}}{C_nH_{2n+2}}$$

Example

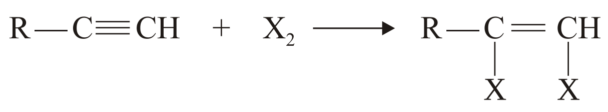
$$\underset{\text{Ethyne}}{CH\equiv CH} + H_2 \xrightarrow[\text{heat}]{\text{Ni}} \underset{\text{Ethene}}{CH_2=CH_2} \xrightarrow[\text{Ni/heat}]{H_2} \underset{\text{Ethane}}{CH_3-CH_3}$$

Partial hydrogenation of alkynes in the presence of Lindlar's catalyst gives alkenes. Lindlar's catalyst is powdered palladium partially deactivated with lead acetate.

$$\underset{\text{2- butyne}}{CH_3-C\equiv C-CH_3} + H_2 \xrightarrow[\text{Catalyst}]{\text{Lindlar's}} \underset{\text{2- butene}}{CH_3-CH=CH-CH_3}$$

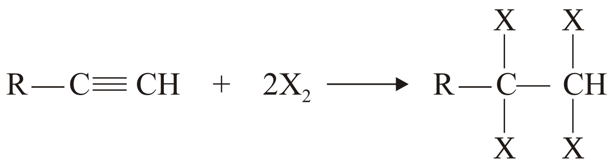
b **Addition of halogens:** When molecule of an alkyne reacts with one and two molecules of halogens, it gives a dihaloalkene and a tetrahaloalkane, respectively.

General Reaction:



$$R-C\equiv CH + X_2 \longrightarrow R-\underset{X}{\underset{|}{C}}=\underset{X}{\underset{|}{C}}H$$

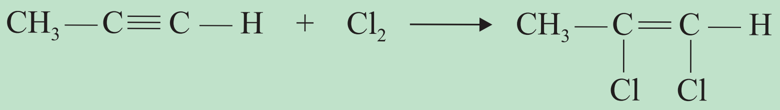
Alkyne Dihaloalkene



$$R-C\equiv CH + 2X_2 \longrightarrow R-\overset{X}{\overset{|}{\underset{X}{\underset{|}{C}}}}-\overset{X}{\overset{|}{\underset{X}{\underset{|}{C}}}}H$$

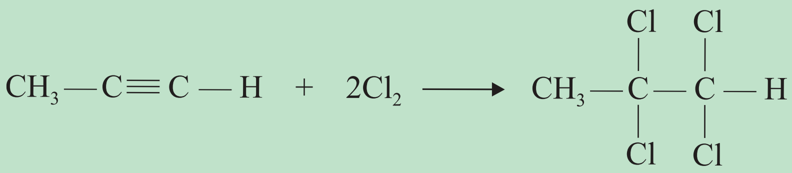
Alkyne Tetrahaloalkane

Example



$$CH_3-C\equiv C-H + Cl_2 \longrightarrow CH_3-\underset{Cl}{\underset{|}{C}}=\underset{Cl}{\underset{|}{C}}-H$$

Propyne 1,2-dichloropropene



$$CH_3-C\equiv C-H + 2Cl_2 \longrightarrow CH_3-\overset{Cl}{\overset{|}{\underset{Cl}{\underset{|}{C}}}}-\overset{Cl}{\overset{|}{\underset{Cl}{\underset{|}{C}}}}-H$$

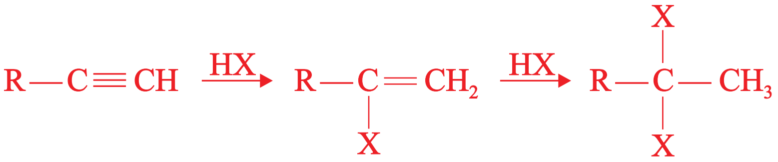
Propyne 1,1,2,2-tetrachloropropane

Activity 1.22

1. Do you expect alkynes to decolorize bromine water; if so why?
2. Write the balanced chemical equation for the reaction between C_2H_2 and $2Br_2$.

c **Addition of Hydrogen Halides:** Alkynes react with hydrogen halides to form a monohaloalkene and a dihaloalkane. The addition reaction occurs according to Markovnikov's rule.

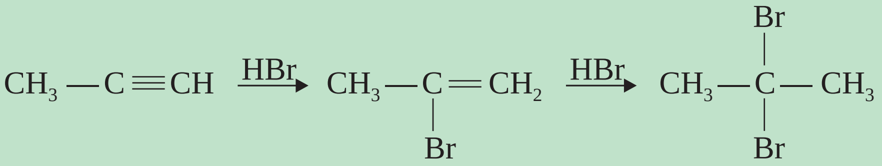
General Reaction:



$$R-C\equiv CH \xrightarrow{HX} R-\underset{X}{\underset{|}{C}}=CH_2 \xrightarrow{HX} R-\overset{X}{\overset{|}{\underset{X}{\underset{|}{C}}}}-CH_3$$

Alkyne Monohaloalkene Dihaloalkane

Example



$$CH_3-C\equiv CH \xrightarrow{HBr} CH_3-\underset{Br}{\underset{|}{C}}=CH_2 \xrightarrow{HBr} CH_3-\overset{Br}{\overset{|}{\underset{Br}{\underset{|}{C}}}}-CH_3$$

Propyne 2-Bromopropene 2, 2-Dibromopropane

Activity 1.23

1. Is Markonikov's rule applied in the reaction between propyne and hydrobromic acid? How?
2. The addition reaction of alkynes proceeds in two steps. Explain what changes occur during the first and the second steps.
3. Compare the reaction products when 1-butyne and 2-butyne react with HBr.

3. **Trimerization of Acetylene:** Acetylene, on prolonged heating at 600 – 700ºC, yields benzene.

$$3\ CH\equiv CH \xrightarrow{600°C\text{-}700°C}$$

Acetylene Benzene

1.3.3 Properties and uses of Acetylene or Ethyne

Acetylene is a colourless, sweet-smelling gas in pure form and is insoluble in water. It is usually stored as a solution of acetone in steel cylinders. Combustion of acetylene with oxygen produces an intensely hot flame of about 3000ºC. Thus, a large quantity of acetylene is used as a fuel in oxy-acetylene torches for cutting and welding metals. Acetylene is also used to prepare acrylonitrile which is a starting material for producing polyacrylonitrile, a raw material for textile fibre. It is also used for making vinyl chloride which polymerizes to give polyvinyl chloride (PVC) commonly used for making floor tiles, electrical insulators, shoe soles, water pipes etc. Acetylene is used to produce 1,1,2,2-tetrachloroethane that serves as a solvent for wax, grease, rubber etc.

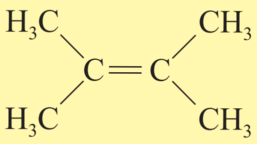
Table 1.8 Comparison of some properties of Ethane, Ethene and Ethyne

Property	Ethane	Ethene	Ethyne
Nature of flame	Non-luminous	Luminous	Smoky luminous
Effect on colour of Br_2 in CCl_4	No effect	Decolorizes	Decolorizes
Effect on colour of alkaline $KMnO_4$	No effect	Decolorizes	Decolorizes

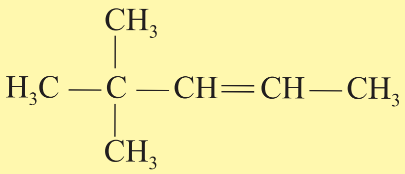
Exercise 1.11

1. What reagents can be used to test for unsaturation of hydrocarbons?
2. Name the following hydrocarbons.

a

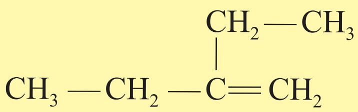


b



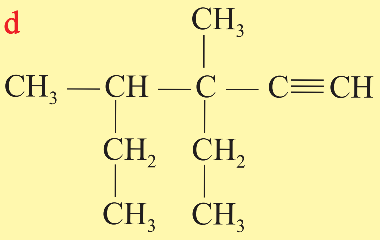
$H_3C-\overset{CH_3}{\underset{CH_3}{C}}-CH=CH-CH_3$

c



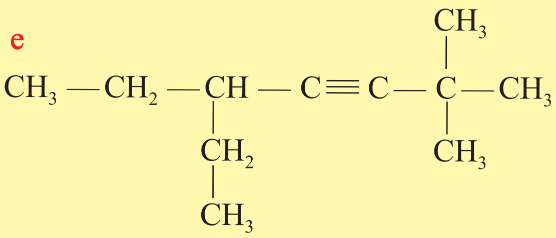
$CH_3-CH_2-\overset{CH_2-CH_3}{C}=CH_2$

d



$CH_3-\underset{\underset{CH_3}{CH_2}}{CH}-\overset{CH_3}{\underset{\underset{CH_3}{CH_2}}{C}}-C\equiv CH$

e



$CH_3-CH_2-\underset{\underset{CH_3}{CH_2}}{CH}-C\equiv C-\overset{CH_3}{\underset{CH_3}{C}}-CH_3$

3. Which of the following hydrocarbons exhibit geometrical isomerism?

a 1-butene
b 2-butene
c 1-pentene
d 3-hexene

4. Complete the following reactions and name the main products:

a $CH_3CH_2CH_2Cl + KOH \xrightarrow{Heat}$

b $CH_3 - CH = CH - CH_3 + Cl_2 \rightarrow$

c $CH_3 - CH_2 - CH = CH_2 + HCl \rightarrow$

d $CH_3 - CH = CH_2 + H_2O \xrightarrow{H^+}$

e $CaC_2 + 2H_2O \rightarrow$

f $CH_3 - C \equiv CNa + CH_3CH_2Br \rightarrow$

g $CH_3 - C \equiv CH + 2H_2 \xrightarrow[\text{Heat}]{\text{Ni}}$

h $CH_3 - CH_2 - C \equiv CH + 2HBr \rightarrow$

i $H - C \equiv C - H + Br_2 \rightarrow$

j $H - C \equiv C - H + 2Br_2 \rightarrow$

1.4 AROMATIC HYDROCARBONS

Competencies

At the end of this section you will be able to:

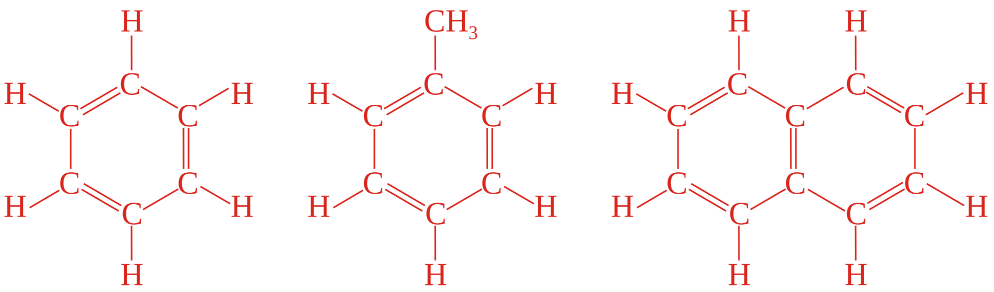
- define the term aromatic hydrocarbons;
- draw the structure of benzene;
- describe the main physical properties of benzene;
- explain the chemical reactions of benzene;
- carry out test-tube reactions with Br_2 in CCl_4, $KMnO_4$, concentrated H_2SO_4.

Activity 1.24

Discuss the following in your group and present it to the class:

1. What comes to your mind when you hear the word "benzene"?
2. What is the word "aroma" mean? Which substances have an aroma smell?
3. Are aromatic hydrocarbons unsaturated as alkenes? Why?

The term aromatic is derived from the word 'aroma' meaning pleasant smell, which was originally used to describe naturally occurring compounds with pleasant smells. At present, the term is used without its original significance. Aromatic hydrocarbons are generally obtained from petroleum and coal tar. They are a group of hydrocarbons characterized by the presence of a benzene ring or related structures. Some examples of aromatic hydrocarbon structures are given below:



Benzene

Methyl benzene (Toluene)

Naphthalene

Figure 1.9 Structures of some Aromatic Hydrocarbons.

1.4.1 Benzene

Benzene is the simplest aromatic hydrocarbon. Its molecular formula is C_6H_6. Friedrich A. Kekule, in 1865, suggested that the six carbon atoms of benzene are arranged in the shape of a hexagon. He also suggested a resonance hybrid structure. He represented benzene by the resonance structures (Figure 1.10) in which the two structures shown make equal contribution for the resonance hybrid or actual structure.

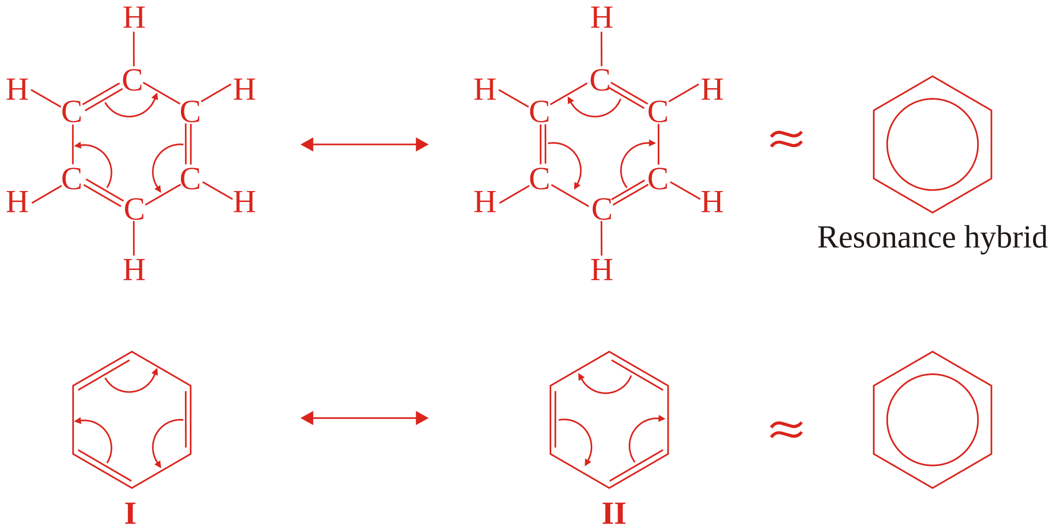
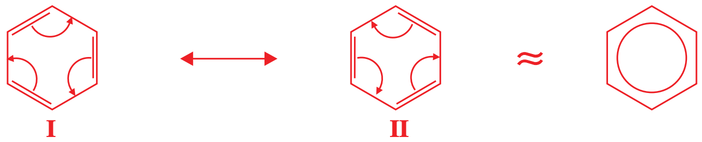


Figure 1.10 Resonance structures of benzene.

The bonds in benzene are neither single nor double but have an intermediate character between those of single and double bonds. All the carbon-carbon bonds in the molecule are same in length and nature. Since structure I or II given above are not the true structures of the benzene molecule, the benzene ring is written, in most cases, in its resonance hybrid form as follows:



The six electrons in the hexagonal ring are delocalized.

From structures I and II in Figure 1.10, one may think that benzene has three double bonds and has the same chemistry as that of alkenes. But, this is not true. Benzene and other aromatic hydrocarbons are not as unsaturated as alkenes because the three double bonds in benzene are delocalized due to resonance. They are more stable than alkenes. They undergo substitution reactions to a far greater extent than addition reactions, which is a different characteristic compared to alkenes.

Physical Properties of Benzene

Benzene is a flammable, colourless, and volatile liquid with a characteristic smell. It is nonpolar and immiscible with water but miscible with non-polar solvents like ether and carbon tetrachloride. It freezes at 5.4ºC and boils at 80.4ºC. It is a carcinogenic (*cancer causing*) substance. Benzene is a good solvent for fats, gums, rubber etc., and is used in the manufacture of dyes, drugs and explosives.

Chemical Properties of Benzene

Benzene and other aromatic hydrocarbons are more stable than alkenes and alkynes due to the stability of the aromatic ring. It neither decolorizes bromine water (Br_2 in CCl_4) nor is reactive towards cold potassium permanganate solution. However, benzene undergoes the following reactions:

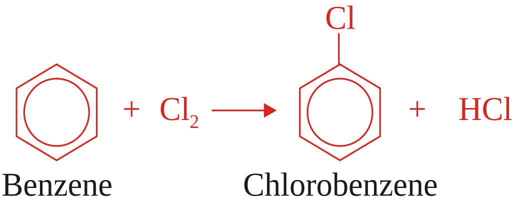
1. **Combustion reaction:** Benzene is highly inflammable. It burns with a smoky luminous flame to form CO_2 and H_2O.

   $$2C_6H_6 + 15O_2 \rightarrow 12CO_2 + 6H_2O + \text{Heat}$$

2. **Substitution reaction:** The reactions of benzene are chiefly substitution but not addition reactions. In this reaction, hydrogen atom from the benzene ring is replaced by another atom or group.

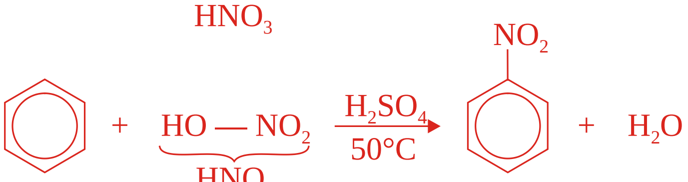
   a **Halogenation:** Benzene reacts with bromine and chlorine in the presence of iron (III) chloride or aluminium chloride catalyst to form substitution products.

   $$C_6H_6 + Cl_2 \xrightarrow{AlCl_3} C_6H_5Cl + HCl$$



b **Nitration:** Concentrated nitric acid mixed with some concentrated sulphuric acid reacts with benzene at moderate temperatures to form nitrobenzene.

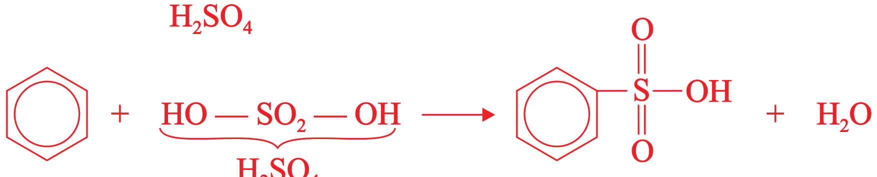
$$C_6H_6 + \underbrace{HO - NO_2}_{HNO_3} \xrightarrow[50°C]{H_2SO_4} C_6H_5NO_2 + H_2O$$



Nitrobenzene

c **Sulphonation:** Benzene reacts with concentrated sulphuric acid, H_2SO_4, at room temperature to form benzenesulphonic acid.

$$C_6H_6 + \underbrace{HO - SO_2OH}_{H_2SO_4} \longrightarrow C_6H_5SO_2OH + H_2O$$



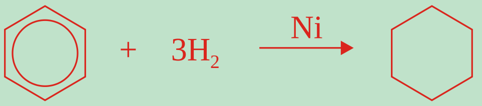
Benzene Benzenesulphonic acid

3. **Addition reaction:** Benzene undergoes addition reactions under special conditions.

Example

When a mixture of benzene vapour and hydrogen is passed over finely divided nickel catalyst at 200°C, cyclohexane is formed.

$$C_6H_6 + 3H_2 \xrightarrow[200°C]{Ni} C_6H_{12}$$



Cyclohexane

Experiment 1.5

Chemical Reaction of Toluene

Objective: To distinguish aromatic hydrocarbons from other unsaturated hydrocarbons

Materials required: Toluene, Br_2 in CCl_4, $KMnO_4$, concentrated H_2SO_4, test tubes, test tube rack, test tube holder, measuring cylinder, Bunsen burner and dropper.

Procedure:

1. Take three test tubes and place them in the test tube rack.
2. Add 5 mL of toluene (*methylbenzene*) to each of the three test tubes.
3. Add one or two drops of Br_2 in CCl_4 in the first test tube and add the same amount of cold $KMnO_4$ solution in the second test tube and observe the changes.
4. Add a few drops of concentrated sulphuric acid to the third test tube and, if necessary, heat it gently, holding it with a test tube holder.

Observations and analysis:

In which test tube does a reaction occur?

Write a complete report of your observations and submit to your teacher.

Exercise 1.12

1. What is an aromatic hydrocarbon?
2. Are aromatic hydrocarbons saturated or unsaturated?
3. What is the name of the simplest aromatic hydrocarbon?
4. Describe the main reactions of benzene?
5. Benzene does not change the colour of Br_2 in CCl_4 or that of $KMnO_4$ solution; why?
6. How do you prepare the following compounds from benzene?
   a Chlorobenzene b Nitrobenzene c Benzene sulphonic acid.

1.5 NATURAL SOURCES OF HYDROCARBONS

Competencies

After completing this subunit, you will be able to:

- list the major natural sources of hydrocarbons;
- describe natural gas;
- define crude oil;
- explain the fractional distillation of crude oil;
- mention the products of the fractional distillation of crude oil;
- tell the uses of petroleum products;
- describe the composition of coal;
- explain the destructive distillation of coal.

Activity 1.25

Discuss the following in your group and present it to the class:

1. What do you think is the major component of natural gas?
2. How can petroleum be separated into different fractions?
3. How are natural gas, petroleum and coal formed in nature? Can they be recycled?

A. Natural Gas

The principal sources of hydrocarbons are natural gas, crude oil and coal. Natural gas is found in association with petroleum or alone. It is found in underground deposits several hundreds or thousands of metres below the earth's surface, where it originated from the decay and decomposition of animal and plant remains millions of years ago. Natural gas mainly contains methane (more than 90%), ethane, propane, butane and small quantities of higher alkanes. Other gases such as, CO_2, N_2, O_2 and H_2S, may also be present in natural gas. The composition of natural gas varies, depending on its place of origin. Natural gas is widely used as a fuel. It is advantageous over liquid and solid fuels and also other gases, except H_2, due to its very high heat of combustion.

B. Petroleum

The word petroleum is derived from two Latin words, '*petra*' meaning rock, and '*oleum*' meaning oil. Thus, petroleum means rock oil. The term petroleum refers to a broad range of fossil hydrocarbons that are found as gases, liquids or solids beneath the surface of the earth. The crude oil is generally found along with natural gas in the form of a dark-coloured viscous liquid, which is a complex mixture of hydrocarbons. Its composition varies according to its place of origin. However, crude oil mainly contains alkanes, cycloalkanes and aromatic hydrocarbons. It also contains organic compounds consisting of nitrogen, sulphur and oxygen in small amounts.

Refining of Crude Oil

Crude oil or petroleum is obtained by drilling wells until the oil-bearing region is reached. After the crude oil is brought to the surface of the earth, it must be refined before it can be used.

Crude oil is refined or separated into several components by fractional distillation based on the differences in boiling ranges of its fractions. (Figure 1.11).

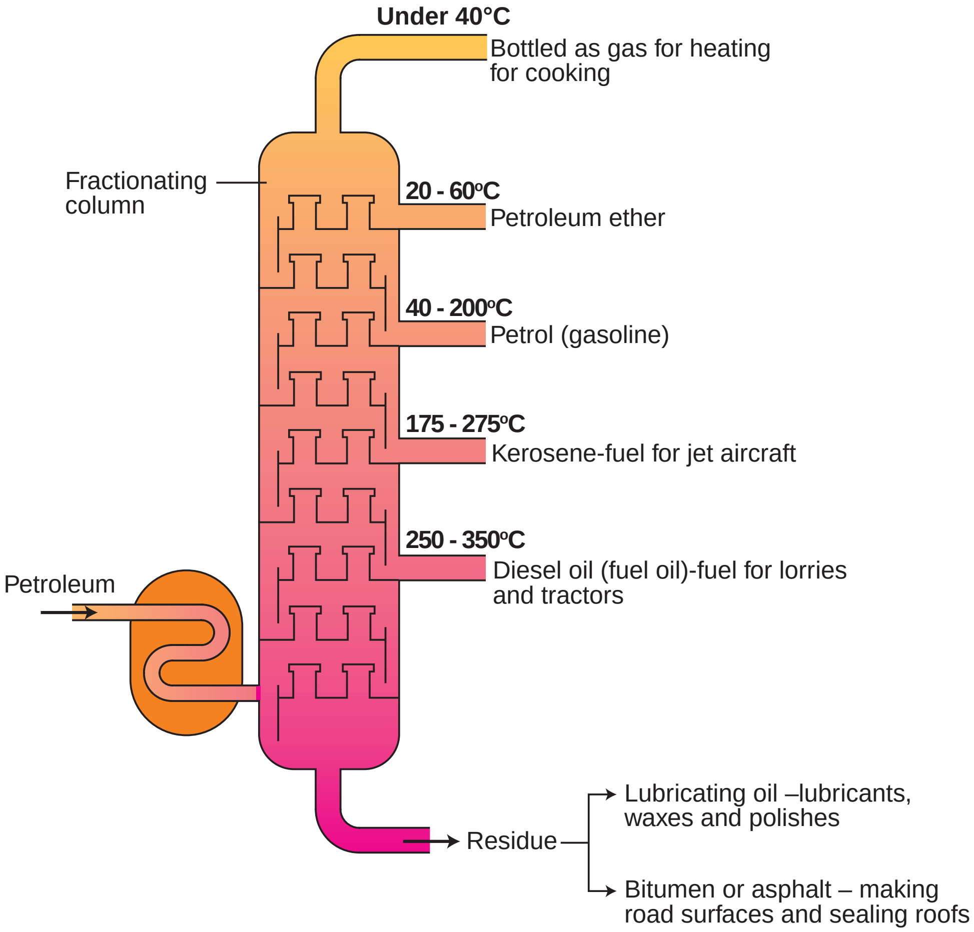


Figure 1.11 Fractional Distillation of Petroleum.

The major products (*fractions*) obtained from fractional distillation of petroleum and their uses are given in Table 1.9.

Table 1.9 Common petroleum products.

Fractions	Approximate composition (carbon number)	Boiling point range (°C)	Uses
Gases	$C_1 \rightarrow C_4$	below 20	– As fuel in the form of bottled gas.
Petroleum ether	$C_5 \rightarrow C_7$	$20 \rightarrow 60$	– As solvent, in dry cleaning.
Gasoline (petrol)	$C_5 \rightarrow C_{10}$	$40 \rightarrow 200$	– Motor fuel for internal combustion engines.
Kerosene	$C_{10} \rightarrow C_{16}$	$175 \rightarrow 275$	– Jet engine fuel, – household fuel.

Continued next page

Fuel oil (diesel oil)	$C_{15} \rightarrow C_{18}$	$250 \rightarrow 350$	– Furnace fuel, diesel engine fuel.
Lubricating oils Greases Petroleum jelly	$> C_{19}$	Non-volatile liquids	– Lubrication.
Paraffin wax Asphalt (bitumen) Coke	$> C_{20}$	Non-volatile solids	– Candles, polishes. – Roofing and road construction. – Electrodes, fuel for power stations.

Most hydrocarbons present in petroleum are long-chain hydrocarbons. However, there is a very high demand for petrol or gasoline, which contains hydrocarbons, composed of five to ten carbon atoms. Therefore, the amount of petrol obtained by fractional distillation of crude oil does not satisfy the demand for it. To satisfy the demand and maximize the output of petrol or gasoline, the process called cracking is carried out during fractional distillation.

What does cracking mean? Cracking is the decomposition of large hydrocarbon molecules into smaller ones by the application of heat (*thermal cracking* or *pyrolysis*) or in the presence of catalysts (*catalytic cracking*).

Example

$$\underset{\text{Hexadecane}}{C_{16}H_{34}} \xrightarrow{\text{heat}} \underset{\text{Octane}}{C_8H_{18}} + \underset{\text{Octene}}{C_8H_{16}}$$

Hydrogen gas can be added during cracking to saturate the alkenes formed in the process.

C. Coal

Coal is formed naturally by the decomposition of plant matter over several millions of years. It is not a pure form of carbon. It is an important source of aromatic hydrocarbons. Heating mineral coal in the absence of air, or oxygen is called destructive distillation of coal or coking of coal. When coal is heated in the absence of air it gives volatile products and coke. The volatile products separate into coal gas and a liquid, called coal tar when cooled. Aromatic hydrocarbons and many other substances are isolated from coal tar by fractional distillation.

Coke, which is a solid and relatively pure form of carbon, is used as a fuel in the blast furnace during the extraction of iron. It is also used to produce gaseous fuels, such as water gas (mixture of H_2 and CO) and producer gas (mixture of N_2 and CO).

Exercise 1.13

1. What are the major natural sources of hydrocarbons?
2. Which hydrocarbons are the main constituents of petroleum?
3. What is destructive distillation?
4. Describe how we can obtain aromatic hydrocarbons from coal.
5. Which fraction of petroleum is in very high demand?
6. What process should be carried out during fractional distillation of crude oil to maximize the output of petrol or gasoline?
7. Describe the main uses of
   - a petroleum ether;
   - b kerosene;
   - c gasoline;
   - d diesel oil;
   - e refinery gases.

Research and writing

Consult reference materials in the library and read about products made from hydrocarbons. Make a list of petroleum-related products you use almost daily.

1.6 ALCOHOLS

Competencies

After completing this section, you will be able to:

- *define alcohols;*
- *tell the functional group of alcohols;*
- *classify alcohols based on the number of hydroxyl groups;*
- *write the general formulas of monohydric alcohols;*
- *write the molecular formulas and the names of the first six members of the monohydric alcohols;*
- *give the IUPAC names for the given alcohols;*
- *classify monohydric alcohols based on the number of alkyl groups attached to the carbon atom carrying the hydroxyl group;*
- *give some examples for primary, secondary and tertiary alcohols;*
- *describe the physical properties of alcohols;*
- *explain general methods of preparation of alcohols;*
- *explain the industrial preparation of ethanol;*
- *perform an experiment to prepare ethanol from sugar;*

- *explain the chemical reactions of alcohols such as oxidation, reaction with active metals, esterification and dehydration;*
- *carry out an activity to show chemical reactions of alcohols with active metals;*
- *write the general structural formula of aldehydes;*
- *write the molecular formulas and names of simple aldehydes;*
- *write the general structural formula of ketones;*
- *write the molecular formulas and names of simple ketones;*
- *write the general structural formula of carboxylic acids;*
- *write the molecular formulas and names of simple carboxylic acids;*
- *write the general structural formula of esters;*
- *write the molecular formulas and names of simple esters.*

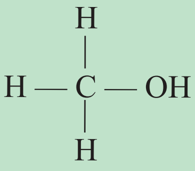
Activity 1.26

1. List some alcohols you know? Name the alcohol used in alcoholic beverages? What are the uses of alcohols in industry?
2. Ethiopia uses an alcohol blended with benzene to drive cars. What is the name of the alcohol? What is the source of this alcohol?

What do you think when you hear the word "alcohol"? Can you define alcohol? Give a few examples of the uses of alcohols. Most people think of two common alcohols- the substance that intoxicates people and the one used in clinics and hospitals. However, there are many types of alcohol. The only alcohol present in all alcoholic beverages is called ethanol. Other alcohols are used for different purposes.

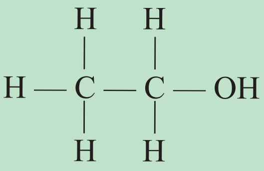
Alcohols are hydroxyl derivatives of hydrocarbons that can be obtained by replacing one or more hydrogen atom(s) of a hydrocarbon with the hydroxyl (–OH) group. The hydroxyl group is the functional group of alcohols.

Examples



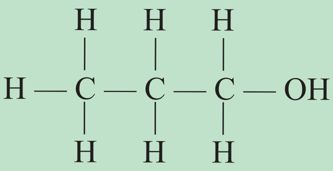
$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & — & C & — & OH \\ & & | & & \\ & & H & & \end{array}$$

Methanol



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & — & C & — & C & — & OH \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

Ethanol



$$\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & | & & | & & | & & \\ H & — & C & — & C & — & C & — & OH \\ & & | & & | & & | & & \\ & & H & & H & & H & & \end{array}$$

1-propanol

1.6.1 Classification of Alcohols

Alcohols are generally classified as monohydric, dihydric and trihydric depending on the number of hydroxyl (–OH) groups they contain in their molecular structure.

Monohydric alcohols are alcohols containing only one hydroxyl group.

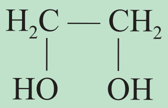
Examples

$CH_3—CH_2—OH$ $\quad$ $CH_3—CH_2—CH_2—OH$

Ethanol $\quad$ 1-propanol

Dihydric alcohols are those containing two hydroxyl groups per molecule. They are also named **glycols** or **diols**.

Example



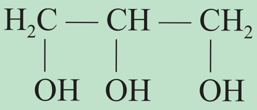
$$\begin{array}{cc} H_2C & — CH_2 \\ | & | \\ HO & OH \end{array}$$

Ethane-1,2-diol (Ethylene glycol)

Trihydric alcohols are those containing three hydroxyl groups in their molecular structure.

Polyhydric alcohols are those containing three or more hydroxyl groups in their molecular structure. Trihydric alcohols are also considered as polyhydric alcohols.

Example



$$\begin{array}{ccc} H_2C & — CH & — CH_2 \\ | & | & | \\ OH & OH & OH \end{array}$$

Propane-1,2,3-triol or Glycerine or glycerol

1.6.2 Nomenclature of Alcohols

An alcohol can be considered to be derived from a hydrocarbon by the replacement of at least one H atom by hydroxyl group. Hence, alcohols can be systematically named by using the suffix *-ol* to replace the terminal *-e* in the corresponding alkane name.

Table 1.10 IUPAC Names, Condensed Structure and Physical Constants of the First Six Monohydric Alcohol.

Structure of monohydric alcohol	IUPAC name	Melting point (°C)	Boiling point (°C)	Density g/mL
CH_3OH	Methanol	→97	64.7	0.792
CH_3CH_2OH	Ethanol	→117	78.3	0.789
$CH_3CH_2CH_2OH$	1-Propanol	→126	97.2	0.804
$CH_3(CH_2)_2CH_2OH$	1-Butanol	→90	117.7	0.810
$CH_3(CH_2)_3CH_2OH$	1-Pentanol	→78.5	138	0.817
$CH_3(CH_2)_4CH_2OH$	1-Hexanol	→52	156.5	0.819

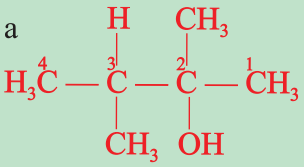
Activity 1.27

Based on the structural formulas given in table 1.10, derive the general formula for the homologous series of monohydric alcohols. Discuss in your group and present to the class.

In the IUPAC system of nomenclature of alcohols containing side chains or –OH groups in different positions, the longest chain to which the –OH group is attached, is chosen as a parent structure. The chain is then numbered, starting from the end closer to the carbon atom to which the –OH group is bonded. The other rules are similar to the nomenclature of hydrocarbons.

Examples

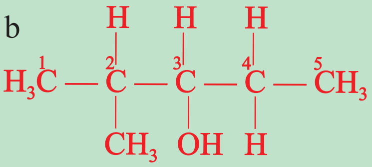
a



$H_3\overset{4}{C}-\underset{CH_3}{\overset{H}{\overset{3}{C}}}-\underset{OH}{\overset{CH_3}{\overset{2}{C}}}-\overset{1}{C}H_3$

2,3-dimethyl-2-butanol

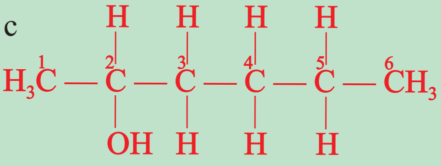
b



$H_3\overset{1}{C}-\underset{CH_3}{\overset{H}{\overset{2}{C}}}-\underset{OH}{\overset{H}{\overset{3}{C}}}-\underset{H}{\overset{H}{\overset{4}{C}}}-\overset{5}{C}H_3$

2-methyl-3-pentanol

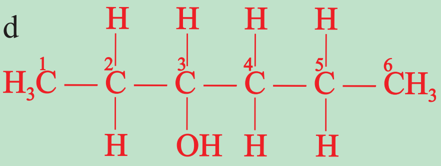
c



$H_3\overset{1}{C}-\underset{OH}{\overset{H}{\overset{2}{C}}}-\underset{H}{\overset{H}{\overset{3}{C}}}-\underset{H}{\overset{H}{\overset{4}{C}}}-\underset{H}{\overset{H}{\overset{5}{C}}}-\overset{6}{C}H_3$

2-hexanol

d



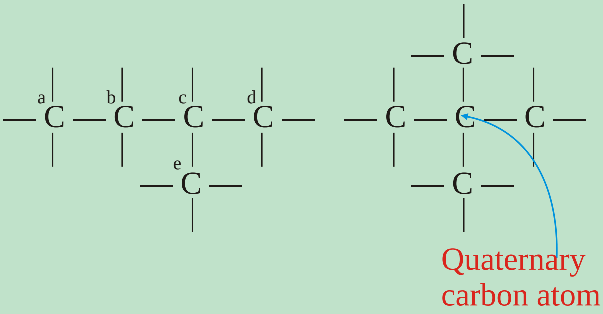
$H_3\overset{1}{C}-\underset{H}{\overset{H}{\overset{2}{C}}}-\underset{OH}{\overset{H}{\overset{3}{C}}}-\underset{H}{\overset{H}{\overset{4}{C}}}-\underset{H}{\overset{H}{\overset{5}{C}}}-\overset{6}{C}H_3$

3-hexanol

Classification of Monohydric Alcohols

Carbon atoms can be classified as primary (1°), secondary (2°), tertiary (3°) and quaternary (4°) if they are bonded to one, two, three and four carbon atoms, respectively.

Example

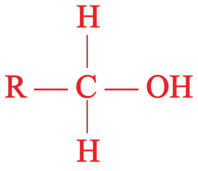


Carbon atoms indicated by letters *a*, *d*, and *e*, are primary. The carbon atom indicated by letter *b* is secondary, and the one indicated by letter *c* is tertiary.

Monohydric alcohols can be classified as primary (1°), secondary (2°) and tertiary (3°) alcohols, depending on the number of hydrocarbon groups (*alkyl groups*) attached to the carbon atom to which the hydroxyl group is bonded.

Primary alcohols are those alcohols which have the hydroxyl group connected to a primary carbon. They can also be defined as a molecule containing a "$-CH_2OH$" group.

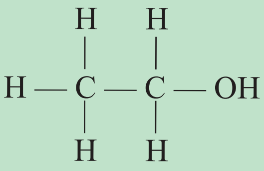
General Structure:



$$R-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-OH$$

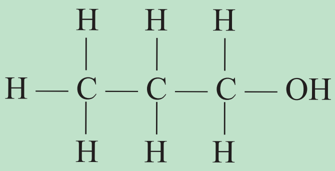
Primary (1°) alcohol

Examples



$$H-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-OH$$

Ethanol

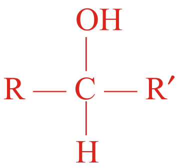


$$H-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-OH$$

1-propanol

Secondary alcohols are those in which the carbon atom bonded to the hydroxyl group is attached to two alkyl groups or contains an –OH group bonded to a secondary carbon atom.

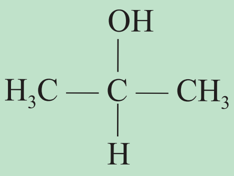
General structure:



$$R-\overset{\overset{\displaystyle OH}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-R'$$

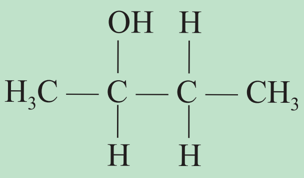
where R and R′ may be same or different

Examples



$$\begin{array}{c} \mathrm{OH} \\ | \\ \mathrm{H_3C - C - CH_3} \\ | \\ \mathrm{H} \end{array}$$

2-propanol

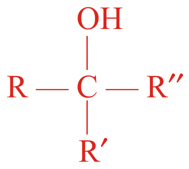


$$\begin{array}{ccccccc} & & \mathrm{OH} & & \mathrm{H} & & \\ & & | & & | & & \\ \mathrm{H_3C} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{CH_3} \\ & & | & & | & & \\ & & \mathrm{H} & & \mathrm{H} & & \end{array}$$

2-butanol

Tertiary alcohols are those in which the carbon atom bonded to the hydroxyl group is attached to three hydrocarbon (*alkyl*) groups or contain –OH group attached to a tertiary carbon atom.

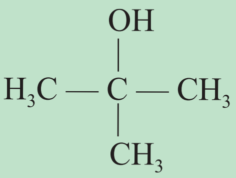
General Structure:



$$\begin{array}{c} \mathrm{OH} \\ | \\ \mathrm{R - C - R''} \\ | \\ \mathrm{R'} \end{array}$$

where R, R′ and R′′ may be same or different

Example



$$\begin{array}{c} \mathrm{OH} \\ | \\ \mathrm{H_3C - C - CH_3} \\ | \\ \mathrm{CH_3} \end{array}$$

2-methyl-2-propanol

Exercise 1.14

1. Classify the following alcohols as monohydric, dihydric and trihydric alcohols.
   a 2-propanol b 1,3-propanediol c 1,2,3-butanetriol
2. Classify the following monohydric alcohols as primary, secondary or tertiary alcohols.
   a 1-pentanol b 2-pentanol c 2-methyl-2-butanol

1.6.3 Physical Properties of Alcohols

Activity 1.28

1. Why do alcohols have higher boiling points than the corresponding hydrocarbons?
2. Why boiling points of dihydric and trihydric alcohols are higher than those of monohydric alcohols of comparable molecular size?

3. Lower alcohols, like methanol and ethanol, are miscible with water in all proportions, while lower hydrocarbons are not so. Explain.
4. Based on the boiling point of water, H_2O, and methanol, CH_3OH, in which one would you expect to observe a greater degree of hydrogen bonding? Explain. Discuss with your group and present to the class.

The hydroxyl group in an alcohol is polar due to the high electronegativity of oxygen. As a result, there is significant hydrogen bonding in alcohols.

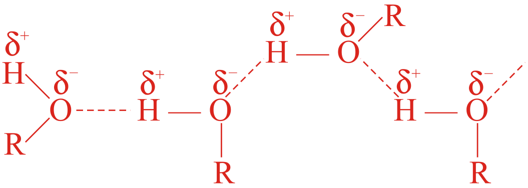
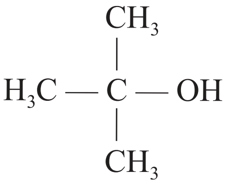


Figure 1.12 Hydrogen bonding between molecules of an alcohol.

Due to the hydrogen bonding in alcohols, they have higher melting and boiling points than hydrocarbons of comparable molecular size (*mass*). Hydrogen bonding is also the cause for even lower members to be liquids at room temperature. The boiling point of more branched isomer is lower than that of its isomeric straight-chain alcohol.

For Example: $CH_3CH_2CH_2CH_2OH$, boils at 117.7°C, while  $H_3C-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-OH$ boils at 82.5°C. Dihydric and the trihydric alcohols have higher boiling points than monohydric alcohols of similar molecular size (*mass*). Ethane-1,2-diol (*dihydric alcohol, molecular mass* = 62), boils at 197°C, while 1-propanol (*monohydric, molecular mass* = *60*) boils at 97.2°C.

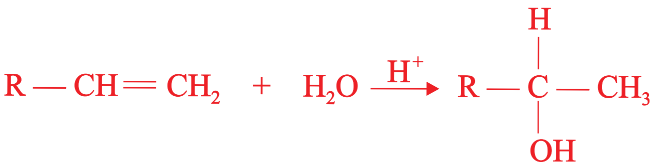
The first three alcohols, methanol, ethanol and 1-propanol are miscible with water in all proportions, while the solubility in water decreases with increasing carbon number. The water solubilities of dihydric and trihydric alcohols are higher than those of monohydric alcohols of similar molecular mass.

1.6.4 Preparation of Alcohols

The general laboratory methods of preparation of alcohols are:

a **Acid-catalyzed hydration of alkenes:**

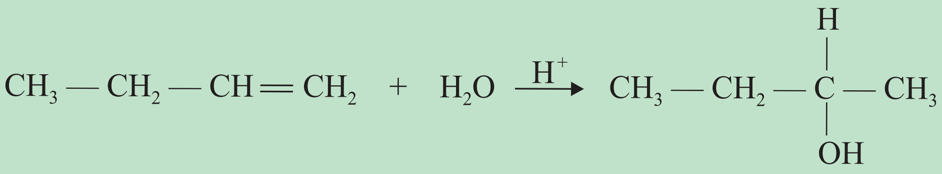
General Reaction:



$$\mathrm{R-CH{=}CH_2 + H_2O \xrightarrow{H^+} R-\underset{OH}{\overset{H}{C}}-CH_3}$$

Alkene Alcohol

Example



$$\mathrm{CH_3-CH_2-CH{=}CH_2 + H_2O \xrightarrow{H^+} CH_3-CH_2-\underset{OH}{\overset{H}{C}}-CH_3}$$

1-butene 2-butanol

b **Hydrolysis of alkyl halides:**

Warming alkyl halides with sodium hydroxide forms alcohols.

General Reaction:

$$\mathrm{R-CH_2X + NaOH \xrightarrow{heat} R-CH_2OH + NaX}$$

Alkyl halide
(where X = Cl, Br or I)

Alcohol

Example

$$\mathrm{CH_3-CH_2Cl + NaOH \xrightarrow{heat} CH_3-CH_2OH + NaCl}$$

Ethyl chloride Ethanol

c **Hydrolysis of Esters:**

Heating esters with potassium hydroxide produce alcohols.

General Reaction:

$$\mathrm{RCOOR' + KOH \xrightarrow{heat} RCOOK + R'OH}$$

Ester Alcohol

Example

$$\mathrm{CH_3COOCH_2CH_3 + KOH \xrightarrow{heat} CH_3COOK + CH_3CH_2OH}$$

Ethyl acetate Ethanol

The two methods, b and c, involve the replacement of other groups by the –OH group. Hence, they are examples of substitution reactions.

Ethanol (Ethyl Alcohol), CH_3CH_2OH

Activity 1.29

1 How do the local people in Ethiopia prepare alcoholic beverages like "Tella", "Tej" and "Katikalla"? What raw materials and apparatus do they use?

2 Which industrial method of production of ethanol is more or less similar to the method followed by the local people? Share your ideas with your class.

Ethanol is the second member of the homologous series of monohydric alcohols. It is one of the constituents of all alcoholic beverages. 'Tella', 'Tej', beer, wine, 'Katikalla', ouzo, gin and whisky contain ethanol. There are a number of methods for preparing ethanol using different materials.

Industrial preparation of Ethanol

Ethanol is manufactured industrially by:

1. **Fermentation of carbohydrates such as sugar:** Fermentation is the slow decomposition of carbohydrates such as sucrose, starch and cellulose in the presence of suitable enzyme, that results in the formation of ethanol and carbon dioxide:

$$\underset{\text{Sucrose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{\text{invertase}} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Fructose}}{C_6H_{12}O_6}$$

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \longrightarrow \underset{\text{Ethanol}}{2CH_3CH_2OH} + 2CO_2$$

Fermentation can produce an alcoholic beverage whose ethanol content is 12 – 15% only. The alcohol kills the yeast and inhibits its activity when the percentage is higher. To produce beverages of higher ethanol content, distillation of the aqueous solution is required.

Most liquor factories in Ethiopia use molasses, a by-product of sugar industries, as a raw material to produce ethanol. In the brewing industry, germinated barley called malt (*in Amharic*, *'Bikil'*) is used as the starting material. The whole process taking place in breweries is summarized as follows:

$$\underset{\text{Starch}}{2\,(C_6H_{10}O_5)_n} + nH_2O \xrightarrow{\text{Diastase}} \underset{\text{Maltose}}{nC_{12}H_{22}O_{11}} \xrightarrow[\text{Maltase}]{nH_2O} \underset{\text{Glucose}}{2nC_6H_{12}O_6}$$

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \xrightarrow{\text{Zymase}} \underset{\text{Ethanol}}{CH_3CH_2OH} + CO_2$$

2. **Catalytic Hydration of Ethene:** Most ethanol is manufactured at present by this method. In this process, ethene is treated with steam at 573 K and 60 atm pressures in the presence of phosphoric acid, H_3PO_4, catalyst.

$$\underset{\text{Ethene}}{CH_2{=}CH_2\,(g)} + H_2O\,(g) \xrightarrow[\text{573 k/60 atm}]{H_3PO_4} \underset{\text{Ethanol}}{CH_3CH_2OH\,(g)}$$

Experiment 1.6

Preparation of Ethanol by Fermentation

Objective: To prepare ethanol from sugar.

Materials required: Conical flask, glass rod, distillation flask, condenser, spatula, thermometer, watch glass, Bunsen burner, beaker, stopper and delivery tube. Sugar, ammonium phosphate or ammonium sulphate, yeast, $Ca(OH)_2$.

Procedure:

1. Take 50 mL of distilled water in a conical flask, add 15 g of sugar to it and stir. Add about 1 gram of yeast and a small amount of ammonium phosphate or ammonium sulphate to the solution. Arrange the set up, as shown below, and let the flask stand for three days at a warm place.

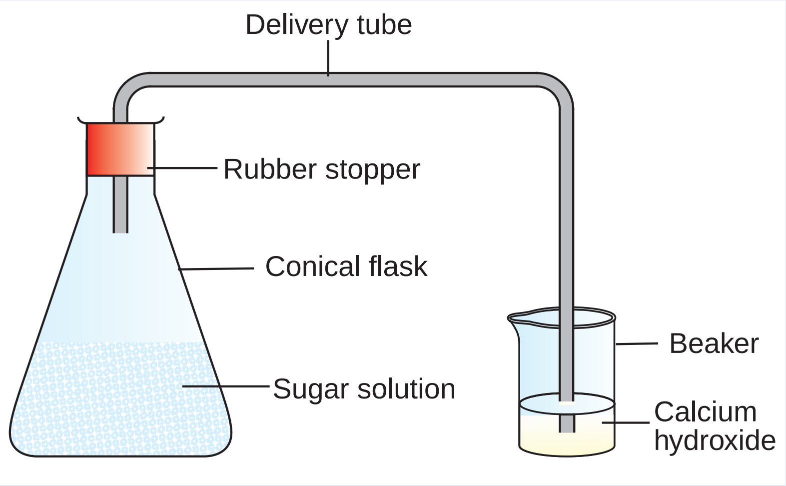


Figure 1.13 The Fermentation of Sugar.

Observations and analysis:

a What is the purpose of adding yeast to the solution?

b Why do we add ammonium phosphate or ammonium sulphate to the sugar solution?

c What happened to the calcium hydroxide solution at the end of the first or second day? Which gas is produced?

d What is the smell of the solution in the flask after three days?

e What has happened in the flask containing the sugar solution as it stood for three days?

2. After three days, filter the solution, and arrange the set up as in Figure 1.14. Pour 20 mL of the filtrate in a distilling flask, heat the solution, and collect the liquid in a receiver.

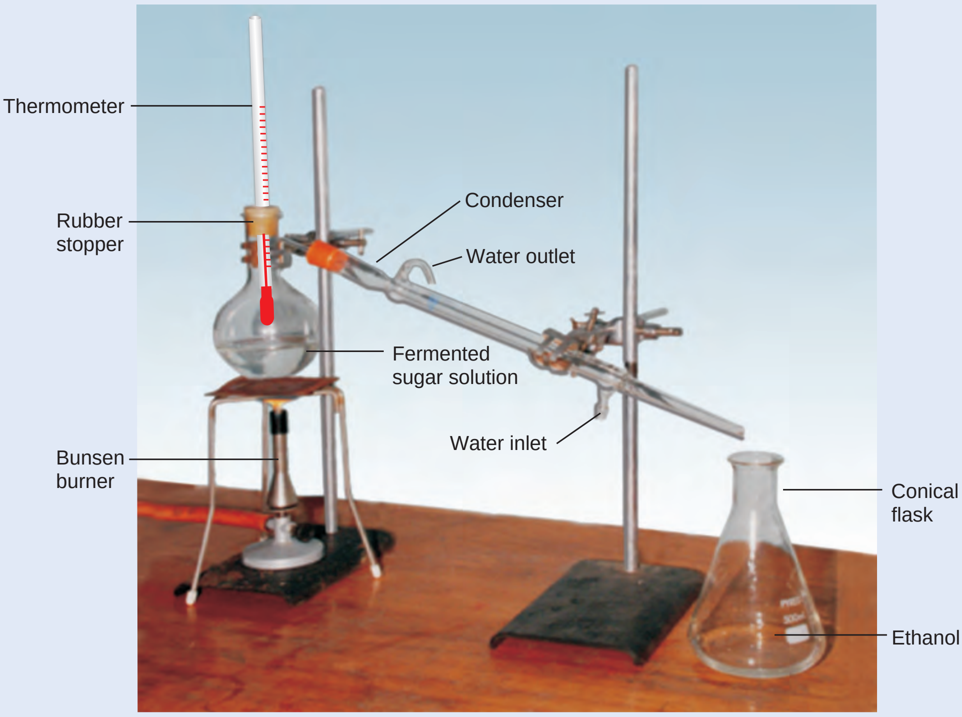


Figure 1.14 Separation of ethanol by distillation.

Points to observe:

a Observe the colour and identify the smell of the distillate.

b Pour a small amount of the distillate on a watch glass, strike a match and bring the flame close to the distillate. Does it catch fire?

Write complete laboratory report on this experiment and submit to your teacher.

Properties and Uses of Ethanol

Ethanol is a colourless liquid with a pleasant smell and a burning taste. It boils at 78.3°C and freezes at –117°C. It is inflammable and burns with a blue flame. It is miscible with water in all proportions, non-poisonous and has an intoxicating effect. It is a hypnotic (*sleep producer*).

Ethanol is a constituent of all alcoholic beverages. It is a good solvent for many organic compounds that are insoluble in water, such as paints, dyes, perfumes etc. It is also used as a fuel for cars and spirit lamps, and to make denatured alcohol which is a mixture of ethanol and other poisonous substance that has been added to make the alcohol unfit for drinking. For example, methylated spirit is a mixture of 95% ethanol and 5% methanol.

- Currently, Ethiopia uses 5% ethanol with 95% benzene as fuel for cars.

1.6.5 Chemical Properties of Alcohols

Activity 1.30

Why alcoholic beverages such as “Tela”, “Tej”, beer and wine turn sour if they are not properly stored? Which reaction of alcohols is responsible for this phenomenon? Write a chemical equation to support your answer. Discuss with your group and present it to the class.

What types of reactions do alcohols undergo? Alcohols contain a hydrocarbon group and a functional group (–OH). Which part of alcohols is responsible for most of their chemical reactions?

Reactions of alcohols may involve the cleavage of the oxygen hydrogen bond (—O—H) or the carbon-oxygen bond (—C—O).

The reactions of alcohols involving the –O–H bond cleavage are:

a Alcohols react with strongly electropositive metals like Na, K and Ca to form alkoxides and liberating H_2 gas.

General reaction:

$$\underset{\text{Alcohol}}{2R—CH_2—O—H} + 2Na \longrightarrow \underset{\text{Sodium ethoxide}}{2R—CH_2—O^-Na^+} + H_2$$

Example

$$\underset{\text{Ethanol}}{2CH_3—CH_2—O—H} + 2Na \longrightarrow \underset{\text{Sodium ethoxide}}{2CH_3CH_2—O^-Na^+} + H_2$$

Experiment 1.7

Reactions of Alcohols with Active Metals

Objective: To observe the reaction of alcohols with sodium and magnesium.

Materials required: Ethanol, sodium and magnesium metal. Test tubes, test tube holder, test tube rack, measuring cylinder, Bunsen burner, scissors or knife.

Procedure:

Take two test tubes and add 2-5 mL of ethanol to each of the test tubes. Cut a very small piece of sodium with a knife and drop it into the first test tube. Take magnesium ribbon and drop it in the second test tube.

Observations and analysis:

1. What do you observe:
   a in the 1st test tube? b in the 2nd test tube?
2. Is there an evolution of gas? What do you think this gas is?
3. If no reaction occurs in any of the test tubes, heat the mixture gently using a Bunsen burner and write your observation.
4. Which bond of the alcohol is broken in the reaction?
5. Write a general reaction for such reactions?
6. What type of metals react in this manner?

b **Oxidation of alcohols:** The oxidation products of alcohols depend on the type of alcohol and the nature of oxidizing agents. Oxidation of alcohols is a very important method for the production of other oxygen-containing compounds of hydrocarbons, such as aldehydes, ketones and carboxylic acids.

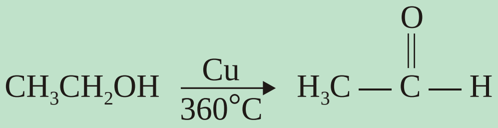
i) Oxidation of primary alcohols in the presence of mild oxidizing agents yields aldehydes.

General reaction:

$$R - CH_2OH \xrightarrow[360^\circ C]{Cu} RCHO$$

Primary alcohol Aldehyde

Example



$$CH_3CH_2OH \xrightarrow[360^\circ C]{Cu} H_3C - \overset{\overset{\displaystyle O}{\|}}{C} - H$$

Ethanol Ethanal

Strong oxidizing agents, such as acidified $KMnO_4$ or $K_2Cr_2O_7$ and CrO_3 in H_2SO_4, oxidize primary alcohol first to aldehydes and then to carboxylic acids. It is difficult to stop the reaction at the aldehyde stage.

$$R-CH_2OH \xrightarrow{H^+/KMnO_4} RCHO \xrightarrow{H^+/KMnO_4} R-COOH$$

Primary alcohol | Aldehyde | Carboxylic acid

Example

$$CH_3CH_2OH \xrightarrow{H^+/KMnO_4} CH_3CHO \xrightarrow{H^+/KMnO_4} CH_3COOH$$

Ethanol | Ethanal | Ethanoic acid

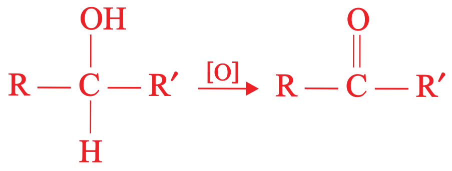
Note that aldehydes are represented by the general structural formula $R-\overset{\overset{\displaystyle O}{\|}}{C}-H$ or RCHO, where R is an alkyl group. In the case of methanal R = H. For naming aldehydes, use the suffix *-al* to replace the terminal *-e* in the corresponding alkane name. The suffix "-al" indicates the functional group –CHO. The names and condensed structures of the first six aldehydes are given in Table 1.11.

Table 1.11 Condensed structures and IUPAC names of some aldehydes.

Molecular formula of aldehyde	Structure of aldehyde	IUPAC name
CH_2O	HCHO	Methanal
C_2H_4O	CH_3CHO	Ethanal
C_3H_6O	CH_3CH_2CHO	Propanal
C_4H_8O	$CH_3(CH_2)_2CHO$	Butanal
$C_5H_{10}O$	$CH_3(CH_2)_3CHO$	Pentanal
$C_6H_{12}O$	$CH_3(CH_2)_4CHO$	Hexanal

ii) Oxidation of secondary alcohols yields ketones.

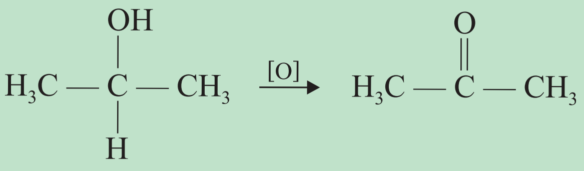
General reaction:



$$R-\underset{\displaystyle H}{\underset{|}{\overset{\displaystyle OH}{\overset{|}{C}}}}-R' \xrightarrow{[O]} R-\overset{\displaystyle O}{\overset{\|}{C}}-R'$$

Secondary alcohol | Ketone

Example

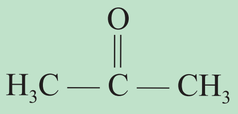


$$H_3C-\overset{OH}{\underset{H}{C}}-CH_3 \xrightarrow{[O]} H_3C-\overset{O}{\overset{\|}{C}}-CH_3$$

2-propanol Propanone

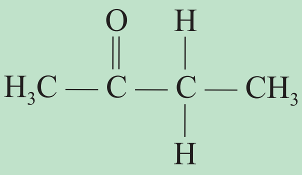
The general structural formula of ketones is: $R-\overset{O}{\overset{\|}{C}}-R'$ or RCOR' where R and R' may be same or different. The IUPAC names of ketones are obtained by using the suffix *-one* to replace the terminal *-e* in the corresponding alkane name. The suffix '*-one*' indicates the functional group. Unlike aldehydes, the position of the functional group must be indicated in the name of higher ketones. To do so, the longest chain containing the functional group is chosen as a parent structure and then the carbon atoms of the chain are numbered starting from the end closer to the carbonyl group.

Examples



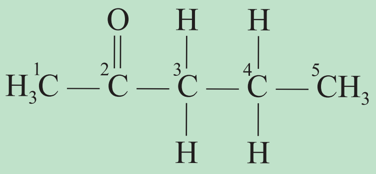
$$H_3C-\overset{O}{\overset{\|}{C}}-CH_3$$

Propanone



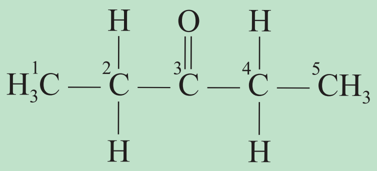
$$H_3C-\overset{O}{\overset{\|}{C}}-\overset{H}{\underset{H}{C}}-CH_3$$

Butanone



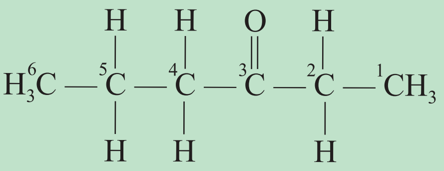
$$H_3{}^{1}C-{}^{2}\overset{O}{\overset{\|}{C}}-{}^{3}\overset{H}{\underset{H}{C}}-{}^{4}\overset{H}{\underset{H}{C}}-{}^{5}CH_3$$

2-pentanone or pent-2-one



$$H_3{}^{1}C-{}^{2}\overset{H}{\underset{H}{C}}-{}^{3}\overset{O}{\overset{\|}{C}}-{}^{4}\overset{H}{\underset{H}{C}}-{}^{5}CH_3$$

3-pentanone or pent-3-one

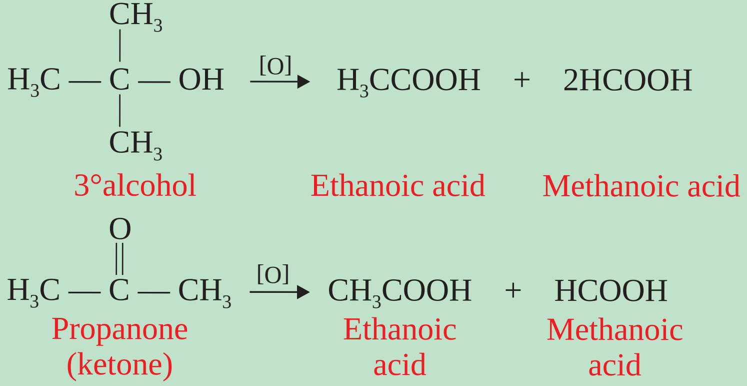


$$H_3{}^{6}C-{}^{5}\overset{H}{\underset{H}{C}}-{}^{4}\overset{H}{\underset{H}{C}}-{}^{3}\overset{O}{\overset{\|}{C}}-{}^{2}\overset{H}{\underset{H}{C}}-{}^{1}CH_3$$

3-hexanone or hexan-3-one

iii) Tertiary alcohols and ketones are generally resistant to oxidation. However, they can undergo oxidation under drastic conditions to form a mixture of carboxylic acids.

Examples



$$H_3C-\overset{\overset{\displaystyle CH_3}{|}}{\underset{\underset{\displaystyle CH_3}{|}}{C}}-OH \xrightarrow{[O]} H_3CCOOH + 2HCOOH$$

3°alcohol　Ethanoic acid　Methanoic acid

$$H_3C-\overset{\overset{\displaystyle O}{\|}}{C}-CH_3 \xrightarrow{[O]} CH_3COOH + HCOOH$$

Propanone (ketone)　Ethanoic acid　Methanoic acid

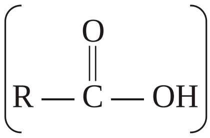
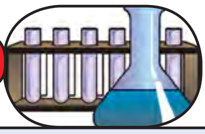
The general structural formula of carboxylic acids is  $\left[R-\overset{\overset{\displaystyle O}{\|}}{C}-OH\right]$ or simply R– COOH where R – is an alkyl group or hydrogen in case of the first member of the carboxylic acid homologous series. The IUPAC names of carboxylic acids are derived by replacing the final *-e* of the corresponding alkane with *-oic acid*. The suffix '-oic acid' representing the functional group –COOH. The molecular formulas, condensed structure and IUPAC names of the first six carboxylic acids are shown in the Table 1.12.

Table 1.12 IUPAC names, formulas and condensed structure of some carboxylic acids.

Formula of carboxylic acid	Condensed structure	IUPAC name of the acid
$HCOOH$	$HCOOH$	Methanoic acid
CH_3COOH	CH_3COOH	Ethanoic acid
C_2H_5COOH	CH_3CH_2COOH	Propanoic acid
C_3H_7COOH	$CH_3 \rightarrow (CH_2)_2\ COOH$	Butanoic acid
C_4H_9COOH	$CH_3 \rightarrow (CH_2)_3 \rightarrow COOH$	Pentanoic acid
$C_5H_{11}COOH$	$CH_3 \rightarrow (CH_2)_4 \rightarrow COOH$	Hexanoic acid

c　Esterification: Carboxylic acids react with alcohols to form esters. This reaction is known as esterification.

Experiment 1.8



The reaction of alcohols and organic acids

Objective: To investigate the reaction of ethanol and ethanoic acid.

Material required: Ethanol, ethanoic acid, concentrated sulphuric acid, test tube, test tube holder, Bunsen burner, beaker, water and glass rod.

Procedure:

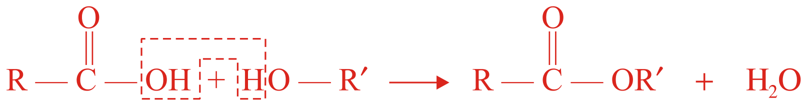
1. Pour 2 mL of ethanol and 4 mL of acetic acid in a test tube. Add a few drops of concentrated suphuric acid to the mixture of the alcohol and acid.
2. Hold the test tube containing the mixture with a test tube holder and heat it gently from three to five minutes. Allow the contents to cool, add it to a beaker half-filled with water. Stir the mixture and smell the product.

Observations and analysis:

1. What smell did you recognize? What do you think is the origin of this smell?
2. Write a balanced chemical equation to show what has happened on heating the mixture of ethanol and ethanioic acid?
3. What is the purpose of adding few drops of concentrated sulphuric acid to the mixture of the alcohol and acid ?

   Write a laboratory report in groups and present to the class.

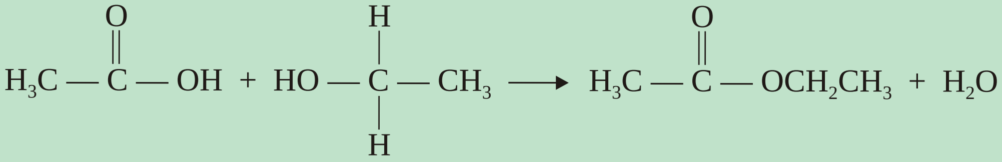
General reaction:



$$R-\overset{\overset{O}{\|}}{C}-\boxed{OH\boxed{+}H}O-R' \longrightarrow R-\overset{\overset{O}{\|}}{C}-OR' + H_2O$$

Carboxylic Acid Alcohol Ester

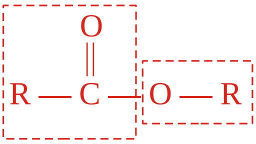
Example



$$H_3C-\overset{\overset{O}{\|}}{C}-OH + HO-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-CH_3 \longrightarrow H_3C-\overset{\overset{O}{\|}}{C}-OCH_2CH_3 + H_2O$$

Ethanoic acid Ethanol Ethyl ethanoate

The general structural formula of esters is: $R-\overset{\overset{O}{\|}}{C}-OR'$ or simply RCOOR′ where R and R′ are alkyl groups. In some cases, R can be a hydrogen atom. In the nomenclature of esters they are considered as derivatives of both carboxylic acids and alcohols.

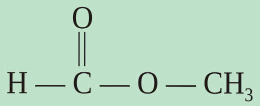


$$\boxed{R-\overset{\overset{O}{\|}}{C}}-\boxed{O-R}$$

Acid portion Alcohol portion

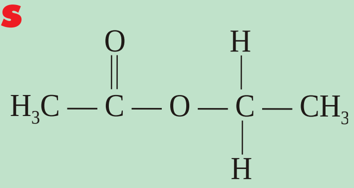
Esters are named first by naming the alkyl group derived from the alcohol followed by the name of the acid changing the suffix "-*ic* acid" to "-*ate*".

Examples



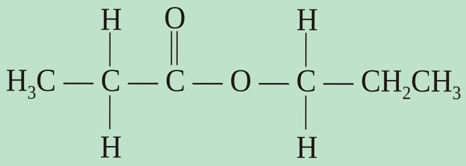
$H-\overset{\overset{O}{\|}}{C}-O-CH_3$

Methyl methanoate



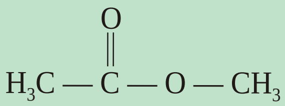
$H_3C-\overset{\overset{O}{\|}}{C}-O-\overset{\overset{H}{|}}{\underset{\underset{H}{|}}{C}}-CH_3$

Ethyl ethanoate



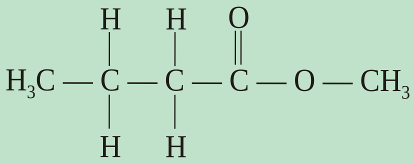
$H_3C-\overset{\overset{H}{|}}{\underset{\underset{H}{|}}{C}}-\overset{\overset{O}{\|}}{C}-O-\overset{\overset{H}{|}}{\underset{\underset{H}{|}}{C}}-CH_2CH_3$

n-propyl propanoate



$H_3C-\overset{\overset{O}{\|}}{C}-O-CH_3$

Methyl ethanoate



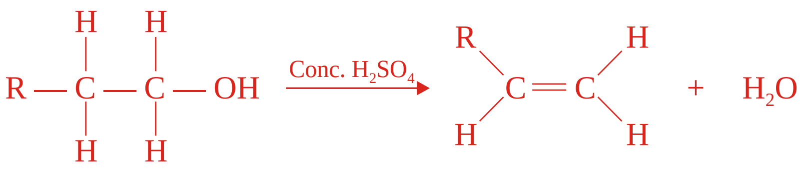
$H_3C-\overset{\overset{H}{|}}{\underset{\underset{H}{|}}{C}}-\overset{\overset{H}{|}}{\underset{\underset{H}{|}}{C}}-\overset{\overset{O}{\|}}{C}-O-CH_3$

Methyl butanoate

The reactions of alcohols involving the – C – O bond cleavage include:

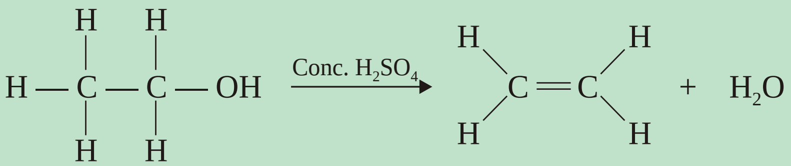
a **Dehydration of alcohols:** Heating alcohols in the presence of dehydrating agents, like concentrated H_2SO_4, yield alkenes.

General reaction:



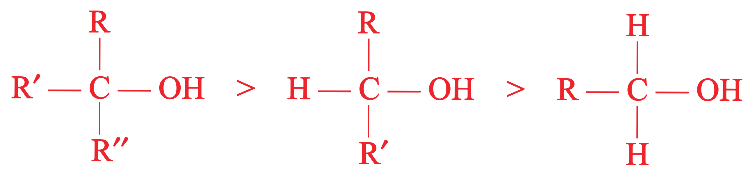
Alcohol Alkene

Example



Ethanol Ethene

The overall tendency of alcohols to undergo dehydration is in the following order:



$$R'-\overset{\displaystyle R}{\underset{\displaystyle R''}{C}}-OH \;>\; H-\overset{\displaystyle R}{\underset{\displaystyle R'}{C}}-OH \;>\; R-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-OH$$

Tertiary alcohol Secondary alcohol Primary alcohol

b **Reactions of alcohols with hydrogen halides produce alkyl halides:**

General reaction:

$$R-CH_2-OH + HX \longrightarrow R-CH_2-X + H_2O$$

Alcohol (X = Cl, Br, I) Alkyl halide

Example

$$CH_3-CH_2-OH + HCl \longrightarrow CH_3-CH_2Cl + H_2O$$

Ethanol Ethyl chloride (1-chloroethane)

Activity 1.31

1. Write the general structural formulas for aldehydes and ketones.
2. What structural difference do you see between aldehydes and ketones?
3. Write the general structural formulas for carboxylic acids and esters.

Discuss with your group and present it to the class.

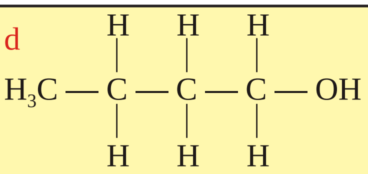
Exercise 1.15

1. Which functional group characterizes alcohols?
2. What is the basis for the classification of alcohols?
3. What is the general formula of alcohols?
4. Classify the following alcohols as primary, secondary and tertiary alcohols:

a

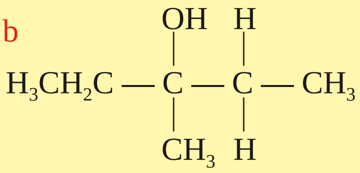
CH_3CH_2OH

d



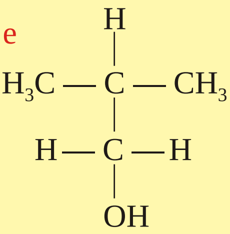
$H_3C-CH_2-CH_2-CH_2-OH$

b



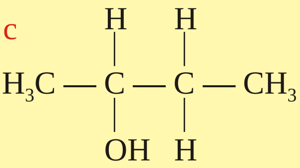
$H_3CH_2C-C(OH)(CH_3)-CH_2-CH_3$

e



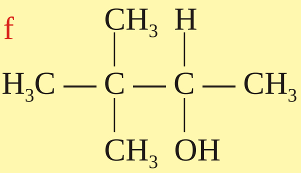
$H_3C-CH(CH_3)-CH_2-OH$

c



$H_3C-CH(OH)-CH_2-CH_3$

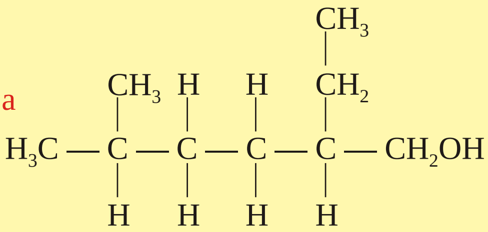
f



$H_3C-C(CH_3)_2-CH(OH)-CH_3$

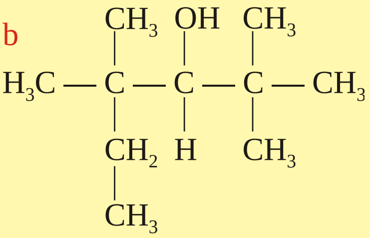
5. Write IUPAC name for each of the following alcohols:

a



$H_3C-CH(CH_3)-CH_2-CH_2-CH(CH_2CH_3)-CH_2OH$

b



$H_3C-C(CH_3)(CH_2CH_3)-CH(OH)-C(CH_3)_2-CH_3$

6. What causes the boiling points of alcohols to be higher than hydrocarbons of similar molecular mass?

7. Complete the following chemical reactions:

   a $CH_3I + NaOH \rightarrow$

   b $CH_3CH_2COOCH_2CH_3 + KOH \rightarrow$

8. What is the functional group of aldehydes?

9. What is the functional group of ketones?

10. What suffixes are used in their IUPAC names to indicate the functional group of aldehydes and ketones respectively?

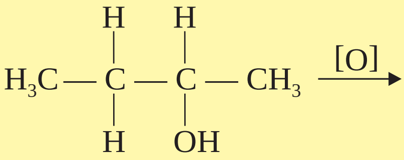
11 What functional group characterizes carboxylic acids?

12 Complete the following chemical reactions:

a

$$CH_3CH_2CH_2OH \xrightarrow{[O]}$$

b



$$H_3C-\underset{H}{\overset{H}{C}}-\underset{OH}{\overset{H}{C}}-CH_3 \xrightarrow{[O]}$$

c

$$CH_3CH_2COOH \quad + \quad CH_3CH_2OH \xrightarrow{H^+}$$

1.7 INDUSTRIAL AND AGRICULTURAL APPLICATIONS OF ORGANIC COMPOUNDS

Competencies

After completing the section, you will be able to:

- discuss the uses of organic compounds in the manufacture of beverages;
- discuss the uses of organic compounds in the manufacture of pharmaceuticals;
- discuss the uses of organic compounds in the manufacture of soaps and detergents;
- discuss the uses of organic compounds in the manufacture of dry cleaning agents;
- discuss the uses of organic compounds in the manufacture of fuels;
- conduct an experiment to prepare soap from naturally existing esters;
- discuss the uses of organic chemicals in the manufacture of pesticides and herbicides;
- discuss the importance and manufacture of urea.

Activity 1.32

1. What are the major application areas of organic compounds?
2. Do you know substances that are used in the preparation of soaps and detergents? If yes name them?
3. Do you know substances (*chemicals*) that are used in dry cleaning?
4. What agricultural applications of organic compounds do you know?

Share your ideas with your group.

Industrial application

Organic chemicals are used for the manufacturing of a large number of industrial products that have a variety of uses. Some of these products include alcoholic beverages, pharmaceuticals, soaps and detergents etc.

A. Alcoholic beverages

All alcoholic beverages commonly contain the alcohol known as ethanol. The ethanol content of all alcoholic beverages is not the same. Some beverages contain small concentrations of ethanol while others contain higher concentrations. These alcoholic beverages can be either undistilled or distilled. The undistilled alcoholic beverages include beer, wine, "Tella", 'Tej' etc while ouzo, gin, brandy, whisky, 'Katikalla', and vodka are among the distilled alcoholic beverages.

Beer: Beer is one of the alcoholic beverages widely manufactured and consumed in most parts of the world. The common raw materials for its production are barley and hops. Although the types of beer produced in the world are very many, the average beer has alcohol content between 3-6 percent by volume.

Wine: Wine is another undistilled alcoholic beverage. The most common raw material for producing wine are grapes. In the production process, grapes are first crushed and then steamed. The liquid derived from crushing is called must. It then goes to a fermentation tank where fermentation takes place. Then it passes to a settling tank, where sediments are allowed to settle, and it proceeds from there to a filter. The clear liquid is cooled in a refrigerator and is pasteurized as it passes through a flash pasteurizer. Most wines have an alcohol content varying from 10-15% by volume.

Liquor: Compared with beer and wine, liquor contains higher concentrations of ethanol. It is not possible to obtain an alcoholic beverage of more than 15% alcohol by volume through fermentations. This is because the yeast cells are not able to stay alive in alcohol of higher concentration. To get alcoholic beverages with higher percentages of alcohol, the alcohol must be separated from the solution by distillation.

The alcoholic beverages like ouzo, gin, cognac, whisky etc, are made by distillation. Different types of liquors have different alcohol concentrations. In most distilled alcoholic beverages the percentage ranges between 30-45% alcohol by volume. However, some alcoholic beverages like Araki are expected to have a higher percentage of ethanol.

B. Pharmaceuticals

Organic chemicals are used to manufacture drugs and medicines for various uses. These drugs and medicines are collectively known as pharmaceuticals. Some of the pharmaceuticals are:

Analgesics: These are substances that reduce pain. For example: aspirin and paracetamol.

Antiseptics: These are substances that help to prevent infections in wounds by killing bacteria; for example, acriflavine.

Sedatives: These are drugs that make a person go to sleep or make them feel calm and relaxed. Examples of such type of medicines are the barbiturates, which include several important drugs.

Disinfectants: These are substances used to disinfect something or to kill bacteria; for example, Dettol.

Sulphonamides: These are medicines used as antibiotics. For example: penicillin.

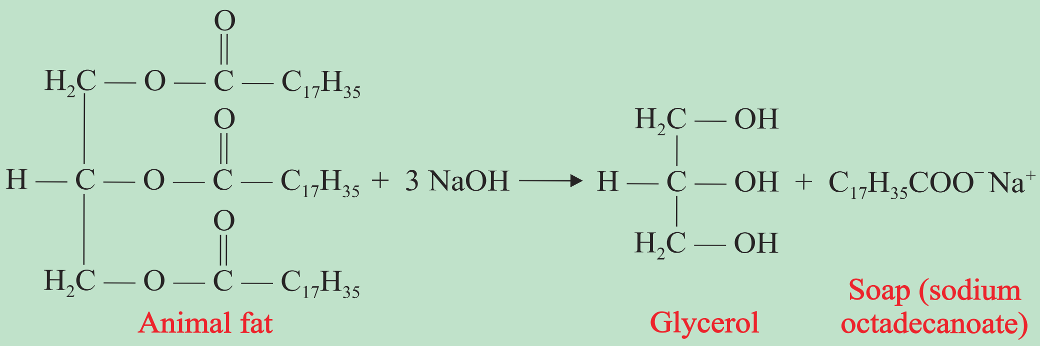
C. Soaps and Detergents

Organic chemicals are used for the synthesis of soaps and detergents. For example, animal fat and vegetable oils are used for manufacturing soap. Fats and oils are naturally occurring esters of glycerol and the higher fatty acids. Long open-chain alcohols and alkyl benzene sulphonic acid can be used for the production of detergents.

Soaps and detergents are substances used to remove dirt. They are also called surfactants or surface active agents. This is because they reduce the surface tension of water and change the surface properties.

Soaps are either sodium or potassium salts of higher (*long-chain*) carboxylic acids. Soaps that are sodium salts are called hard soaps and those that are potassium salts are soft soaps. Soaps are prepared by boiling animal fat or vegetable oil with a base. The reaction that produces soap is called saponification.

Example



$$C_3H_5(OCOC_{17}H_{35})_3 + 3\,NaOH \longrightarrow C_3H_5(OH)_3 + C_{17}H_{35}COO^-Na^+$$

Detergents contain either a sulfate or a sulphonate group. One example of detergents is sodium lauryl sulfate, $C_{12}H_{25}—O—SO_2—ONa$. It is prepared first by reacting dodecyl (lauryl) alcohol with sulphuric acid followed by reaction with sodium hydroxide.

The reaction equation is:

$$\underset{\substack{\text{Dodecyl alcohol}\\ \text{(lauryl alcohol)}}}{C_{12}H_{25}—OH} + \underbrace{HO—SO_2—OH}_{H_2SO_4} \longrightarrow \underset{\substack{\text{Lauryl hydrogen}\\ \text{sulphate}}}{C_{12}H_{25}—O—SO_2—OH} + H_2O$$

$$C_{12}H_{25}—O—SO_2—OH + NaOH \longrightarrow \underset{\text{Sodium lauryl sulphate}}{C_{12}H_{25}—O—SO_2—ONa} + H_2O$$

Experiment 1.9

Preparation of Soap

Objective: To prepare soap from animal fat or vegetable oil.

Materials required: Animal fat or vegetable oil, NaOH, NaCl, measuring cylinder, beaker, glass rod, Bunsen burner, filter paper, funnel, conical flask, and test tube.

Procedure:

Measure 3 mL vegetable oil or 3 g animal fat and place it in a 100 mL beaker; add 3 mL of ethanol and 3 mL of 5M NaOH. Stir the mixture vigorously with a glass rod and gently heat over a flame for 15 minutes or until it turns in to a paste. When the paste begins to form, stir very carefully to prevent frothing. After all the paste has formed, set the beaker on the bench to cool. Add about 15 mL of saturated NaCl solution to the paste mixture and stir thoroughly. This process is called salting out the soap. Filter off the soap mixture by suction filtration and wash the collected soap precipitate with 15 mL of ice water.

Observations and analysis:

a Why do we add ethanol during the preparation?

b What is the purpose of adding saturated NaCl solution to the paste mixture?

Write a laboratory report and present to the class.

D. Dry Cleaning

The qualities of some clothes decrease when they are washed with water using ordinary soap. In order to avoid this, other chemicals are used for washing purposes that remove dirt in the same manner as soaps. Dry cleaning refers to the use of different chemicals that are capable of dissolving grease and other dirt stains in a similar manner as soaps without the use of water. The most commonly used chemicals in dry cleaning are organic chemicals such as tetrachloromethane, CCl_4; tetrachloroethylene, $Cl_2C = CCl_2$; benzene and gasoline.

E. Fuels

The term fuel refers to any material that is capable of burning to produce energy, heat and light. Most fuels occurring in nature are organic compounds. However, some inorganic substances like hydrogen, producer gas and water gas are also used as gaseous fuels. But, the most widely used fuels at present are of organic origin. This includes petroleum which chiefly contains alkanes. Natural gas which is used as a fuel for stoves contains mainly methane. Gasoline which is used as a fuel for internal combustion engines also contains alkanes. Paraffin wax which is used to make candles is another fuel to get light energy and it is a mixture of alkanes containing more than twenty carbon atoms. Besides its use as a constituent of all alcoholic beverages, ethanol can also be used as a fuel for internal combustion engines. At present, it is one of the substances that we can rely on for use as a fuel for automobiles. The use of ethanol as a fuel is now practiced in our country by mixing it with petrol. Ethanol and other plant seed oils can be classified as bio fuels.

Agricultural Applications

Organic compounds also play an important role in agriculture, specially to increase crop productivity by controlling the damages caused by insects, rodents, fungi, birds and weeds. So, organic chemicals can be used in the manufacture of pesticides and herbicides.

What is the distinction between herbicides and pesticides?

Pesticides are the chemicals used for controlling the damage that can be caused by fungi, insects and other pests that attack crops. Among the pesticides, Bordeaux mixture is used as fungicide. Other chemicals like DDT, aldrine, dieldrine, malathion are used as insecticides.

Herbicides are the chemicals that are applied on agricultural lands to remove unwanted plants or weeds. Some examples of compounds that are used as herbicides include paraquat, diquat, ammonium sulphamate, ammonium glyphosinate, sodium chlorate etc.

Fertilizers: In order to increase crop productivity we use either synthetic or natural fertilizers. Synthetic fertilizers are grouped into three classes as nitrogen, potash and phosphate fertilizers. Nitrogen is one of the essential plant nutrients. It is absorbed by plants in the form of nitrate ion, NO_3^-. Nitrogen enables green plants to synthesize amino acids and proteins, and it is also a constituent of DNA molecules. To provide nitrogen for plants, nitrogen-containing fertilizers are usually added to the soil. These include, ammonium salts like NH_4Cl, $(NH_4)_2SO_4$; nitrates like KNO_3 and urea. Urea is one of the most important nitrogen fertilizers. It is a component of urine. On an industrial scale, urea is manufactured by the dehydration of ammonium carbamate:

$$H_2N—COO^-NH_4^+\,(s) \longrightarrow H_2NCONH_2\,(s) + H_2O\,(g)$$

It can also be prepared by direct combination of ammonia and carbon dioxide at 180℃ and pressure of about 140 atm.

$$2NH_3\,(g) + CO_2\,(g) \longrightarrow \underset{\text{Urea}}{NH_2CONH_2\,(s)} + H_2O\,(g)$$

Check list

Key terms of the unit

- addition reaction
- alcohol
- aldehyde
- alkane
- alkene
- alkyl halide
- alkyl radicals
- alkynes
- benzene
- biogas
- carboxylic acid
- chain isomerism
- cracking
- crude oil
- cycloalkanes
- cycloalkene
- decarboxylation
- dehydrohalogenation
- destructive distillation
- detergents
- elimination reaction
- ester
- fermentation
- fertilizer
- functional group
- geometrical isomerism
- halogenation
- hedrohalogenation
- herbicide
- homologous series
- hydrogenation
- inorganic compound
- isomers
- ketone
- lifeforce theory
- Markovnikov's rule
- natural gas
- nitration
- organic compound
- pesticide
- petroleum
- pharmaceuticals
- polymerization
- position isomerism
- resonance structure
- saturated hydrocarbons
- soaps
- substitution reaction
- sulphonation
- unsaturated hydrocarbons
- Wurtz reaction

Unit Summary

- *The "life force" theory states that living organisms (plants and animals) have a special life force which helps them to synthesize organic compounds and that organic compounds cannot be synthesized artificially by man in the laboratory.*
- *Organic chemistry is the study of carbon compounds including natural and synthetic ones.*
- *Organic compounds are classified based on the functional group they contain in their molecules.*
- *The functional group is a part of a molecule that determines the chemical and physical properties of a compound.*
- *Hydrocarbons are compounds composed of carbon and hydrogen atoms only.*
- *Saturated hydrocarbons contain only single bonds between carbon atoms*
- *Unsaturated hydrocarbons are those containing one or more double or triple bonds between carbon atoms.*
- *A homologous series is a group of compounds in which each member of the group differs from the next member by* $–CH_2–$ *group.*
- *Alkanes are saturated hydrocarbons represented by the general formula* C_nH_{2n+2}. *Alkanes are named by using prefixes that indicate the number of carbon atoms and the suffix '-ane'.*
- *Isomerism is the existence of two or more compounds with the same molecular formula but different structures. These compounds are called isomers.*
- *Alkenes are unsaturated hydrocarbons containing a carbon-carbon double bond as their functional group. Their general formula is* C_nH_{2n}. *The suffix '-ene' in their names indicates the presence of a carbon-carbon double bond.*
- *Alkynes are unsaturated hydrocarbons containing a carbon - carbon triple bond as their functional group. They are represented by the general formula* C_nH_{2n-2}. *The suffix '-yne' indicates the carbon-carbon triple bond.*
- *Alkenes and alkynes undergo mainly addition reactions while alkanes undergo substitution reactions.*
- *Aromatic hydrocarbons are compounds containing benzene rings. Benzene is the simplest aromatic hydrocarbon.*
- *Benzene mainly undergoes substitution reactions.*
- *The natural sources of hydrocarbons are crude oil, natural gas and coal.*

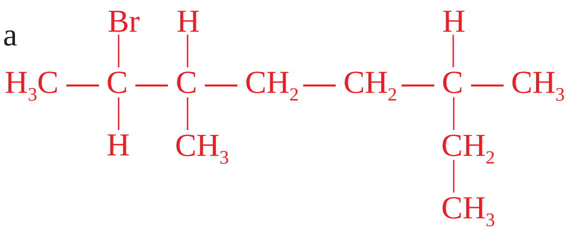
- *Crude oil is a complex mixture of hydrocarbons, mainly alkanes, and also contain cycloalkanes and aromatics.*
- *Crude oil is separated into a number of useful fractions by fractional distillation.*
- *Alcohols are compounds containing the hydroxyl (–OH) group as their functional group and represented by the general formula* $C_nH_{2n+1}OH$.
- *Alcohols are classified depending on the number of hydroxyl groups they contain as monohydric, dihydric and trihydric alcohols.*
- *Monohydric alcohols are classified as primary (1°), secondary (2°) and tertiary alcohols (3°).*
- *The names of alcohols contain the suffix '-ol' which indicates the presence of –OH group in the molecule.*
- *Primary alcohols oxidize to give aldehydes and then carboxylic acids, and secondary alcohols yield ketones on oxidation.*
- *Organic chemicals have industrial applications such as in the production of alcoholic beverages and pharmaceuticals.*
- *Organic chemicals are also used in the production of fertilizers, pesticides and weed killers for agricultural uses.*
- *Organic chemicals are also used as fuels, and to produce soaps and detergents and also for dry cleaning.*

REVIEW EXERCISE ON UNIT 1

Part I: Nomenclature based problems

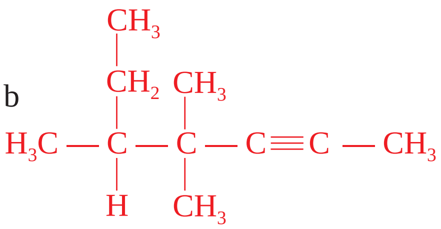
1. Give the IUPAC names of the following compounds:

a



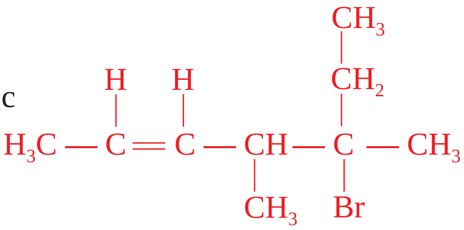
$$H_3C-\overset{Br}{\underset{H}{C}}-\overset{H}{\underset{CH_3}{C}}-CH_2-CH_2-\overset{H}{\underset{\underset{CH_3}{CH_2}}{C}}-CH_3$$

b

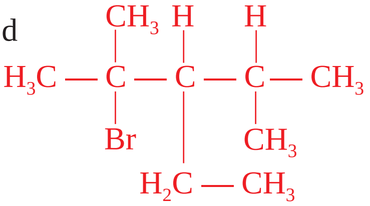


$$H_3C-\overset{\overset{CH_3}{CH_2}}{\underset{H}{C}}-\overset{CH_3}{\underset{CH_3}{C}}-C\equiv C-CH_3$$

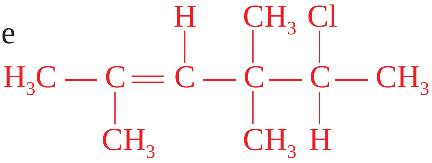
c



d

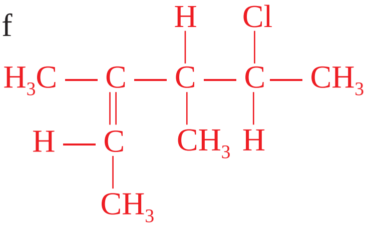


e

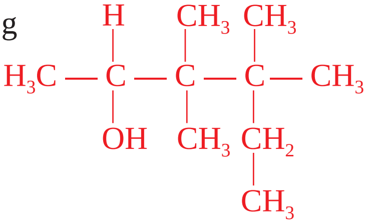


$H_3C-C(CH_3)=CH-C(CH_3)_2-CHCl-CH_3$

f



g



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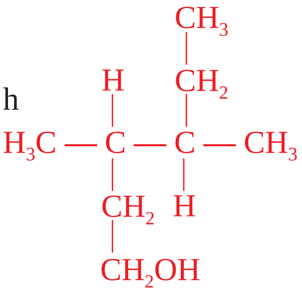


2. Write the structural formulas of the following compounds:

   a 3-bromo-2-chlorohex-1-ene

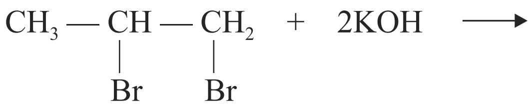
- b 4-ethyl-2,2,3-trimethylhexane
- c 2-methyl-2-butanol

3. Complete the following chemical equations:

a $CH_2{=}CH_2 + H_2 \xrightarrow[Heat]{Ni}$

b $CH_3COONa + NaOH \xrightarrow{CaO,\ heat}$

c $2CH_3{-}CH_2Br + 2Na \longrightarrow$

d 

$CH_3{-}\underset{\displaystyle Br}{\underset{|}{CH}}{-}\underset{\displaystyle Br}{\underset{|}{CH_2}} + 2KOH \longrightarrow$

e $CH_3CH_2CH_2OH \xrightarrow[Heat]{H_2SO_4}$

f $CH_3CH_2CH_2Cl + KOH \xrightarrow[Heat]{}$

g $HC{\equiv}CNa + CH_3CH_2Br \longrightarrow$

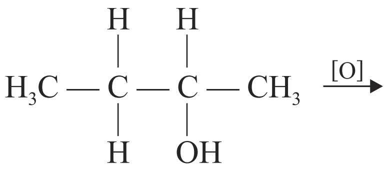
h $CH_3COOCH_2CH_3 + KOH \longrightarrow$

4. Complete the following reaction equations:

a $CH_3{-}CH{=}CH_2 + HBr \longrightarrow$

b $HC{\equiv}C{-}CH_2{-}CH_3 + 2HCl \longrightarrow$

c $CH_3{-}CH_2{-}CH{=}CH_2 + H_2O \xrightarrow{H^+}$

d 

$H_3C{-}\underset{\displaystyle H}{\underset{|}{\overset{\displaystyle H}{\overset{|}{C}}}}{-}\underset{\displaystyle OH}{\underset{|}{\overset{\displaystyle H}{\overset{|}{C}}}}{-}CH_3 \xrightarrow{[O]}$

e $CH_3{-}CH_2{-}CH{=}CH_2 + H_2O \xrightarrow[KMnO_4]{Alkaline}$

f $CH_3{-}CH_2{-}CH_2OH \xrightarrow{[O]}$

g $CH_3CH_2CH_2COOH + CH_3{-}CH_2{-}CH_2OH \longrightarrow$

h $C_6H_6 + Cl_2 \xrightarrow{FeCl_3}$

Part II: Multiple choice Type Questions

5. Which of the following hydrocarbons does not belong to the homologous series of alkanes?

a C_3H_8 b C_8H_{18} c C_6H_{10} d $C_{10}H_{22}$

6. Which of the following alkanes is a liquid at room temperature?

a CH_4 b $C_{10}H_{22}$ c C_4H_{10} d C_3H_8

7. The hydrocarbon used as a fuel in an oxyacetylene torch is:

a C_2H_2 b C_2H_4 c C_4H_{10} d CH_4

8. The general formula that represents the olefin homologous series is:

a C_nH_{2n+1} b C_nH_{2n+2} c C_nH_{2n-2} d C_nH_{2n}

9. The most common reaction that alkenes undergo is:

a elimination b substitution c addition d decomposition

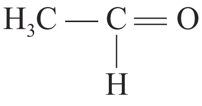
10. Benzene is an unsaturated hydrocarbon; it mainly undergoes:

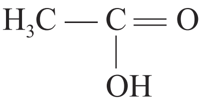
a addition b elimination c polymerization d substitution

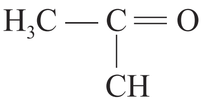
11. Which of the following compounds is an alkene?

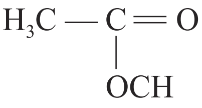
a $H_3C - CH_2 - CH_3$ b $H_2C = CH - CH_3$
c $HC \equiv C - CH_3$ d $CH_3 - CH_2 - CH_2 - OH$

12. Which of the following compounds is a ketone?

a 
$H_3C - \underset{\displaystyle H}{\underset{|}{C}} = O$

b 
$H_3C - \underset{\displaystyle OH}{\underset{|}{C}} = O$

c 
$H_3C - \underset{\displaystyle CH}{\underset{|}{C}} = O$

d 
$H_3C - \underset{\displaystyle OCH}{\underset{|}{C}} = O$

13. Which of the following classes of hydrocarbons is the most reactive?

a Alkynes b Alkanes
c Alkenes d Aromatic hydrocarbons

14. The compounds CH_3OH and CH_3COOH react in the presence of an acid catalyst to form:

a a carboxylic acid b an aldehyde
c a ketone d an ester

15. Which hydrocarbon is the main constituent of natural gas and biogas?

a C_4H_{10} b CH_4
c C_2H_6 d C_6H_{14}

16. During the fractional distillation of crude oil, the process of cracking is carried out to:

a separate the crude oil into different fractions

b vaporize the liquid components

c maximize the output of petrol or gasoline

d separate alkanes from alkenes

17. Ethyne decolorizes Br_2 in CCl_4. This is due to the formation of:

a 1,1-dibromoethane

b 1,1,2,2-dibromoethene

c 1,2-dibromoethane

d 1,1,2,2-dibromoethane

18. The following reaction can be classified as:

$$CH_4 + Br_2 \rightarrow CH_3Br + HBr$$

a an addition reaction

b an elimination reaction

c a substitution reaction

d a saponification reaction

19. Which one of the following substance is not used in dry cleaning?

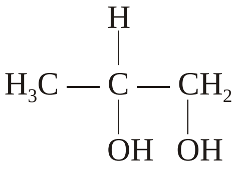
a CCl_4

b $Cl_2C == CCl_2$

c C_6H_6

d CH_3COOH

20. The compound with the structure



$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H_3C & — & C & — & CH_2 \\ & & | & & | \\ & & OH & & OH \end{array}$$

is a:

a secondary alcohol

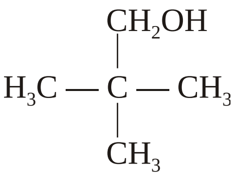
b trihydric alcohol

c carboxylic acid

d dihydric alcohol

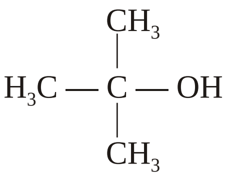
21. Which of the following alcohols is the easiest to dehydrate?

a



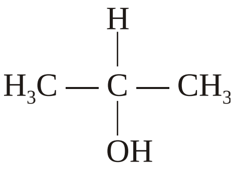
$$\begin{array}{ccccc} & & CH_2OH & & \\ & & | & & \\ H_3C & — & C & — & CH_3 \\ & & | & & \\ & & CH_3 & & \end{array}$$

b



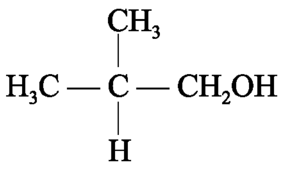
$$\begin{array}{ccccc} & & CH_3 & & \\ & & | & & \\ H_3C & — & C & — & OH \\ & & | & & \\ & & CH_3 & & \end{array}$$

c



$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H_3C & — & C & — & CH_3 \\ & & | & & \\ & & OH & & \end{array}$$

d



$$\begin{array}{ccccc} & & CH_3 & & \\ & & | & & \\ H_3C & — & C & — & CH_2OH \\ & & | & & \\ & & H & & \end{array}$$

22. Alcohols that yield ketones on oxidation are classified as:

a primary alcohols	b secondary alcohols
c dihydric alcohols	d trihydric alcohols

23. The first organic compound was synthesized in the laboratory by:

a Friedrich Wohler	b A. Kekule
c John Dalton	d Wurtz

Part III: Which of the following statements are true?

24. a A weed killer is a pesticide.
    b Carbon tetrachloride is used in dry cleaning.
    c Antiseptics are sleep inducing drugs.
    d ‘Tella’ is a distilled alcoholic beverage.
    e Soaps and detergents are surfactants.
    f Alkanes easily undergo addition reactions.
    g Benzene burns with a sooty flame.
    h Biogas mainly contains n-butane.

UNIT 2

Important Inorganic Compounds

Unit Outcomes

After completing this unit, you will be able to:

- *understand the classification of inorganic compounds on the basis of their composition and/or their chemistry;*
- *know the types of oxides and their chemical properties;*
- *understand the Arrhenius, Brønsted-Lowry and Lewis concepts of acids and bases;*
- *understand the classification of acids and salts;*
- *know the general properties, preparations and uses of common acids, bases and salts;*
- *understand the differences between strong and weak acids/bases, and concentrated and dilute acids/bases;*
- *recognize the corrosive nature of acids and bases, and exercise the necessary precautions in handling and using them;*
- *develop skills for identifying acidic, basic and neutral compounds;*
- *develop skills in calculating, pH, pOH, H^+ ion and OH^- ion concentration of a solution;*
- *know essential plant nutrients, fertilizers and pesticides; and*
- *demonstrate scientific inquiry skill: observing, classifying, comparing and contrasting, inferring, predicting, communicating, measuring, asking questions, interpreting data, drawing conclusion, applying concepts, relating cause and effect and problem solving.*

MAIN CONTENTS

2.1 INTRODUCTION

Competencies

By completing this section, you will be able to:

- define inorganic compounds; and
- classify inorganic compounds as oxides, acids, bases and salts.

Activity 2.1

In the laboratory, take samples of different compounds and classify them as organic and inorganic. When these compounds are burnt in air, it has been found that most organic compounds burn when heated in air, but most inorganic compounds just melt or vaporize; why? Discuss your observations in groups and share your opinion with the class.

Inorganic compounds are the compounds consisting of mineral constituents of the earth or generally found in non-living things. The term inorganic compound refers to all compounds that do not contain carbon. Although, carbon dioxide, carbon monoxide, carbonates and hydrogen carbonates are carbon-containing compounds, which are classified as inorganic compounds. Inorganic compounds are mostly found in nature as silicates, oxides, carbonates, sulphides, sulphates, chlorides and nitrates, etc.

There are different ways for the classification of inorganic compounds. They can be classified on the bases of their composition. For example; they can be classified on the basis of the:

i) metal they contain such as copper compounds, aluminium compounds, etc.

ii) non-metal they contain such as sulphur compounds, nitrogen compounds, etc.

iii) group they contain such as sulphates, nitrates, carbonates, etc.

This unit emphasizes on the four groups of inorganic chemicals namely oxides, acids, bases and salts.

Exercise 2.1

1. List some inorganic compounds with which you are familiar.
2. Which branch of chemistry is concerned with the study of all elements?

2.2 OXIDES

Competencies

After Completing this section, you will be able to:

- define oxides;
- classify oxides as acidic, basic, amphoteric, neutral and peroxides;
- define acidic oxides and give examples;
- explain the chemical properties of acidic oxides;
- define basic oxides and give examples;
- explain the chemical properties of basic oxides;
- conduct experiments to distinguish acidic oxides from basic oxides;
- compare and contrast acidic and basic oxides;
- define amphoteric oxides and give examples;
- explain the chemical properties of amphoteric oxides;
- discuss the salt forming nature of acidic, basic and amphoteric oxides;
- define neutral oxides and give examples;
- define peroxides and give examples;
- explain the chemical properties of peroxides; and
- conduct an experiment to distinguish peroxides from other oxides.

What are oxides? Oxygen reacts directly with almost all elements except the noble gases and inactive metals like gold, platinum, and palladium. Such compounds of oxygen are called oxides. Oxides are binary compounds containing oxygen and any other element (*metal, non-metal or metalloid*). Binary compounds are those consisting of only two elements. Examples of oxides are calcium oxide, CaO, aluminium oxide, Al_2O_3, sulphur dioxide, SO_2, and carbon monoxide, CO.

The classification of oxides into different groups is based on their chemical behaviour; they are classified as:

- Acidic oxides
- Basic oxides
- Amphoteric oxides
- Neutral oxides, and
- Peroxides

Exercise 2.2

Decide whether the following compounds are oxides or not:

a Na_2O

b KOH

c Ga_2O_3

d P_4O_6

e N_2O_4

f H_2O

g Na_2CO_3

h KNO_3

i H_2SO_4

Activity 2.2

1. The oxides, CO_2, N_2O_5, P_4O_{10}, SO_2 are acidic oxides.
   a Are these oxides formed by the combination of oxygen with
   i) metals ii) non-metals or iii) metalloids?
   b What general conclusion can you draw about the composition of acidic oxides?
2. The presence of CO_2 is confirmed by reacting CO_2 with lime water.
   a What is lime water? Is it a base or an acid?
   b Write a balanced chemical equation for the above reaction.
   c What type of oxides react with bases?

Discuss in your group and present your findings to the class.

A Acidic Oxides

Acidic oxides are the oxides formed by the chemical combination of oxygen with non-metals. Thus, acidic oxides are non-metal oxides. These oxides are also called acid anhydrides, since they form acidic solutions when reacted or dissolved in water. Acid anhydride means acid without water.

Generally speaking, acidic oxides are non-metal oxides. Examples of acidic oxides include carbon dioxide, CO_2, nitrogen dioxide, NO_2, and sulphur dioxide, SO_2. However, it is very important to note that all non-metal oxides are not necessarily acidic oxides. For example, carbon monoxide, CO, and di-nitrogen monoxide, N_2O, are non-metal oxides, but they are neutral oxides which will be discussed later.

Chemical Properties of Acidic Oxides

Acidic oxides undergo the following reactions:

1. Acidic oxides (*acid anhydrides*) dissolve in water to form acidic solution (*acid*).

   Acid anhydride + water → Acid

Examples

$CO_2 + H_2O \rightarrow H_2CO_3$ (*Carbonic acid*)
$N_2O_3 + H_2O \rightarrow 2HNO_2$ (*Nitrous acid*)
$SO_2 + H_2O \rightarrow H_2SO_3$ (*Sulphurous acid*)

2. Acidic oxides react with basic or metallic oxides to form salt.

   Acidic oxide + Basic oxide → Salt

Examples

$CO_2 + Na_2O \rightarrow Na_2CO_3$
$SO_3 + CaO \rightarrow CaSO_4$

3. Acidic oxides react with bases to form salt and water. This reaction is called neutralization reaction.

   Acidic oxide + Base → Salt + Water

Examples

$SO_2 + 2NaOH \rightarrow Na_2SO_3 + H_2O$
$CO_2 + 2LiOH \rightarrow Li_2CO_3 + H_2O$

Exercise 2.3

1. List five examples of acidic oxides.
2. Complete and balance the following equations.

   a $P_4O_6 + H_2O \rightarrow$

b $SO_3 + H_2O \rightarrow$

c $CaO + CO_2 \rightarrow$

d $Ca(OH)_2 + SO_3 \rightarrow$

e $NaOH + CO_2 \rightarrow$

B. Basic Oxides

Oxides that are composed of metals and oxygen are basic oxides. But, all metal oxides are not necessarily basic oxides; for example Al_2O_3 and ZnO are amphoteric oxides, which will be discussed in part (C).

Oxides of metals that dissolve in water and react with it to form basic or alkaline solutions are called basic anhydrides. There are metallic oxides which have basic properties but are insoluble in water. These oxides react with acids to give salt and water.

Example

$$FeO + 2HCl \rightarrow FeCl_2 + H_2O$$

The oxides of active metals, group IA and heavier members of group IIA, dissolve in water and readily form bases. The term base is used to describe both soluble and insoluble basic oxides. Some examples of basic oxides are Li_2O, Na_2O, K_2O, MgO, CaO, BaO, and CuO.

Chemical Properties of Basic Oxides

What common reaction do basic oxides undergo? What products do they form in their reactions with water, acidic oxides and acids?

1. Basic oxides dissolve in water to form alkaline solutions. As they dissolve, they react with water to form the corresponding metal hydroxides.

   Basic oxide + water → Base (Alkali)

Examples

$$Li_2O + H_2O \rightarrow 2LiOH$$

$$CaO + H_2O \rightarrow Ca(OH)_2$$

2. Basic oxides react with acidic oxides to form salts.

   Basic oxide + acidic oxide → salt

Examples

$$BaO + SO_3 \rightarrow BaSO_4$$

$$CaO + CO_2 \rightarrow CaCO_3$$

$$Na_2O + CO_2 \rightarrow Na_2CO_3$$

3. Basic oxides react with acids to form a salt and water.

   Basic oxide + Acid → salt + water

Example

$$CaO + 2HCl \rightarrow CaCl_2 + H_2O$$

$$CuO + H_2SO_4 \rightarrow CuSO_4 + H_2O$$

Exercise 2.4

1. Complete and balance the following chemical equations:

a $K_2O + H_2O \rightarrow$

b $MgO + H_2O \rightarrow$

c $Na_2O + CO_2 \rightarrow$

d $Li_2O + SO_2 \rightarrow$

e $BaO + H_2SO_4 \rightarrow$

f $CuO + HCl \rightarrow$

2. Classify the following oxides as basic or acidic:

a MgO

b BaO

c P_4O_{10}

d N_2O_5

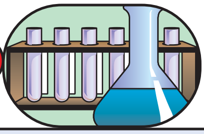
e Cu_2O

f Fe_2O_3

g K_2O

h SO_2

Experiment 2.1



Test for Acidity and Basicity of Oxides

Objective: To identify basic and acidic oxides.

Materials required: Deflagrating spoon, gas jar and gas jar lid, test tubes. Sulphur, magnesium or calcium metal, water, universal indicator, litmus paper (*blue* and *red*).

Procedure:

1. Ignite a small amount of powdered sulphur on a deflagrating spoon and insert in a gas jar of oxygen. Add 10 mL water after ignition is complete. Cover the gas jar with a lid and shake. Take two test tubes and pour 5 mL of the solution to each test tube. Add a few drops of universal indicator solution to the first test tube and blue litmus paper in the second.
2. Ignite a small amount of magnesium or calcium metal on a deflagrating spoon and insert in to a gas jar of oxygen. Add 10 mL water to the ash formed and shake. Take two test tubes and pour 5 mL of the solution to each of the test tubes. Add a few drops of universal indicator in the first and red litmus paper to the second test tube.

Observations and analysis:

a What compounds are formed by the combustion of sulphur and magnesium or calcium? Write chemical equations to show the reactions.

b What happens when water is added to the gas jars in which sulphur was burnt?

c What colours are observed by adding drops of universal indicator and blue or red litmus to the solutions in the test tubes?

d Why does the change in the colour of indicators occur in the various solutions?

Write a laboratory report and submit to your teacher.

Universal indicator and litmus paper serve as indicators. Indicators are substances used to identify whether a given solution is acidic or basic by showing colour changes. Table 2.1 shows some common indicators and the colour they develop in acidic and basic solutions.

Table 2.1 Some common indicators and their colours in acidic and basic solution.

Indicator	Colour in aqueous solution of acidic oxide	Colour in aqueous solutionof basic oxide
Universal Indicator	Yellow – Orange (*in weakly acidic*) and red (*in strongly acidic*)	Blue (*in weakly basic*) and purple (*in strongly basic*)
Litmus	Red	Blue
Phenolphthalein	Colourless	Pink (*red*)
Methyl orange	Red	Yellow

In addition to their effects on indicators, acidic and basic oxides can be identified by their chemical properties. Acidic oxides react with bases while basic oxides react with acids. But acidic oxides do not react with acids and basic oxides do not react with bases.

C. Amphoteric Oxides

Activity 2.3

1. How would you classify the oxides of period III elements?
2. What trend do you observe in the properties of oxides of the elements in a period as you go from left to right in the periodic table?

   Discuss this in your group and present to the class.

There are oxides which exhibit both acidic and basic properties. These are known as amphoteric oxides. In their reaction with acids, they behave as bases and, in their reaction with bases they act as acids. The following reaction shows the amphoteric behaviour of aluminium oxide, Al_2O_3.

Amphoteric oxide	+	Acid	→	salt	+	water
Al_2O_3 (s)	+	6HCl (aq)	→	$2AlCl_3$ (aq)	+	$3H_2O$ (l)
Amphoteric oxide	+	base	→	salt	+	water
Al_2O_3 (s)	+	2NaOH (aq)	→	$2NaAlO_2$ (aq) *sodium aluminate*	+	H_2O (l)

Some other examples of amphoteric oxides are ZnO, PbO, PbO_2, SnO, and SnO_2. It is also important to realize that hydroxides which react with both acids and bases are described as amphoteric substances. For example, aluminium hydroxide, $Al(OH)_3$, reacts with both acids and bases to form salt and water. So, $Al(OH)_3$, is amphoteric in nature.

What is the common characteristic of acidic, basic and amphoteric oxides? Acidic oxides form salts when reacted with basic oxides and bases. Basic oxides also produce salts in their reactions with acidic oxides and acids. Amphoteric oxides form salts when they react with acids and bases. Thus, acidic oxides, basic oxides and amphoteric oxides are salt-forming oxides.

Exercise 2.5

Write chemical equations to show the amphoteric properties of ZnO and PbO when they react with:

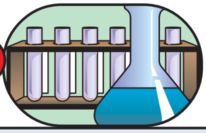
a HCl

b NaOH

c HNO_3

d KOH

Experiment 2.2



Investigating Amphoteric Behaviour of Oxides

Objective: To observe the amphoteric behaviour of Al_2O_3.

Materials required:

Spatula, reagent bottles, beakers, glass rod, Al_2O_3, HCl, NaOH, Universal indicator and water.

Procedure:

1. Prepare solutions by:
   - a mixing 20 mL concentrated HCl and 80 mL water in one reagent bottle;
   - b dissolving 8 g NaOH in 100 mL water in another reagent bottle.
   - c Add universal indicator to the acid and base, and observe the colour change.
2. Take two beakers and place a spatula full of Al_2O_3 in each of the beakers.
3. Pour the HCl solution (which you prepared) into one of the beakers and NaOH solution into the other. Stir the mixture with a glass rod.
4. Add universal indicator in the two beakers and observe the colour change.

Observations and analysis:

1. Does Al_2O_3 react with the substances in both solutions?
2. What does the change in colour of the indicator in the mixtures indicate?
3. Write chemical equations to show what has happened?

Write a laboratory report and present to the class.

D. Neutral Oxides

Neutral oxides react neither with acids nor with bases to form salt and water. Hence, neutral oxides do not show basic and acidic properties. Examples of neutral oxides are water, H_2O, carbon monoxide, CO, dinitrogen monoxide, N_2O, and nitrogen monoxide, NO. Neutral oxides are very few in number.

Activity 2.4

1. In a beauty saloon which chemical is used to decolorize hair? What is the oxidation number of oxygen in this compound?

2. If Na_2O_2 and CaO_2 are reacted with water, do you get the same compound, which is used to decolorize hair? Compare the oxidation number of oxygen in Na_2O and MgO with the oxidation number of the compound used for decolorizing hair.

   Discuss your findings in group and present to the class.

E. Peroxides

In acidic, basic, amphoteric and neutral oxides, the oxidation state of oxygen is –2, but in peroxides it is –1. In peroxides, the two oxygen atoms are linked to each other and with atoms of other elements. They contain the peroxide, "– O – O –" link. In the oxides discussed above, oxygen atoms are linked directly with atoms of other elements.

Some examples of peroxides are hydrogen peroxide, H_2O_2, sodium peroxide, Na_2O_2, calcium peroxide, CaO_2, barium peroxide, BaO_2, and strontium peroxide, SrO_2.

Most peroxides of metals are formed by burning the metals in a sufficient amount of oxygen.

$$2Na\ (s) + O_2\ (g) \rightarrow Na_2O_2\ (s)$$
$$Ca\ (s) + O_2\ (g) \rightarrow CaO_2\ (s)$$

Chemical Properties of Peroxides

What chemical properties do the peroxides exhibit? Some of the chemical properties of peroxides include:

a Peroxides are powerful oxidizing agents; they react with different substances by losing oxygen.

Examples

$$PbS\ (s) + 4H_2O_2\ (aq) \rightarrow PbSO_4\ (s) + 4H_2O\ (l)$$
$$2KI\ (aq) + H_2SO_4\ (aq) + H_2O_2\ (aq) \rightarrow I_2\ (s) + K_2SO_4\ (aq) + 2H_2O\ (l)$$

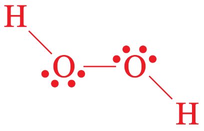
b Peroxides react with aqueous acids to form hydrogen peroxide.

Examples

$$Na_2O_2\ (s) + 2HCl\ (aq) \rightarrow 2NaCl\ (aq) + H_2O_2\ (aq)$$
$$CaO_2\ (s) + H_2SO_4\ (aq) \rightarrow CaSO_4\ (s) + H_2O_2\ (aq)$$

Hydrogen Peroxide

The structure of the hydrogen peroxide molecule is:



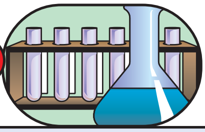
Hydrogen peroxide decomposes to release oxygen. This reaction is slow but can be speeded up by the addition of manganese (IV) oxide, MnO_2, as a catalyst.

$$2H_2O_2\,(aq) \rightarrow 2H_2O\,(l) + O_2\,(g)$$

Hydrogen peroxide is a strong oxidizing agent. Its oxidizing power is responsible for its effectiveness as an antiseptic for mouthwash and cleansing wounds. It is also used as a bleaching agent. When hydrogen peroxide is added to a coloured dye, the molecule responsible for the colour will oxidize and so the colour will disappear. For example, if hydrogen peroxide is added to a black dye (*paint*) that contains lead sulphide, PbS, the black colour turns white. This is due to the oxidation of PbS to $PbSO_4$. The equation for this process is:

$$PbS\,(s) + 4H_2O_2 \rightarrow PbSO_4 + 4H_2O\,(l)$$

Experiment 2.3



Distinguishing Peroxides from Other Oxides

Objective: To identify peroxides from other oxides.

Materials required: CaO or MgO, Al_2O_3 or ZnO or PbO, Na_2O_2 or BaO_2, P_4O_{10}, KI, dilute H_2SO_4, starch, water, reagent bottle, six beakers, dropper, and spatula.

Procedure:

1. Take three beakers. In the first beaker, dissolve 20 g KI in water to prepare a 250 mL solution. Dilute 2 mL concentrated H_2SO_4 by pouring it in 18 mL of water in the second beaker. Prepare starch solution in the third beaker by boiling 1g starch in 100 mL water.
2. Take four beakers and pour 50 mL KI solution to each of them. Acidify the solutions in each of the beakers by adding 5-10 drops of dilute H_2SO_4. Add a spatula full of CaO or MgO in the first, Al_2O_3 or ZnO or PbO in the second, Na_2O_2 or BaO_2 in the third and P_4O_{10} in the fourth beaker and then add about 5 mL starch solution to each of the four beakers.

Observations and analysis:

a In which beaker do you see a colour change?

b What is the cause of the colour change?

c Write a balanced chemical equation for the change?

Write a laboratory report and present to the class.

Exercise 2.6

1. Classify the following oxides as acidic, basic, amphoteric, neutral and peroxides:

   a K_2O
   b CO
   g MgO
   h N_2O
   i ZnO
   j BaO_2
   c SO_2
   d Al_2O_3
   k NO
   l PbO
   m Na_2O_2
   e CaO
   f NO_2
   n CaO_2
   o Li_2O
   p P_4O_6

2. Complete and balance the following equations:

   a $BaO + P_4O_{10} \rightarrow$
   b $SrO + SO_3 \rightarrow$
   c $CO_2 + KOH \rightarrow$
   d $ZnO + H_3PO_4 \rightarrow$
   e $Al_2O_3 + HNO_3 \rightarrow$
   f $CaO + HCl \rightarrow$
   g $PbO + NaOH \rightarrow$
   h $MgO + H_2SO_4 \rightarrow$

3. Which acidic oxide should react with water to form each of the following acids?

   a HNO_3
   b H_2CO_3
   c H_2SO_4
   d H_2SO_3
   e H_3PO_4
   f H_3PO_3

4. Identify the basic anhydrides that react with water to form each of the following bases:

   a $Ba(OH)_2$
   b $Sr(OH)_2$
   c $Mg(OH)_2$
   d $LiOH$
   e KOH
   f $CsOH$

5. How do peroxides differ from other groups of oxides?

6. How can you identify whether an oxide is acidic or basic?

2.3 ACIDS

Competencies

After completing this section, you will be able to:

- define acids in terms of Arrhenius, Brønsted-Lowry and Lewis;

- give examples of acids based on Arrhenius, Brønsted-Lowry and Lewis concepts;
- classify acids as monoprotic and polyprotic based on the numbers of ionizable hydrogen atoms;
- group acids as binary and ternary based on the number of elements they contain;
- explain the general properties of acids;
- define strong and weak acids;
- distinguish between strong and weak acids;
- define concentrated and dilute acids;
- describe the conceptual difference between strong and concentrated acids;
- use the necessary precautions while working with acids;
- define pH and describe the pH scale;
- identify a given pH labelled solution as acidic, basic or neutral;
- perform activities to determine the pH of some common substances using universal indicator or a pH-meter;
- calculate the pH of a given acidic solution;
- calculate the hydrogen ion concentration from the given information;
- perform activities to investigate some physical properties of acids;
- perform activities to investigate some chemical properties of acids;
- explain the direct combination of elements, the reaction of acidic oxides with water, formation of volatile acids from non-volatile acids as the three methods of preparation of acids;
- conduct simple experiments to prepare acids in a laboratory; and
- describe the uses of three common laboratory acids.

Activity 2.5

1. How do you describe an acid?
2. Give some examples of acids and bases that you have encountered in your everyday life?
3. List as many sour foods as possible which you have ever tasted.
4. In which form does the hydrogen ion, H^+, exist in aqueous solutions?

Discuss with your group and present it to the class.

Acids are among the most familiar of all chemical compounds. Acetic acid in vinegar, citric acid in lemons and other citrus fruits, are among the acids that we encounter every day. Hydrochloric acid is the acid in gastric juice; it is essential to digestion. Phosphoric acid gives flavour to many carbonated beverages.

Definitions of Acids

a Arrhenius Definition of Acids

The simplest definition of acids is suggested by Savante Arrhenius, a Swedish Chemist. Arrhenius defined an acid as a substance that releases hydrogen ion or proton, H^+, or hydronium ion, H_3O^+, in aqueous solution.

Example

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

or,

$$HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$$

Some examples of Arrhenius acids are HCl, HNO_3, H_2SO_4, HI, HBr, and HF. For a substance to be called an Arrhenius acid, it should contain ionizable hydrogen.

Despite its early success and usefulness, the definition of an acid, first proposed by Arrhenius has some limitations. The Arrhenius definition of acids explains their behaviour only in aqueous solution. In addition, it does not explain why some substances show acidic behaviour in the gaseous state and in non-aqueous solutions.

For example, when ammonia and hydrogen chloride gases are brought together, they react to form ammonium chloride as follows:

$$NH_3\,(g) + HCl\,(g) \rightarrow NH_4Cl\,(s)$$

In this reaction, the hydrogen chloride provides hydrogen ion (or proton), H^+, which reacts with NH_3 to form NH_4^+. But, this happens in the gaseous state not in aqueous solution. Due to the limitations of Arrhenius' definition, chemists tried to define acids in a more general way.

Brønsted-Lowry Definition of Acids

A broader and more general definition of acids was provided independently in 1923, by Johannes Brønsted and Thomas M. Lowry. According to Brønsted-Lowry definition; an acid is a substance that donates protons, H^+, to some other substance.

Examples

$$HCl\,(aq) + H_2O\,(l) \rightarrow H_3O^+\,(aq) + Cl^-\,(aq)$$

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

$$H_3PO_4\,(aq) + 2H_2O\,(l) \rightleftharpoons HPO_4^{2-}\,(aq) + 2H_3O^+\,(aq)$$

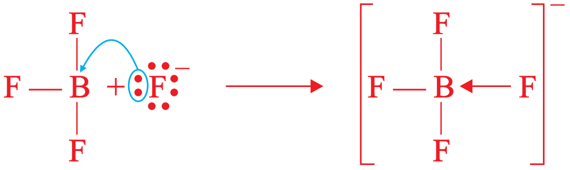
In the above reactions, HCl in the first, H_2O in the second and H_3PO_4 in the third are Brønsted-Lowry acids because they are proton donors. Here it is very important to realize that all Arrhenius acids are Brønsted-Lowry acids. However, the reverse is not true because Brønsted-Lowry acids include substances that are not acids according to Arrhenius.

Although the Brønsted-Lowry definition of an acid is more general than the definition proposed by Arrhenius, it still depends on the transfer of protons. However, the presence of acids that are not proton-donors, initiated chemists to search for another definition of acids.

b Lewis Definition of Acids

In 1923, the American chemist Gilbert Newton Lewis produced a definition of acid that extends the concept of acids even further than that of Brønsted-Lowry.

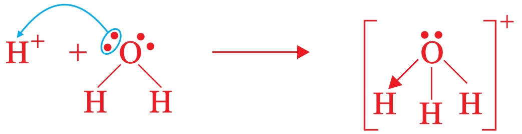
According to Lewis, an *acid is a substance that can form a coordinate covalent bond by accepting an electron pair from another* substance. In other words, an acid is an electron-pair acceptor. Consider the following reactions:



Lewis acid

In the above reaction, between BF_3 and F^-, BF_3 acts as a Lewis acid since it accepts a pair of electrons from F^-.

The Lewis definition of an acid is also valid for the Arrhenius concept of an acid. This is because as the acid releases an hydrogen ion, H^+, in aqueous solution, the released proton or H^+ accepts a pair of electrons from a water molecule to form an hydronium, H_3O^+ ion.

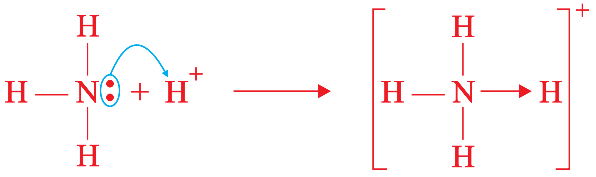


Lewis acid Hydronium ion

The Lewis definition of an acid is also valid for the Brønsted-Lowry concept of acids. Since Brønsted-Lowry defined an acid as a proton donor, the donated proton can be accepted by a molecule or species that has lone pair of electrons. So the proton, H^+, is an electron pair acceptor and hence a Lewis acid. Consider the following reaction.

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

In this reaction, H_2O is a proton donor and hence a Brønsted-Lowry acid. The donated proton from water to ammonia, accepts a pair of electrons from the nitrogen atom in NH_3 to form NH_4^+ as shown below:



Lewis acid

The Lewis concept of acids not only includes H^+ as an acid, but also ions or molecules capable of accepting an electron pair that neither release H^+ in aqueous solution nor donate a proton.

Classification of Acids

Activity 2.6

Phosphoric acid, H_3PO_4, has three hydrogen atoms and it is a triprotic acid. Acetic acid, CH_3COOH, has four hydrogen atoms and is classified as a monoprotic acid. Discuss the reason in your group and present it to the class.

There are different ways of classifying acids; they can be classified depending on the number of replaceable (*ionizable*) hydrogen atom(s) they contain per molecule as monoprotic or polyprotic acids.

Monoprotic acids are the acids containing only one ionizable (replaceable) hydrogen atom per molecule or those acids that can furnish only one hydrogen *ion per molecule in aqueous solution*. Common examples of monoprotic acids are HCl, HNO_3, HBr, HI, and CH_3COOH. The ionization of a monoprotic acid in aqueous solution is presented using HCl and HNO_3 as specific examples, as shown below:

$$HCl\,(aq) \rightarrow H^+\,(aq) + Cl^-\,(aq)$$

$$HNO_3\,(aq) \rightarrow H^+\,(aq) + NO_3^-\,(aq)$$

Polyprotic acids are those acids containing more than one ionizable (*replaceable*) hydrogen ion in aqueous solution. Example of acids in this category includes H_2SO_4, H_2CO_3, and H_3PO_4.

The ionization of polyprotic acids in aqueous solution is shown in the following chemical equations:

$$H_2SO_4\,(aq) \rightarrow 2H^+\,(aq) + SO_4^{2-}\,(aq)$$

$$H_2CO_3\,(aq) \rightleftharpoons 2H^+\,(aq) + CO_3^{2-}\,(aq)$$

$$H_3PO_4\,(aq) \rightleftharpoons 3H^+\,(aq) + PO_4^{3-}\,(aq)$$

Polyprotic acids which contain two ionizable hydrogen atoms such as H_2SO_4, H_2S, and H_2CO_3 are also called diprotic acids; those containing three ionizable hydrogen atoms like H_3PO_4 are called triprotic acids.

Activity 2.7

Ammonia and phosphoric acid have three hydrogen atoms but ammonia does not behave as triprotic acid. Why? Discuss in your group and present it to the class.

Acids can also be classified depending on the number of their constituent elements as binary and ternary acids. Binary acids are those acids composed of only two elements. Examples of binary acids are HCl, HBr, HF, HI, and H_2S.

Ternary acids also called oxy-acids are acids composed of three different elements. They usually contain hydrogen, oxygen and a non-metal. Examples are H_2SO_4, H_2CO_3, $HClO_4$, and H_3PO_4.

General Properties of Acids

Activity 2.8

Add a drop of lemon juice on your tongue and try to identify its taste. Repeat your observation with orange juice. Do the two juices taste bitter or sour? Try to classify them as acid or base, depending on their taste. Share your observations with the rest of class.

Acids generally have the following properties:

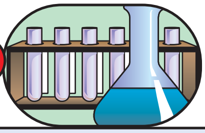
1. *Acids have a sour taste*

Aqueous solutions of acids have a sour taste. Lemon juice and orange juice taste sour due to the presence of citric acid. Citric acid is harmless. However, most concentrated acids are corrosive and poisonous. So it is strictly forbidden to attempt to identify such acids by tasting them.

2. *Acids change the colour of indicators*

The common indicators available in high school laboratories are litmus, phenolphthalein, methyl orange or methyl red and universal indicator. The effect of acids on the colour of indicators is summarized in Table2.1, Section 2.2.

Experiment 2.4



Effect of Acids on Indicators

Objective: To detect acidity of a solution using indicators.

Materials required: Lemon juice, dilute HCl, dilute HNO_3, dilute H_2SO_4 phenolphthalein, litmus, methyl red, universal indicator, test tubes, test tube rack, test tube holder, and reagent bottles.

Procedure:

Take four clean test tubes and place some lemon juice in the first, dilute HCl in the second, dilute HNO_3 in the third and dilute H_2SO_4 in the fourth. Dip a strip of blue litmus paper into each of the four test tubes and observe. Follow the same procedure and repeat the experiment until each acid has been tested by each indicator. Record your observation.

Observations and analysis:

What colours have you observed when each indicator was added to each of the four acid solutions? Use the following Table to record your observation:

	Colour of indicator in			
Indicator	**Lemon juice**	**dilute HCl**	**dilute HNO_3**	**dilute H_2SO_4**
Phenolphthalein				
Litmus				
Methyl red				
Universal indicator				

Write a laboratory report and present to the class.

3. *Acids react with active metals to form salt and hydrogen gas*

Metals like magnesium, zinc, and iron react with dilute acids to form salt and liberate hydrogen gas.

Acid + Active metal → Salt + Hydrogen gas

Examples

$$2HCl + Zn \rightarrow ZnCl_2 + H_2$$

$$H_2SO_4 + Mg \rightarrow MgSO_4 + H_2$$

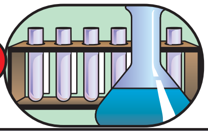
Very active metals like sodium, potassium, and calcium react very violently with dilute acids. The reaction is very dangerous and should not be performed.

Acids reacting with metals do not necessarily produce hydrogen gas. For example, concentrated nitric acid and hot concentrated sulphuric acid react with copper producing nitrogen dioxide and sulphur dioxide gases, respectively, instead of hydrogen. This is because concentrated HNO_3 and hot concentrated H_2SO_4 are oxidizing acids. The reactions of these acids with copper are given by the following equations:

$$Cu + 4HNO_3 \rightarrow Cu(NO_3)_2 + 2NO_2 + 2H_2O$$

$$Cu + 2H_2SO_4 \rightarrow CuSO_4 + SO_2 + 2H_2O$$

Experiment 2.5



Investigating the Reactions of Metals with Dilute Acids

Objective: To investigate the reaction between active metals and dilute acids.

Materials required: Dilute H_2SO_4, dilute HCl, zinc, magnesium and iron, test tubes, test tube holder, test tube rack, burner, wooden splint, spatula.

Procedure:

Take three test tubes and place a spatula-full of powdered zinc in the first, powdered magnesium in the second and iron filings in the third. Pour dilute HCl into each of the test tubes until the metals are completely covered by the acid. To test the type of gas evolved, cover one of the test tubes with a piece of cardboard for a few seconds. Bring a burning splint close to the mouth of the test tube and remove the cardboard.

Repeat the experiment with dilute H_2SO_4 after placing each of the three metals in three different test tubes.

Observations and analysis:

- a What does the formation of bubbles indicate?
- b What sound do you hear when the burning splint is close to the mouth of the test tube?
- c Which gas is evolved during the reaction?
- d Which metal's reaction with dilute HCl or H_2SO_4 is the most violent?

Write a laboratory report on your observations and present to the class.

4. *Acids react with carbonates and hydrogen carbonates to form salt, water and carbon dioxide gas*

Acid + hydrogen carbonate → salt + water + carbon dioxide

Acid + carbonate → salt + water + carbon dioxide

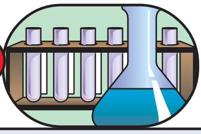
Examples

$$2HCl + MgCO_3 \rightarrow MgCl_2 + H_2O + CO_2$$

$$H_2SO_4 + Ca(HCO_3)_2 \rightarrow CaSO_4 + 2H_2O + 2CO_2$$

$$2HNO_3 + Na_2CO_3 \rightarrow 2NaNO_3 + H_2O + CO_2$$

Experiment 2.6



Reactions of Acids with Carbonates and Hydrogen Carbonates

Objective: To investigate the reaction between acids and carbonates and bicarbonates.

Materials required: Sodium carbonate, calcium carbonate, calcium or magnesium or sodium bicarbonate, dilute HCl, dilute H_2SO_4, dilute HNO_3, lime water ($Ca(OH)_2$ solution) blue and red litmus paper, conical flask, delivery tube, rubber stopper, beaker.

Procedure:

1. Take three conical flasks and add powdered Na_2CO_3 in the first, powdered $CaCO_3$ to the second and powdered sodium bicarbonate to the third. Pour dilute HCl into each of the three conical flasks until the acid covers the carbonates and bicarbonate. Hold damp blue litmus paper close to the mouth of the conical

flasks. Repeat this with damp red litmus paper and record your observations. Bubble the gas through limewater as shown in Figure 2.1.

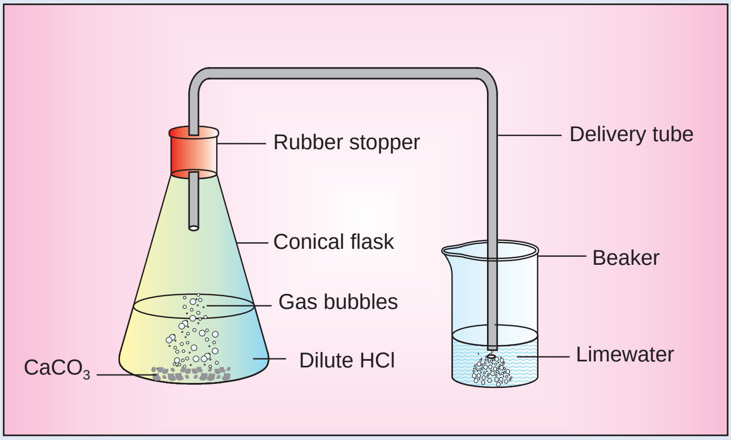


Figure 2.1 Test for Carbon dioxide.

2. Repeat the experiment using the same carbonates and hydrogencarbonate with dilute H_2SO_4 and dilute HNO_3.

Observations and analysis:

a What does the formation of bubbles in the conical flasks indicate?

b Does the colour of the damp blue litmus paper change when you hold it close to the mouth of the conical flasks? What about the colour of damp red litmus?

c What happened to the colour of lime water when you bubble the gas through it? If there was any change, what did it prove? Write a balanced chemical equation for the change?

Write a laboratory report on your observation and present to the class.

5. *Concentrated acids react with sulphites liberating sulphur dioxide gas and forming a salt and water*

Sulphite + Acid → Sulphur dioxide + Salt + Water

Examples

$$Na_2SO_3 + 2HCl \rightarrow SO_2 + 2NaCl + H_2O$$

$$CaSO_3 + H_2SO_4 \rightarrow SO_2 + CaSO_4 + H_2O$$

6. *Acids neutralize basic oxides and bases or alkalis to form salt and water*

The reaction of acids with basic oxides or bases to form salt and water is called neutralization reaction.

Acid + Basic oxide → Salt + Water

Examples

$2HCl + MgO \rightarrow MgCl_2 + H_2O$

$H_2SO_4 + CaO \rightarrow CaSO_4 + H_2O$

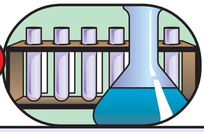
Acid + *Base* → *Salt* + *Water*

Examples

$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$

$HNO_3 + KOH \rightarrow KNO_3 + H_2O$

Experiment 2.7



Neutralization Reaction

Objective: Investigate the reaction between acids and bases

Materials required: 1 M HCl, 1 M NaOH, 0.5 M $Ca(OH)_2$, red and blue litmus papers, four 150 mL beakers, two droppers, stirring rod, two watch glasses.

Procedure:

1. Make 1 M NaOH solution by dissolving 4.0 g NaOH in enough water to make 100 mL solution.
2. Make a 1 M HCl solution by dissolving 8.3 mL of concentrated HCl in enough distilled water until the volume of the solution is 100 mL.
3. Dissolve 3.7 g of $Ca(OH)_2$ in enough distilled water to make 100 mL solution.
4. To a 150 mL beaker add 10 mL HCl solution and 9.5 mL NaOH solution and stir thoroughly and test with blue and red litmus paper. Continue adding NaOH solution dropwise using a dropper, stirring after each addition and checking with red and blue litmus until the blue remains blue and the red stays red. Put 2 mL of the neutral solution in a watch glass and allow the water to evaporate until the next day.
5. To another 150 mL beaker add 10 mL Ca $(OH)_2$ solution and 9.5 mL HCl solution. Repeat all the steps, which you followed in procedure 4.

Observations and analysis:

- a Is there any colour change, when you dip blue and red litmus papers into the solution of the acid and the base?
- b Why is it necessary to add NaOH solution dropwise (one drop at a time) in procedure 4?
- c During this experiment, under what conditions does the blue litmus remain blue and the red remain red?
- d What are the products formed in procedures 4 and 5? Write balanced chemical equations for the reactions?

Write a laboratory report on your observations and submit to your teacher.

7. *Acids are electrolytes* They conduct electricity in aqueous solutions.

Strength of Acids (Strong and Weak Acids)

Activity 2.9

1. Add a few drops of citric acid solution and nitric acid separately on a piece of waste cotton cloth; what happens? Based on your observations, can you classify these acids as weak acid or strong acid?
2. You are allowed to taste some acids like acetic acid (in the form of vinegar), and citric acid at home, but you are never allowed to taste any kind of acids in the laboratory. What is the reason?

Discuss your findings in your group and present to the class.

Acids can be classified as strong acids and weak acids *depending on their degree of ionization in aqueous solution*, i.e., the extent to which the acids dissociate to form hydrogen or hydronium ions when they dissolve in water. A strong acid is one that ionizes almost completely in aqueous solution. Examples of strong acids are $HClO_4$, HI, HBr, HCl, HNO_3, and H_2SO_4. These acids dissociate to a very high extent as shown below:

$$HCl\,(aq) \rightarrow H^+\,(aq) + Cl^-\,(aq)$$

$$HNO_3\,(aq) \rightarrow H^+\,(aq) + NO_3^-\,(aq)$$

$$HClO_4\,(aq) \rightarrow H^+(aq) + ClO_4^-\,(aq)$$

A dilute aqueous solution of strong acids contains predominantly the ions derived from the acids instead of the acid molecules. For example, HCl and HNO_3 are almost completely ionized in water.

An acid that releases few hydrogen ions in aqueous solution is a weak acid. The aqueous solution of a weak acid contains hydronium ions, anions and dissolved molecules of the acid.

Organic acids which contain the acidic carboxyl group –COOH, are generally weak acids. For example, CH_3COOH, ionizes slightly in water to give hydronium ions and acetate ions, CH_3COO^-.

$$CH_3COOH\ (aq) + H_2O(l) \rightleftharpoons CH_3COO^-\ (aq) + H_3O^+(aq)$$

Concentrated and Diluted Acids

Activity 2.10

1. In a solution, if there is 95% H_2O and the rest is HCl, what kind of solution is it?
2. In a car battery, the electrolyte used is 35% of H_2SO_4. How many percent of it is water? What do you think about the concentration of the electrolyte?

"Concentrated" and "dilute" are terms used to describe the relative amount of acid in a given acid solution.

A concentrated acid contains a relatively large amount (*percentage*) of acid and a small amount of water. For example, concentrated sulphuric acid is 98% H_2SO_4 and 2% water. Concentrated acetic acid is 99% acetic acid and 1% water. But, H_2SO_4 is a strong acid and CH_3COOH a weak acid.

A dilute acid contains a relatively small amount of acid dissolved in large amount of water. For example, a diluted solution of sulphuric acid may contain 10% H_2SO_4 and 90% H_2O.

The concentration of an acid is the measure of the number of moles of the acid in one litre of acid solution and is expressed in mol/L. This unit of concentration is called Molarity, denoted by M. Mathematically,

$$\text{Molarity (M)} = \frac{\text{Number of moles of the substance dissolved}}{\text{Volume of solution in litres}}$$

$$\text{Number of moles of the substance} = \frac{\text{Mass of the substance dissolved in grams}}{\text{Molar mass of the substance}}$$

For example, the concentration of 98% H_2SO_4 is about 18 mol/L. If one litre of this acid is added to 2 litres of water to make 3 litres of solution, the concentration will become 6 mol/L. The new solution obtained is a dilute solution of H_2SO_4. Thus, concentrated acids contains a greater number of moles of acid while dilute acids contain less number of moles of the acid per litre of the acid solution.

Example

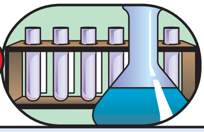
How many moles of HCl are present in 0.8 L of a 0.5 *M* HCl solution?

Solution:

$M = \dfrac{n}{V} \Rightarrow n = MV = 0.5\ M \times 0.8\ \text{L} = 0.4$ mol HCl, where *M* is the molarity, *n*, the number of moles and *V*, volume of solution in litre.

An important aspect of the property of acids is that they conduct electricity in aqueous solutions, i.e., the acids are electrolytes. The extent of conduction of electricity depends on the amount of ions present in the solution. Thus, aqueous solutions of strong acids are better conductors of electricity than the same concentrations of weak acid solutions. The conduction of electricity through acid solution is also used as one means of identification between weak and strong acids.

Experiment 2.8



Can Aqueous Acid Solution Conduct Electricity?

Objectives: To investigate the conductivity of acids

Materials required: 1 M HCl, 1 M HNO_3, 1 M CH_3COOH, three 150 mL beakers, two graphite electrodes, insulated electric wires, two dry cells, and bulb

Procedure:

Take about 100 mL of 1 M HCl in the first beaker, the same volume and concentration of HNO_3 and CH_3COOH in the second and third beakers respectively.

Arrange the set up as shown in Figure 2.2. First test the conduction of electricity through HCl solution by inserting the two graphite electrodes. See whether the bulb glows or not. Is the light bright or dim? Record your observation. Repeat the same activity with HNO_3 and CH_3COOH. Rinse the electrodes after use in each of the acid solutions. Compare the intensity of light produced with HNO_3 and CH_3COOH.

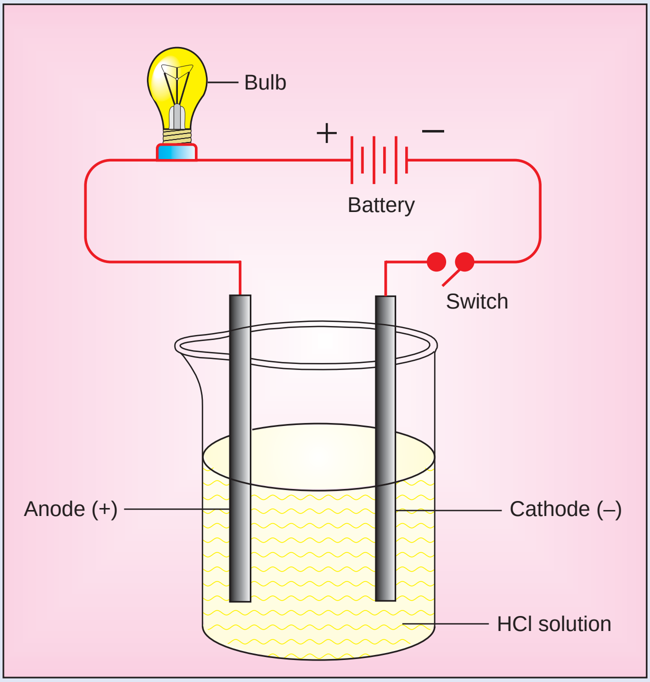


Figure 2.2 Conductivity of acid solution.

Observations and analysis:

a In which of the acid solutions does the bulb produce:

i) bright light? *ii)* dim light?

b What conclusions can you draw from your observations?

Write a laboratory report on your observations and present to the class.

Precautions when Handling Acids

Concentrated acids are extremely corrosive and poisonous. They can destroy metals and clothes; produce a chemical burn on skin or inside the body. If taken internally they can be fatal. So acids must be handled with care.

The following precautions are helpful while working with acids:

a Wear goggles, gloves and a laboratory coat.

b If a concentrated acid is spilled or splashed on your body, first wash the affected part with running water and then with 10% Na_2CO_3 solution.

c If concentrated acid is spilled on to cloth, immediately wash it with running water.

d If an acid enters your eye, wash with water repeatedly and then consult a doctor.

e If corrosive acids are swallowed, administer weak bases such as $Mg(OH)_2$ or $Al(OH)_3$.

f Use bellows to pipette acid instead of sucking using yours lips.

g To dilute concentrated acids, pour the concentrated acid in to water and not water in to the acid.

pH and pH scale

Expressing acidity as the concentration of H_3O^+ can be cumbersome because the values tend to be very small. A more convenient quantity called pH is used to indicate the concentration of H_3O^+. The letter pH stands for the French words *pouvoir hydrogène*, meaning "hydrogen power".

pH is defined as the negative logarithm of the *hydrogen ion* concentration (*hydronium ion concentration*). The mathematical expression is:

$$pH = \log \frac{1}{[H^+]} = -\log [H^+]$$

The square bracket [ ] means concentration in mol/L.

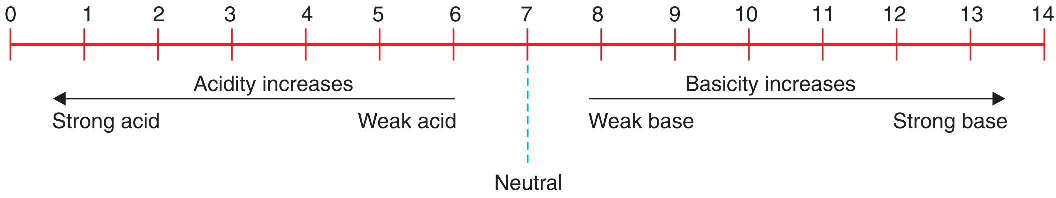
To calculate the hydrogen ion concentration of a solution from its pH we can proceed as follows.

$$[H^+] = \text{antilog}\ (-pH) = 10^{-pH}$$

The pH of a solution can be measured using universal indicator solution, pH indicator paper or a pH-meter. When universal indicator solution or pH indicator papers are added to an acid solution, they develop different colours depending on the pH of the solution. So, to identify the pH, we need to compare the colour developed with the standard colour chart. A pH meter is an electronic device, which reads the pH of a solution directly. (Figure 2.3).

Figure 2.3 ***a) The colour of universal indicator in solutions of pH from 1 to 12, b) A pH meter with its electrical probe dipped into an orange.***

Acidity and alkalinity are usually expressed on the pH scale. The range is between 0 and 14.



A neutral solution has a pH value of 7 at 298 K. Acidic solutions have pH values less than 7. As the pH value decreases the acidity of the solution increases. For example, if two solutions A and B have pH values of 4 and 6, respectively, then we can conclude that solution A is more acidic than solution B. The hydrogen ion concentration in solution A is one hundred times greater than that in B.

The following examples will guide us through how to calculate pH values of solutions.

Example

Calculate the pH of a 0.001 M solution of HCl?

Solution:

HCl is a strong acid and dissociates almost completely.

The dissociation of 0.001 M (0.001 mol/L) of HCl produces 0.001 mol/L of H^+ and 0.001 mol/L of Cl^- as follows:

$$\begin{array}{ccccc} HCl\ (aq) & \rightarrow & H^+(aq) & + & Cl^-\ (aq) \\ 0.001\ mol/L & & 0.001 mol/L & & 0.001\ mol/L \end{array}$$

Thus, $[H^+] = 0.001\ mol/L = 1 \times 10^{-3}\ M$

$pH = -\log [H^+] = -\log 1 \times 10^{-3} = 3$

Example

The hydrogen ion concentration in a dilute solution of vinegar is 4.6×10^{-5} M. What is the pH of the solution?

Solution:

$pH = -\log [H^+] = -\log (4.6 \times 10^{-5}) = -(\log 4.6 + \log 10^{-5})$

$= -(\log 4.6 - 5) = -(0.663 - 5) = 4.337$

Example

The pH of lemon juice was determined to be 3. What is the hydrogen ion concentration in the lemon juice?

Solution:

$\text{pH} = -\log[\text{H}^+]$; $\quad -\text{pH} = \log[\text{H}^+]$

$[\text{H}^+] = \text{antilog}(-\text{pH}) = 10^{-\text{pH}} = 10^{-3}\text{M}$

Exercise 2.7

1. The pH of a given solution is 8. What is the hydrogen ion concentration of the solution?
2. Two solutions A and B have pH values of 2 and 6 respectively. How many times greater is the hydrogen ion concentration in solution A than that of solution B?

Experiment 2.9

pH of Solutions of Common Substances

Objective: To determine the pH of different substances

Materials required: Lemon juice, vinegar, tonic water, tomato juice, beakers, and universal indicator solution or pH indicator paper

Procedure:

Take four beakers and place lemon juice in the first, vinegar solution in the second, tonic water in the third and filtered tomato juice solution in the fourth. Then pour a few drops of universal indicator solution or dip a piece of pH indicator paper into each of the solutions. Compare the colour developed with standard colour chart to decide the pH of each solution.

Observations and analysis:

a What is your conclusion based on your observations?

b Are the substances used in this experiment acidic or neutral? Why?

c Record your observations using the following Table:

Substance	Colour developed	pH
Lemon juice		
Vinegar solution		
Tonic water		
Tomato juice		

Write a laboratory report on your observations and present to the class.

Preparation of Acids

Acids can be prepared by:

1. **The reaction of oxides of non-metals (acidic oxides) and water:**

   Acidic oxide + Water → Acid

Examples

$$SO_2\,(g) + H_2O\,(l) \rightarrow H_2SO_3\,(aq)$$
$$N_2O_5\,(s) + H_2O\,(l) \rightarrow 2HNO_3\,(aq)$$
$$P_4O_{10}\,(s) + 6H_2O\,(l) \rightarrow 4H_3PO_4\,(aq)$$

2. **Direct combination of some non-metals like S, Cl, Br with hydrogen:** This method is mostly used to prepare binary acids (acids consisting only two elements)

Examples

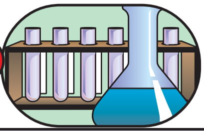
$$H_2\,(g) + Cl_2\,(g) \rightarrow 2HCl\,(g)$$
$$H_2\,(g) + Br_2\,(g) \rightarrow 2HBr\,(g)$$

When gaseous hydrogen chloride and hydrogen bromide dissolve in water, they form hydrochloric acid and hydrobromic acid respectively.

3. **Using a non-volatile acid:** Volatile acids can be prepared by heating their salts with a non-volatile acid such as concentrated sulphuric acid, H_2SO_4. Hydrochloric acid HCl and nitric acid, HNO_3 can be prepared by this method according to the following equations.

$$NaCl\,(s) + H_2SO_4\,(l) \rightarrow NaHSO_4\,(s) + HCl\,(l)$$
$$NaNO_3\,(s) + H_2SO_4\,(l) \rightarrow NaHSO_4\,(s) + HNO_3\,(l)$$

Experiment 2.10



Preparation of Chlorous Acid

Objective: To investigate the product formed from $Ba(ClO_2)_2$ and H_2SO_4

Materials required: Two 250 mL beakers, glass rod, water, dropper, test tubes, test tube rack, blue and red litmus papers, methyl red, $Ba(ClO_2)_2$ and concentrated H_2SO_4.

Procedure:

1. Dissolve 12 g $Ba(ClO_2)_2$ to prepare 100 mL solution in one beaker. Dilute 2 mL concentrated H_2SO_4 with water to prepare 50 mL of dilute H_2SO_4 solution in the second beaker.
2. Add 80 mL of $Ba(ClO_2)_2$ solution to the dilute solution of H_2SO_4 in the second beaker. Is there any formation of the white precipitate? What do you think is the precipitate formed? Wait for some time till the precipitate settles. Continue adding $Ba(ClO_2)_2$ solution using a dropper, one drop at a time until formation of white precipitate stops. After all the precipitate settles, take 5 mL of the clear liquid in a test tube and test with litmus or methyl red.

Observations and analysis:

a Is the final solution acidic or basic?
b Which acid is formed?
c Write a balanced chemical equation for the reaction.

Write a laboratory report as a group and present to the class.

Reading assignment

Refer to chemistry books from the library and write the uses of sulphuric acid, nitric acid and hydrochloric acid.

Uses of some important acids

Activity 2.11

1. List uses of some common acids in your daily life.
2. High consumption of sulphuric acid in a country indicates the economic growth of the country. What is the reason? Discuss in groups and present to the class.

Hydrochloric Acid, HCl is present naturally in the gastric juice of our body and helps in the digestion of food. Industrially, hydrochloric acid is important for pickling of iron and steel (*to remove surface impurities*) before galvanizing and tin plating. It is also used to produce aniline dyes, drugs, photographic films, plastics like polyvinyl chloride (PVC), and to recover magnesium from sea water.

Nitric Acid, HNO_3 is used industrially in the manufacture of explosives such as trinitrotoluene (TNT) and trinitroglycerine, fertilizers such as KNO_3 and NH_4NO_3, rubber, chemicals, plastics, dyes and drugs.

Sulphuric acid, H_2SO_4 is the leading industrial chemical. It is widely used in the production of sulphate and phosphate fertilizers, synthetic fibres, paints, drugs, detergents, paper and dyes. It is also used in petroleum refining, production of metals and as electrolyte in car batteries.

Exercise 2.8

1. Which one of the following substances are Arrhenius acids:

   a $HClO_4$

   b HI

   c HBr

   d BF_3

   e HF

   f PCl_5

2. In each of the reactions listed below, identify the Brønsted-Lowry acid:

   a $CH_3COOH\ (aq) + H_2O\ (l) \rightleftharpoons CH_3COO^-\ (aq) + H_3O^+\ (aq)$

   b $HCN\ (aq) + SO_4^{2-}\ (aq) \rightleftharpoons CN^-\ (aq) + HSO_4^-\ (aq)$

   c $HF\ (aq) + NH_3\ (g) \rightleftharpoons F^-\ (aq) + NH_4^+\ (aq)$

   d $HClO_4\ (aq) + N_2H_4\ (aq) \rightleftharpoons ClO_4^-\ (aq) + N_2H_5^+\ (aq)$

3. Identify the Lewis acids in each of the following reactions:

   a $AlCl_3 + Cl^- \rightarrow AlCl_4^-$

   b $BF_3 + NH_3 \rightarrow F_3B - NH_3$

   c $SiCl_4 + 2Cl^- \rightarrow SiCl_6^{-2}$

   d $PF_5 + F^- \rightarrow PF_6^-$

4. Classify the following acids as monoprotic, diprotic or triprotic, binary or ternary, strong or weak acids. (*give three answers for each type*):

   a $HClO_4$
   b H_2SO_4
   c H_2CO_3
   d HF
   e HCl
   f HNO_2
   g HCN
   h HNO_3
   i CH_3COOH
   j H_2SO_3
   k H_2S
   l H_3PO_4

5. A reagent bottle (labelled as A) is filled with HCl solution and the other (labelled as B) is filled with water. Both liquids in the bottles are colourless. What method do you recommend to identify the acid and water?

6. What is the basis for the classification of acids as strong and weak?

7. What is the pH of a solution having the following hydrogen ion concentrations?

   a 5×10^{-3} M
   b 0.003 M
   c 2.0×10^{-6} M

8. Calculate the hydrogen ion concentrations in solutions having the following pH values:

   a 4
   b 2
   c 5

9. How many moles of H_2SO_4 are present in 0.500 L of a 0.150 M H_2SO_4 solution?

2.4 BASES

Competencies

After completing this section, you will be able to:

- define bases in terms of the concepts of Arrhenius, Brønsted-Lowry and Lewis;
- give examples of bases based on Arrhenius, Brønsted-Lowry and Lewis concepts;

- explain the general properties of bases;
- define strong and weak bases;
- distinguish between strong and weak alkalis (soluble bases);
- define concentrated and dilute alkalis;
- distinguish between concentrated and dilute alkalis (soluble bases);
- use the necessary precautions while working with bases;
- define pOH;
- show the mathematical relationship between pH and pOH;
- calculate the pOH of a given solution;
- calculate the concentration of hydroxide ions from the given information;
- conduct activities to investigate some chemical properties of bases;
- explain the reaction of active metals with water, the reaction of basic oxides with water, and double displacement reactions as the three methods of preparation of bases;
- conduct simple experiments to prepare bases in a laboratory;
- describe the uses of the three common laboratory bases (NaOH, $Ca(OH)_2$ and NH_3).

Activity 2.12

1. Have you ever wondered about the origin of the saying "it is a bitter pill (kosso) to swallow"? Discuss and give a meaning to the saying.
2. Discuss why farmers sometimes need to put crushed limestone on their soil.
3. While taking bath, have you ever had soap in your mouth? How does it taste?

Share your experience with your class.

Bases belong to the class of inorganic compounds that include most oxides and hydroxides of metals. They are of great importance in chemical industries and in our daily lives, directly or indirectly. For example, sodium hydroxide, NaOH is used in the production of soap, paper, textile etc. Potassium hydroxide, KOH is used to produce soft soap, fertilizers etc. Calcium hydroxide, $Ca(OH)_2$, is used to manufacture mortar and bleaching powder, to remove soil acidity etc.

Definition of Bases

There are different definitions of bases, as suggested by different chemists namely Arrhenius, Bronsted-Lowry and Lewis.

Arrhenius definition of bases: *A base is any substance that ionizes (dissociates) in aqueous solution to release hydroxide,* OH^- *ions*. Arrhenius bases are mostly ionic metal hydroxides such as, LiOH, NaOH, KOH and $Ba(OH)_2$. The dissociation of a few bases is shown by the following equations:

$$NaOH\ (aq) \rightarrow Na^+\ (aq) + OH^-\ (aq)$$

$$Ba(OH)_2\ (aq) \rightarrow Ba^{2+}\ (aq) + 2OH^-\ (aq)$$

Brønsted-Lowry definition of bases: *A base is a substance that is capable of accepting proton(s),* H^+*. Thus, a base is a proton,* H^+ *acceptor*.

Note:

Note that not all Brønsted-Lowry bases are Arrhenius bases, but all Arrhenius bases contain the hydroxide ion which is a Brønsted-Lowry base. This is because OH^- can accept a proton, H^+, to form water.

According to the Brønsted-Lowry definition, an acid-base reaction is the transfer of a proton from an acid to a base.

Example

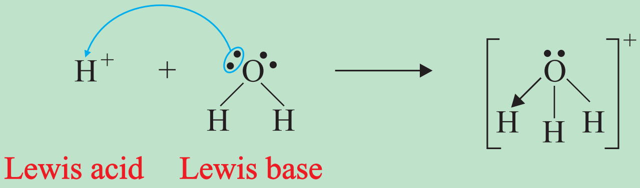
$$\underset{\text{Base}}{NH_3\ (aq)} + \underset{\text{Acid}}{HCl\ (aq)} \rightarrow NH_4^+\ (aq) + Cl^-\ (aq)$$

$$\underset{\text{Acid}}{HCO_3^-\ (aq)} + \underset{\text{Base}}{OH^-\ (aq)} \rightleftharpoons CO_3^{2-}\ (aq) + H_2O\ (l)$$

Lewis Definition of Bases

The Lewis definition is a more general definition than the Arrhenius and Brønsted-Lowry definitions. According to Lewis, *a base is a substance that is capable of donating a pair of electrons. In other words, a base is an electron-pair donor*. Brønsted-Lowry bases are also bases according to the Lewis concept. This is because for Brønsted-Lowry bases to accept a proton, H^+ they should have a lone pair. However, Lewis base include other species that can form a coordinate covalent bond by sharing their lone pair with substances other than a proton, H^+. It is important to note that Lewis acid-base reactions include many reactions that do not involve protons. The following equation shows an acid-base reaction according to Lewis concept:

Example



Activity 2.13

Consider the following reactions:

$NH_3 + H^+ \rightarrow NH_4^+$

$BF_3 + F^- \rightarrow BF_4^-$

In the above reactions, name the Lewis acids and Lewis bases. Do NH_3 and F^- act as Lewis acid or Lewis base? Why?

General Properties of Bases

Activity 2.14

Dissolve one table-spoon of washing soda in a glass of water. Try to wash your hands with this solution. How do you feel? Does it give a soapy touch or an oily touch. Share your observations with the rest of the class.

Bases like NaOH, KOH, and $Ba(OH)_2$ are readily soluble in water, while others such as $Mg(OH)_2$ are slightly soluble. Bases that are soluble in water are also called alkalis.

Bases or alkalis show the following properties:

1. **Bases are slippery to the touch and have a bitter taste:** Bases have a bitter taste; feel slippery to the skin in dilute aqueous solutions. Strong bases such as NaOH and KOH are very corrosive and poisonous. So they should be neither brought in to contact with the skin nor tasted.
2. **Soluble bases change the colour of indicators:** Aqueous solutions of bases turn the colour of red litmus to blue, phenolphthalein to pink (*red*), methyl red to yellow and universal indicator blue (*purple*).

3. **Soluble bases release hydroxide ion in aqueous solution:** The characteristic properties of bases in aqueous solutions are due to the presence of the hydroxide ion, OH^- which they release on dissolution.

Examples

$$KOH\,(aq) \rightarrow K^+\,(aq) + OH^-\,(aq)$$

$$Ca(OH)_2\,(aq) \rightleftharpoons Ca^{2+}\,(aq) + 2OH^-\,(aq)$$

4. **Bases neutralize acids or acidic oxides to form salt and water:**

Base + Acid (or acidic oxide) → Salt + Water

Examples

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

$$2KOH\,(aq) + SO_3\,(g) \rightarrow K_2SO_4\,(aq) + H_2O\,(l)$$

$$Ca(OH)_2\,(aq) + 2HCl\,(aq) \rightarrow CaCl_2\,(aq) + 2H_2O\,(l)$$

5. **Aqueous solutions of bases conduct electricity:** Soluble bases are electrolytes. Solutions of strong bases are good conductors while solutions of weak bases are poor conductors.

Strength of Bases (Strong and Weak Bases)

Activity 2.15

Is a concentrated base a strong base and a dilute base a weak base? Discuss in your group and present to the class.

Both acids and bases are classified as strong and weak depending on their degree of ionization (*dissociation*) in aqueous solution.

Strong bases are those which ionize (*dissociate*) completely or almost completely in water solutions. Examples of strong bases include hydroxides of alkali (Group IA) metals and lower members of alkaline earth metals such as LiOH, NaOH, KOH, and $Ba(OH)_2$.

Examples

$$LiOH\,(aq) \rightarrow Li^+\,(aq) + OH^-\,(aq)$$

$$KOH\,(aq) \rightarrow K^+\,(aq) + OH^-\,(aq)$$

Weak bases are those bases which ionize (*dissociate*) only partially or slightly in aqueous solution. Examples of weak bases include NH_3, and $Ca(OH)_2$.

The dissociation of a weak base can be shown as follows using, NH_3, as an example.

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

The double arrow shows that the dissociation of a weak base does not proceed to completion. This means an aqueous solution of a weak base contains only a small amount of ions derived from the dissociation of the base and a large amount of the non-ionized base. For example, a solution of ammonia containing 0.1 mole NH_3 per litre of solution ionizes only to the extent of 1.3%.

Concentrated and Dilute Bases

Concentrated and dilute solutions are terms used to describe the amount of a substance present in a given volume of solution. The amount can be described in terms of either percentage or number of moles. Concentrated bases contain relatively large amounts of a base in a given volume of solution while dilute base solutions contain only a small amount of base. The concentration of a base is the measure of the number of moles of the alkali (*base*) dissolved in one litre of solution. The concentration is expressed in terms of mole per litre (*Molarity*).

$$\text{Molarity of the base} = \frac{\text{number of moles of the base}}{\text{volume of solution in litres}}$$

The greater the number of moles of the base per litre of the solution the more concentrated is the solution. For example, a solution containing ten moles of NaOH per litre is more concentrated than the solution containing two moles of NaOH per litre. The latter solution is more dilute than the former. Thus, both a strong base and a weak base may be concentrated or dilute depending on the number of moles of the base present per litre.

Precautions when Handling Bases

Strong bases such as sodium hydroxide and potassium hydroxide can attack human skin, and even damage animal and plant tissues. That is why NaOH and KOH are named caustic soda and caustic potash respectively. The word “caustic” refers to a substance that can cause burning. Thus, it is very important to avoid the contact of bases with any part of our body or clothing. Not only strong bases but weak bases are also corrosive. For example, concentrated ammonia solution can cause blindness if splashed into the eye.

The following safety precautions are useful in handling bases in school laboratories or anywhere while working with them.

a Wear eye goggles, gloves and a laboratory coat.

b If bases are spilled on your working table wipe the spillages immediately.

c Whenever bases are splashed on your cloth, wash the affected part with running water.

d If a base enters your eyes, wash with water repeatedly as first aid treatment and seek medical advice.

e If a base is swallowed by accident, drink 1-2% acetic acid or lemon juice immediately.

f Whenever bases come in to contact with your skin, wash the affected part with plenty of water and then wash the affected part with a very dilute solution (*about* 1%) of a weak acid such as acetic acid.

pOH

Activity 2.16

1. Since water, H_2O, has H^+ and OH^-, it is both acidic and basic. Is this true?
2. If $[OH^-]$ increases in a solution what happens to its $[H^+]$? Share your comments with your group.

pH is the measure of the hydrogen (H^+) or hydronium (H_3O^+) ion concentration in a solution. In the same manner, pOH is the measure of the hydroxide, OH^- ion concentration in a solution. It also measures the acidity or alkalinity of a solution as pH does.

pOH is defined as the negative logarithm of hydroxide, OH” ion concentration.

$$\text{pOH} = -\log [OH^-]$$

To calculate the hydroxide ion concentration from a given pOH value, we proceed as follows:

$$[OH^-] = \text{antilog} (-\text{pOH}) = 10^{-\text{pOH}}$$

Relationship Between pH and pOH

How can you derive the mathematical relationship between pH *and* pOH? To understand the relationship between pH and pOH let us start from the ionization of water. Water undergoes ionization to a small extent as follows:

$$H_2O\,(l) \rightleftharpoons H^+\,(aq) + OH^-\,(aq)$$

or

$$2H_2O\ (l) \rightleftharpoons H_3O^+\ (aq) \quad + \quad OH^-\ (aq)$$

We can write a mathematical expression for the ionic product of water or dissociation constant for water, K_w as

$$K_w = [H^+]\ [OH^-] = [H_3O^+]\ [OH^-] \qquad (2.1)$$

$$K_w = 1.0 \times 10^{-14}\ (mol/L)^2 \text{ at } 25°C$$

Since water is neutral, $[H^+] = [OH^-]$ or $[H_3O^+] = [OH^-]$. So we can write equation 2.1 as

$$K_w = [H^+]\ [OH^-] = [H^+]^2 = 1.0 \times 10^{-14}(mol/L)^2$$

Solving for $[H^+]$

$$[H^+] = \sqrt{1.0\times10^{-14}\left(mol/_L\right)^2} = 1.0\times10^{-7}\ mol/L$$

Thus, in any neutral aqueous solution at 25°C,

$$[H^+] = [OH^-] = 1.0 \times 10^{-7}\ mol/L$$

In an acid solution, $[H^+] > [OH^-]$ and in a basic solution, $[OH^-] > [H^+]$. However, the product $[H^+] \times [OH^-]$ remains constant, i.e., 1.0×10^{-14} at 25°C. Thus, if the concentration of either H^+ or OH^- is known in a given solution, we can calculate the concentration of the other.

$$[OH^-] = \frac{K_w}{[H^+]}; \qquad [H^+] = \frac{K_w}{[OH^-]}$$

To find the relationship between pH and pOH let us begin with equation 2.1.

$$K_w = [H^+]\ [OH^-] = 1.0 \times 10^{-14}\ (mol/L)^2$$

Take the negative logarithm of both sides

$$-\log K_w = -\log [H^+]\ [OH^-] = -\log 1.0 \times 10^{-14}$$

$$-\log K_w = -\log [H^+] + (-\log [OH^-]) = -\log 1.0 \times 10^{-14}$$

but, $-\log K_w = pK_w$,

$$-\log [OH^-] = pOH,$$

$$-\log [H^+] = pH$$

$$-\log 1.0 \times 10^{-14} = 14$$

So, the above equation becomes

$$pk_w = pH + pOH = 14 \text{ (at 25°C)} \qquad (2.2)$$

Thus, the sum of pH and pOH is 14 for any aqueous solution, at 25°C. Since pH, pOH, $[H^+]$ and $[OH^-]$ are interrelated through K_w, knowing any one of the values enables us to determine the others.

Table 2.2: Acidity and Basicity in relation to $[H^+]$, $[OH^-]$, pH and pOH.

Solution	$[H^+]$ (mol/L)	$[OH^-]$ (mol/L)	pH	pOH
Acidic solution	$> 10^{-7}$	$< 10^{-7}$	< 7	> 7
Basic solution	$< 10^{-7}$	$> 10^{-7}$	> 7	< 7

Example

The hydroxide ion concentration in a solution is 5.0×10^{-5}M? Calculate:

a pOH b $[H^+]$ c pH

Solution:

a To calculate pOH we proceed as follows.

$$pOH = -\log [OH^-] = -\log (5 \times 10^{-5}) = -(\log 10^{-5} - \log 5)$$

$$= 5 - \log 5 = 4.3$$

b $[H^+]$ is calculated using the relationship

$$[H^+] = \frac{K_W}{[OH^-]} = \frac{1.0 \times 10^{-14}\ (mol/L)^2}{5.0 \times 10^{-5}\ mol/L} = 2.0 \times 10^{-10}\ M$$

c $pH = -\log [H^+] = -\log 2.0 \times 10^{-10}$

$$= 10 - \log 2 = 9.7$$

Since the pOH of the solution is found in part (a), we can also calculate the pH using the relationship

$pH + pOH = 14$

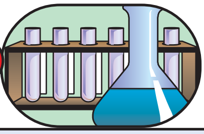
$pH + 4.3 = 14$

$pH = 14 - 4.3 = 9.7$

Exercise 2.9

1. Determine the $[OH^-]$ in 3×10^{-5} M solution of HCl.
2. Determine the pH of 2.0×10^{-2} M $Sr(OH)_2$ solution assuming complete dissociation.

Experiment 2.11



Chemical Behaviour of Bases

Objectives: To investigate the thermal stability and reaction of bases with acids.

Materials required: NaOH or KOH, $Ca(OH)_2$, HNO_3, water, blue and red litmus papers, cobalt chloride, test-tube, test-tube rack, test-tube holder, Bunsen burner, three beakers, dropper, measuring cylinder, glass rod and watch glass.

Procedure:

1. Place 4.5 g NaOH or KOH in one test-tube and the same amount of $Ca(OH)_2$ in another test-tube. Heat the test-tube containing NaOH or KOH gently using a Bunsen burner, by holding the test tube with a test tube holder. Hold the cobalt chloride paper partly inserted in the test tube. See whether the cobalt chloride paper shows a colour change or not. Repeat the same experiment with the second test tube that contains $Ca(OH)_2$.
2. Dissolve 3.6 g KOH in distilled water to prepare 100 mL solution in one beaker. Dilute 2 mL concentrated HNO_3 to make a 50 mL solution in another beaker. Add 10 mL KOH solution and 9.5 mL HNO_3 to the third beaker, stir thoroughly and test with blue and red litmus papers. Continue adding HNO_3 using a dropper, one drop at a time stirring after each addition and checking with red and blue litmus until the blue remains blue and the red remains red. Put 5 mL of the neutral solution on a watch glass and allow the water to evaporate until the next day.

Observations and analysis:

1. What type of reaction occurred between the KOH and HNO_3? Write the balanced chemical equation for the reaction.
2. What is left on the watch glass?
3. Which hydroxide melts on heating? Which base decomposes on heating to give metal oxide and water? How do you know this? Write the balanced chemical equation for the reaction.

Write a laboratory report and present to the class.

Preparation of Bases

Bases containing hydroxide ion (*hydroxide bases*) can be prepared by the following methods:

1. By the reaction of highly reactive metals from Group IA and Group IIA (*below magnesium*) with water. This reaction produces the metal hydroxide with the liberation of hydrogen gas.

Examples

$2Li\ (s) + 2H_2O\ (l) \rightarrow 2LiOH\ (aq) + H_2\ (g)$

$2K\ (s) + 2H_2O\ (l) \rightarrow 2KOH\ (aq) + H_2\ (g)$

$Ca\ (s) + 2H_2O\ (l) \rightarrow Ca\ (OH)_2 + H_2\ (g)$

2. By the reaction of Group IA or Group IIA metal oxides with water, which gives the metal hydroxides.

Metal oxide + Water → Metal hydroxide

Examples

$Na_2O\ (s) + 2H_2O\ (l) \rightarrow 2NaOH\ (aq)$

$CaO\ (s) + 2H_2O\ (l) \rightarrow Ca(OH)_2\ (aq)$

$BaO\ (s) + 2H_2O\ (l) \rightarrow Ba(OH)_2\ (aq)$

3. By double displacement reaction.

   This method involves the reaction of an aqueous solution of a soluble base and a soluble salt, which gives another soluble base and an insoluble salt as products.

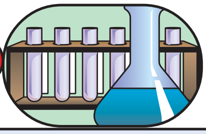
   Soluble base + Soluble salt → Another Soluble base + Insoluble salt

Examples

$Ba(OH)_2\ (aq) + K_2SO_4\ (aq) \rightarrow 2KOH\ (aq) + BaSO_4\ (s)$

$Ca(OH)_2\ (aq) + Na_2CO_3\ (aq) \rightarrow 2NaOH\ (aq) + CaCO_3\ (s)$

Experiment 2.12



Preparation of Bases

Objective: To prepare bases from metal and metal oxides.

Materials required: Water, trough, a knife, tongs, filter paper, litmus paper, test tubes, test tube rack, calcium or sodium metal, CaO or MgO, Na_2SO_4

or K_2SO_4, $Ba(OH)_2$ solution, spatula, balance, three beakers, measuring cylinder, dropper, glass rod.

Procedure:

1. Pour clean water into a trough to three-fourth of its volume. Then take a piece of sodium metal or calcium metal from the bottle with tongs. If you use sodium, place it on filter paper and then blot it to remove the oil. Carefully cutoff a very small piece with a knife and drop this piece onto the surface of the water in the trough. Observe the reaction.

   After the reaction is complete, take some solution from the trough and add it to two test tubes. Test the solution in the first test tube using red litmus paper and add a few drops of methyl orange to the second.

2. Add a half a spatula measure of CaO or MgO to a test tube containing clean water. Shake well and then test whether the solution is acidic or basic using red litmus paper. Does the colour of the red litmus paper change?

3. Add 6 g Na_2SO_4 or 7 g K_2SO_4 to the first and 7 g $Ba(OH)_2$ to the second beaker. Add water to each beaker and stir with a glass rod to prepare a 100 mL solution of each sample. After dissolution is complete, take 20 mL $Ba(OH)_2$ solution and pour it into the third beaker. Measure 20 mL Na_2SO_4 or K_2SO_4 solution, mix it with the solution in the third beaker and shake well. Observe what is happening. Continue adding Na_2SO_4 or K_2SO_4 solution drop by drop using a dropper while shaking the solution after the addition of each drop. When the formation of a white precipitate does not occur anymore stop adding Na_2SO_4 or K_2SO_4 solution and test whether the solution in the third beaker is acidic or basic using litmus paper.

Observations and analysis:

1. Does the colour of red litmus paper change when dipped into the solutions obtained in procedure 1 and 2? Are the solutions acidic or basic?
2. What gas is given off during the reaction in procedure 1?
3. Why do you think is the white precipitate formed?
4. What is the nature of the final solution in the third beaker?
5. Write balanced chemical equations for the reactions.

Write a laboratory report on your observations and present to the class.

Uses of Some Important Bases

Sodium hydroxide, NaOH: This is known by the common name lye or caustic soda. It is one of the most important laboratory and industrial chemicals. It is used in the laboratory for absorbing carbon dioxide and other acidic gases, in a number of organic reactions and in chemical analysis. Industrially, it is used in the manufacture of soaps and detergents, pulp and paper, textiles, dyes, cosmetics, pharmaceuticals, in purifying aluminium ore and petroleum refining. It is also used to clean drains since it dissolves grease and other organic matter.

Potassium hydroxide, KOH: It is commonly known as caustic potash. It is a stronger base and is more expensive than NaOH and has limited uses. It is used as an electrolyte in some dry cells and to make soft soap.

Calcium hydroxide, $Ca(OH)_2$: It is also called slaked lime or lime water when it is dissolved in water. It is a weaker base than NaOH and KOH, and is widely used to remove soil acidity, to make mortar (*mixture of lime, sand and water*) which serves as binding material for bricks and plastering walls, to remove temporary hardness of water and in manufacturing bleaching powder. Its aqueous solution is also used to test for carbon dioxide gas.

Ammonia: A solution of gaseous ammonia, NH_3 in water is used as household cleaning agent and as a laboratory reagent. It is used to manufacture ammonium fertilizers,

Reading Assignment

The common uses of NaOH, KOH, $Ca(OH)_2$ and NH_3 have been described above. After reading reference books in your library, search for some more uses of these compounds. Present your findings to the class.

Exercise 2.10

1. Identify the Brønsted-Lowry bases and acids in each of the following chemical reactions:

   a $HCOOH\ (aq) + CN^-\ (aq) \rightleftharpoons HCOO^-\ (aq) + HCN\ (aq)$

   b $H_2S\ (g) + OH^-\ (aq) \rightleftharpoons HS^-\ (aq) + H_2O\ (l)$

2. Identify the substances acting as Lewis bases and acids in each of the following chemical reactions:

   a $AlCl_3\ (aq) + Cl^-\ (aq) \rightarrow AlCl_4^-\ (aq)$

   b $H^+\ (aq) + NH_3\ (g) \rightarrow NH_4^+\ (aq)$

3. What is the concentration of the base (in molarity) containing:
   a 80 g NaOH is dissolved in water to make 1 litre of solution?
   b 224 g KOH is dissolved in water to make 2 litres of solution?
4. Calculate the pOH, $[H^+]$ and pH of the solutions having the following hydroxide ion concentrations:
   a $[OH^-] = 4.6 \times 10^{-3}$ mol/L b $[OH^-] = 2.5 \times 10^{-6}$ mol/L
5. Potassium hydroxide solution is added from a burette to dilute hydrochloric acid solution in a beaker. Which of the following changes will not occur in the beaker:
   a The pH of the solution in the beaker increases.
   b The $[H^+]$ of the solution in the beaker decreases.
   c The pOH of the solution in the beaker increases.
6. How many moles of NaOH are contained in 65 mL of a 2.20 M solution of NaOH in H_2O?
7. A solution of barium hydroxide, $Ba(OH)_2$, contains 4.285 g of barium hydroxide in 100.0 mL of solution. What is the molarity of the solution?

2.5 SALTS

Competencies

After completing this section, you will be able to:

- define salts;
- give examples of salts;
- classify salts as acidic, normal and basic salts;
- explain the direct combination of elements, the reaction of acids with bases and the reaction of acids with metals as methods of salt preparation;
- conduct simple experiments to prepare a salt by neutralization;
- list some important salts and discuss their uses;
- explain the properties of salts;
- describe the chemical tests of some salts by conducting activities;
- mention the essential nutrients of plants;
- describe the functions of nitrogen, phosphorus and potassium in plant growth;

- define fertilizers;
- list some common fertilizers;
- explain the importance of fertilizers; and
- list some common inorganic compounds that are used as pesticides and herbicides.

Activity 2.17

Discuss the following in your group and present it to the class:

1. List all the salts that you know and tell where they are found.
2. Make a list of coloured salts available in your school laboratory.
3. Which salts are found in Dalol area, Ethiopia?

Salts are ionic compounds that contain positive ions (cations) derived from bases and negative ions (anions) derived from acids. Salts are also defined as ionic compounds formed when the ionizable hydrogen of acids are partly or completely replaced by metal ions or ammonium ions. For example, $Ca(HCO_3)_2$ and $CaCO_3$ are salts derived from the acid H_2CO_3 while the salts $Mg(H_2PO_4)_2$, $MgHPO_4$ and $Mg_3(PO_4)_2$ are salts derived from H_3PO_4.

- A salt is produced when an acid is neutralized by a base:

$$\text{Acid} + \text{Base} \rightarrow \text{Salt} + \text{Water}$$

Examples

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

$$H_2SO_4\ (aq) + Ca(OH)_2\ (aq) \rightarrow CaSO_4(s) + 2H_2O\ (l)$$

Some common examples of salts are sodium chloride (NaCl), calcium carbonate ($CaCO_3$), potassium nitrate (KNO_3), copper sulfate ($CuSO_4$) etc.

Classification of Salts

Activity 2.18

Recall the concept of the neutralization reaction between an acid and a base to give a salt and water.

a What would be the nature of the salt, if all the acid hydrogen ions are not replaced by metal ions or ammonium ion?

b What would be the nature of the salt, if all the base hydroxide ions are not replaced by the anions of the acid?

Discuss in your group and present the findings to the class.

Salts can be classified as:

- **Acidic salts:** These are salts in which not all of the hydrogen ions in an acid have been replaced by metal ions or ammonium (NH_4^+) ions.

  Example: Sodium hydrogen sulphate, $NaHSO_4$.

  When acidic salts are dissolved to make an aqueous solution, they release H^+ ions which make the solution acidic. For example, $NaHSO_4$ releases ions in aqueous solution as follows:

  $$NaHSO_4\,(aq) \rightarrow Na^+\,(aq) + H^+\,(aq) + SO_4^{2-}\,(aq)$$

- **Normal salts:** These are salts in which all of the hydrogen ions in an acid have been replaced by metal ions or ammonium ions.

  Example: Sodium sulphate, Na_2SO_4.

  Normal salts do not contain ionizable H^+ or OH^-.

Example

Na_2SO_4 release ions as follows:

$$Na_2SO_4\,(aq) \rightarrow 2Na^+\,(aq) + SO_4^{2-}\,(aq)$$

- **Basic salts:** These are salts in which not all of the hydroxide ions in a base have been replaced by the anions of the acid.

  Example: Zinc hydroxychloride, Zn(OH)Cl.

  When basic salts are dissolved to make an aqueous solution, they release OH^- ions and this makes the solution basic.

  $$Zn(OH)Cl\,(aq) \rightarrow Zn^{2+}\,(aq) + OH^-\,(aq) + Cl^-\,(aq)$$

Preparation of Salts

Activity 2.19

List a few methods to prepare sodium chloride in the laboratory? Discuss in groups and present it to the class.

Salts can be prepared by the following methods:

1. **Direct combination of elements:** This method is used to prepare binary salts, that is, salts consisting of only two elements.

Examples

$2Na\ (s) + Cl_2\ (g) \rightarrow 2NaCl\ (s)$

$Fe\ (s) + S\ (s) \rightarrow FeS\ (s)$

$Fe\ (s) + 3Cl_2\ (g) \rightarrow 2FeCl_3\ (s)$

2. **Reacting active metals with dilute acids:**

Active metal + Acid → Salt + Hydrogen gas

Examples

$2Al\ (s) + 6HCl\ (aq) \rightarrow 2AlCl_3\ (aq) + 3H_2\ (g)$

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

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

Since, the reactions of metals of Group IA like sodium and potassium are very vigorous, it is advisable not to use the metals of Group IA for the preparation of salts by this method.

Sometimes, the reaction of active metals with dilute acids to prepare salts may not be as successful as expected. For example, calcium sulphate is only sparingly soluble in water. So in the reaction with dilute sulphuric acid, calcium tends to become coated with calcium sulphate which inhibits the reaction from proceeding.

3. **Reacting metal oxides with acids** (*by neutralizing basic oxides with dilute acids*):

Metal oxide + Dilute acid → Salt + Water

Examples

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

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

$ZnO\ (s) + 2HNO_3\ (aq) \rightarrow Zn(NO_3)_2\ (aq) + H_2O\ (l)$

4. **Reacting metal hydroxides with dilute acids:** This reaction is commonly called neutralization.

Metal hydroxides + Dilute acid → Salt + Water

Examples

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

$$2KOH\ (aq) + H_2SO_4\ (aq) \rightarrow K_2SO_4\ (aq) + 2H_2O\ (l)$$

5. **Reacting metal carbonates or hydrogen carbonates with dilute acids:** The reaction of carbonates or hydrogen carbonates with dilute acids always releases carbon dioxide gas along with the formation of a salt and water.

Metal carbonates + Dilute acid → Salt + Water + Carbon dioxide

Examples

$$MgCO_3\ (s) + H_2SO_4\ (aq) \rightarrow MgSO_4\ (aq) + CO_2\ (g) + H_2O\ (l)$$

$$CuCO_3\ (s) + 2HCl\ (aq) \rightarrow CuCl_2\ (aq) + H_2O\ (l) + CO_2\ (g)$$

$$Na_2CO_3\ (s) + 2HNO_3\ (aq) \rightarrow 2NaNO_3\ (aq) + H_2O\ (l) + CO_2\ (g)$$

$$Ca(HCO_3)_2\ (s) + 2HCl\ (aq) \rightarrow CaCl_2\ (aq) + 2H_2O\ (l) + 2CO_2\ (g)$$

6. **Double decomposition reaction** (*double displacement reaction*): In this method, two different soluble salts react to form a soluble and an insoluble salt as products that can be separated easily.

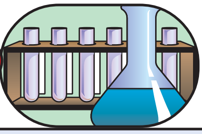
Examples

$$Pb(NO_3)_2\ (aq) + NaI\ (aq) \rightarrow PbI_2\ (s) + 2NaNO_3\ (aq)$$

$$CaCl_2\ (aq) + Na_2CO_3\ (aq) \rightarrow CaCO_3\ (s) + 2NaCl\ (aq)$$

It may be noted that each method of preparing salts cannot be used to make every salt; i.e., different methods may be used to make different salts.

Experiment 2.13



Preparing salts from Metallic Oxides and Acid

Objective: To prepare copper sulphate from copper oxide and sulphuric acid.

Materials required: Copper oxide, sulphuric acid, beaker, filter funnel, filter paper, evaporating dish.

Procedure:

1. Pour some sulphuric acid in beaker and add copper (II) oxide, warm and stir gently.
2. When the reaction is complete, filter the solution to remove excess copper oxide.
3. Transfer the filtrate to the evaporating dish and evaporate some of the water from the filtrate. Leave for the salt to crystallize out.

Observations and analysis:

1. What is the product formed? Write a balance chemical equation for the reaction.
2. What is the colour change as the reaction occurs? What does this show?

Write a laboratory report and present to the class.

Some Important Salts and their Uses

Activity 2.20

1. Have you ever taken Oral Rehydration Salt (ORS) for diarrhoea? What are the contents of the ORS?
2. Can you prepare your own ORS?

Discuss in your group and present to the class.

Sodium chloride (common salt, NaCl) is widely used in the preparation and preservation of food, as raw a material for the manufacture of sodium, chlorine, and sodium hydroxide. It is used as component of Oral Rehydration Salt (ORS) that has medical applications. It is also used to manufacture baking soda ($NaHCO_3$) and Na_2CO_3 that serve as raw materials for the production of glass.

Ammonium nitrate, (NH_4NO_3) is used as a nitrogenous fertilizer and in explosives.

Copper (II) sulphate, ($CuSO_4$) is used to make Bordeaux mixture (*mixture of* $CuSO_4$ *and* $Ca(OH)_2$) and other fungicides. Bordeaux mixture is used to prevent fungal attack of leaves and vines. $CuSO_4$ is also useful in electroplating.

Iron (III) chloride, ($FeCl_3$) is used in the treatment of waste water, and in etching printed circuits.

Potassium nitrate, (KNO_3) is used in making gun powder (*mixture of* KNO_3, *carbon and sulphur*) and other explosives. It is also used as a fertilizer.

Calcium sulphate, ($CaSO_4 \cdot 2H_2O$, Gypsum) is used for plastering walls and supporting fractured bones.

Barium sulphate, ($BaSO_4$) is given to patients as a "barium meal" before gastro-intestinal x-ray photography; it is also used as a white pigment.

Iron (II) sulphate ($FeSO_4$) is given as iron tablets to patients who suffer from anaemia.

Properties of salts

Salts can be classified depending on the anion (*negative ion*) they possess, because the anion is partly responsible for the solubility of the salt.

1. Solubility of salts. The following table summarizes some simple observations about the solubility of some groups of salts.

Table 2.2 Solubility of salts.

Soluble salts	Exceptions
• All nitrates (NO_3^-), perchlorates (ClO_4^-), chlorates (ClO_3^-) and acetates (CH_3COO^-)	• No exception
• Most halides	• Those containing Ag^+, Hg^{2+}, Pb^{2+} ($AgCl$, $AgBr$, AgI, $HgCl_2$, $HgBr_2$, HgI_2, $PbCl_2$, $PbBr_2$, PbI_2) ($PbCl_2$ is soluble in hot water)
• Most sulphates	• $BaSO_4$, $HgSO_4$, $PbSO_4$, $SrSO_4$
• Carbonates (CO_3^{2-}), phosphates (PO_4^{3-}) and sulphides (S^{2-}) of alkali metals and ammonium ion (NH_4^+)	• All carbonates, phosphates and sulphides of other elements are insoluble
• Sulphides of alkaline-earths, Group IIA, elements	

2. Tendency to absorb water from the atmosphere or release water to the atmosphere.

Depending on their tendency to absorb water from or release water to the atmosphere, salts can be classified as hygroscopic, deliquescent and efflorescent.

Hygroscopic salts are those which absorb water from the atmosphere but remain solid.

Deliquescent salts absorb water from the atmosphere to form a solution. The process of absorbing water from the atmosphere by a solid to form a solution is called deliquescence.

Efflorescent salts lose their water of crystallization to the atmosphere. The loss of water of crystallization by solid crystals to the atmosphere is known as efflorescence.

It is very important to note that all deliquescent substances are hygroscopic, but all hygroscopic substances are not necessarily deliquescent.

Table 2.3 Examples of hygroscopic, deliquescent and efflorescent salts.

Deliquescent	Hygroscopic	Efflorescent
• Calcium chloride , $CaCl_2$	• Anhydrous Copper(II) sulphate, $CuSO_4$	• Hydrated sodium carbonate $Na_2CO_3{\cdot}10H_2O$
• Sodium Nitrate, $NaNO_3$		• Hydratedsodium sulphate, $Na_2SO_4{\cdot}10H_2O$
• Iron (III) chloride, $FeCl_3$		
• Magnesium chloride, $MgCl_2$		
• Lithium nitrate, $LiNO_3$		
• Sodium nitrate, $NaNO_3$		

3. Aqueous solutions of soluble salts are good conductors of electricity, because they release mobile positive and negative ions in solution.

Examples

$$NaNO_3\ (aq) \rightarrow Na^+\ (aq) + NO_3^-\ (aq)$$

$$CaCl_2\ (aq) \rightarrow Ca^{2+}(aq) + 2Cl^-\ (aq)$$

4. **Thermal stability of salts:** When different salts containing the same anion are heated, they may not show similar behaviour. Some salts are thermally stable while others undergo decomposition. The following examples illustrate this fact.

a Thermal decomposition of carbonates:

Carbonates are salts containing a carbonate, as an anion. Carbonates of Group IIA and most transition metals decompose on heating to give the metal oxides and carbon dioxide:

$$MgCO_3\,(s) \xrightarrow{\text{heat}} MgO\,(s) + CO_2\,(g)$$

$$CuCO_3\,(s) \xrightarrow{\text{heat}} CuO\,(s) + CO_2\,(g)$$

However, carbonates of sodium and potassium are not decomposed by heat.

b Thermal decomposition of nitrates

Nitrates are salts containing a nitrate, as an anion. Heating nitrates of Group IIA and most transition metals produces a metal oxide, nitrogen dioxide and oxygen:

$$\text{Nitrate} \xrightarrow{\text{heat}} \text{Metal oxide} + \text{Nitrogen dioxide} + \text{Oxygen}$$

Examples

$$2Mg(NO_3)_2\,(s) \xrightarrow{\text{heat}} 2MgO\,(s) + 4NO_2\,(g) + O_2\,(g)$$

$$2Pb(NO_3)_2\,(s) \xrightarrow{\text{heat}} 2PbO\,(s) + 4NO_2\,(g) + O_2\,(g)$$

Nitrates of sodium and potassium decompose on heating to give nitrites and oxygen gas;

$$2NaNO_3\,(s) \xrightarrow{\text{heat}} 2NaNO_2\,(s) + O_2\,(g)$$

$$2KNO_3\,(s) \xrightarrow{\text{heat}} 2KNO_2\,(s) + O_2\,(g)$$

The carbonate and nitrate of lithium differ from those of sodium and potassium; they decompose on heating in the following manner:

$$4LiNO_3\,(s) \xrightarrow{\text{heat}} 2Li_2O\,(s) + 4NO_2\,(s) + O_2\,(g)$$

$$Li_2CO_3\,(s) \xrightarrow{\text{heat}} Li_2O\,(s) + CO_2\,(g)$$

Chemical Tests of Some Ions in Salts

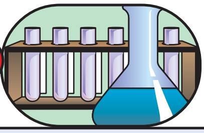
Activity 2.21

1. Do you know why fireworks give different colours? Consult books in your library, and discuss in your group. Explain to the class.
2. How do chemists know of the presence of certain ions in a compound?

There are several simple tests which may help in the identification of metal ions and anions present in salts.

1. **Flame tests:** Certain metals give a characteristic colour to a Bunsen flame when their solid salts or moist salts are heated directly in the flame.A flame test is commonly used to identify the presence of lithium, sodium, potassium, calcium, strontium and barium ions in salts.

Experiment 2.14



Test for cations-I

Objective: To identify the presence of Li^+, Na^+, K^+, Ca^{2+}, Sr^{2+} and Ba^{2+} in salts by flame tests.

Materials required: Platinum or nichrome wire, watch glass, Bunsen burner, distilled water, salts containing Li^+, Na^+, K^+, Ca^{2+}, Sr^{2+} and Ba^{2+}.

Procedure:

1. Place a small amount of the salt containing a Li^+ ion on a watch glass, moisten it with pure concentrated HCl, dip the tip of the platinum or Nichrome wire into the moist salt and then bring to the Bunsen flame.
2. Observe the colour produced.
3. Repeat the same step for salts containing Na^+, K^+ Ca^{2+}, Sr^{2+} and Ba^{2+} and record your observations. Rinse the platinum or Nichrome wire with distilled water after each test.

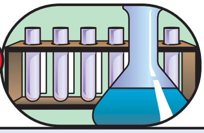
Observations and analysis:

a Write the colour of the flame produced in the following table.

Metal ion in the salt	Colour of flame produced
Lithium (Li^+)	
Sodium (Na^+)	
Potassium (K^+)	
Calcium (Ca^{2+})	
Strontium (Sr^{2+})	
Barium (Ba^{2+})	

Write a laboratory report and present to the class.

Experiment 2.15



Test for cations-II

Objectives: To identify the presence of Cu^{2+}, Fe^{2+} and Fe^{3+} in salts.

Materials required: Beakers, test tubes, test tube rack, glass rod, ammonia solution, sodium hydroxide solution, salts containing each of Cu^{2+}, Fe^{2+} and Fe^{3+} ions

Procedure:

1. Dissolve a salt containing Cu^{2+} in the first beaker, Fe^{2+} in the second and Fe^{3+} in the third. Take three test tubes and add a 2 mL solution of (each ion) Cu^{2+} salt to the first, Fe^{2+} salt solution to the second and Fe^{3+} salt solution to the third.
2. Add aqueous ammonia in small quantities until it is in excess, to the first test tube containing a copper (II) salt solution and record your observations.
3. Add sodium hydroxide solution in small quantities, until it is present in excess, to the second and third test tubes, and record your observations.

Observations and analysis:

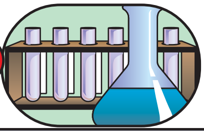
1. What does the formation of a blue precipitate in the first indicate? Write the chemical equation for the blue precipitate formation.
2. Observe the colours of the precipitates formed and complete the following Table:

Colour observed	Confirms the presence of

3. Write balanced chemical equations for the reactions.

Write a laboratory report in group and present to the class.

Experiment 2.16



Test for Halide Ions

Objectives: To identify the presence of Cl^-, Br^- and I^- ions.

Materials required: test tubes, test tube rack, NaCl, NaBr, NaI, $AgNO_3$, ammonia solution, reagent bottles, dilute HNO_3

Procedure:

1. Prepare 125 mL solution by dissolving 2.0 g $AgNO_3$ in the first, 1.59 g NaCl in the second, 2.50 g NaBr in the third and 3.75 g NaI in the fourth reagent bottle respectively.
2. Take three test tubes and pour about 5 mL of NaCl solution in to the first, 5 mL NaBr solution in to the second and 5 mL NaI solution in to the third. To each of the solutions in the test tube add 1 mL of dilute HNO_3 followed by addition of about 5 mL $AgNO_3$ solution. Observe if a precipitate is formed in each beaker.
3. After a precipitate has been formed, add ammonia solution to each test tube and see what happens to the precipitate.

Observations and analysis:

1. What did the formation of the white precipitate in the first test tube confirm? Name the compound formed as the white precipitate.
2. What did the formation of the yellow precipitate in the second test tube confirm? Name the compound formed as the yellow precipitate.
3. What did the formation of the deep-yellow precipitate in the third test tube confirm? Name the compound formed as the deep-yellow precipitate.

4. What happened to the contents in the three test tubes, when ammonia solution was added to each of the test tubes?
5. Write balanced chemical equations for the reactions taking place in each test tube.

Write a laboratory report and present to the class.

Experiment 2.17

Test for Sulphates

Objective: To identify for the presence of sulphate using barium salts.

Materials required: Beakers, test tubes, and test tube rack, any soluble sulphate salt (such as sodium sulphate), barium chloride or barium nitrate solution, and dilute HCl.

Procedure:

Add some sodium sulfate solution to a test tube and acidify the solution by adding a few drops of dilute HCl. Then add $BaCl_2$ or $Ba(NO_3)_2$ solution and note if a white precipitate is formed.

Observations and analysis:

1. Name the white precipitate formed?
2. Why is it necessary to add a few drops of dilute HCl?
3. Write a balanced chemical equation for the reaction.

Write a laboratory report and present to the class.

Experiment 2.18

Test for Carbonates and Hydrogen Carbonates

Objective: To distinguish betweem carbonates and hydrogen carbonates

Materials required: Na_2CO_3, $NaHCO_3$, dilute HCl, lime water, conical flasks, beakers, rubber stopper, gas delivery tube, calcium chloride solution

Procedure:

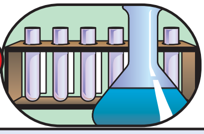
1. Take 20 mL solution of Na_2CO_3 and add it to one conical flask and 20 mL $NaHCO_3$ solution to another. Add the same amount of dilute HCl to each of the conical flasks; Fit a rubber stopper to which a delivery tube is inserted to each conical flask. Allow the gas produced to pass through lime water and observe the changes.
2. Again take Na_2CO_3 solution in one conical flask and $NaHCO_3$ solution in the other. Add the same amount of $CaCl_2$ solution to each of the conical flasks.

Observations and analysis:

1. What has happened to the lime water in each case?
2. Which solution forms a white precipitate on the addition of $CaCl_2$ solution?
3. Write balanced chemical equations for all the reactions.

Write a laboratory report and present to the class.

Experiment 2.19



Test for Nitrates (Brown Ring Test)

Objectives: To identify the presence of nitrate in a solution.

Materials Required: Test tube, test tube rack, beaker, nitrate solution, iron (II) sulphate solution, concentrated H_2SO_4

Procedure:

Take 2 mL of nitrate solution in a test tube and add an equal volume of freshly prepared iron (II) sulphate solution. Hold the test tube in an inclined position and carefully pour concentrated sulphuric acid down along the inclined side of the test tube. The acid sinks to the bottom. Carefully observe the changes in test tube.

Observations and analysis:

1. Where is the brown ring formed?
2. Write the chemical equation for the formation of the brown ring.
3. What does the formation of brown ring in the solution indicate?

Write a laboratory report and present to the class.

Exercise 2.11

1. Name the acid and base pairs required to prepare each of the following salts:
   - a K_2SO_4
   - b $Ca(NO_3)_2$
   - c $MgBr_2$
   - d BaI_2
2. Suggest at least three methods for the preparation of salts.
3. Classify the following salts as soluble or insoluble in water:
   - a NH_4Cl
   - b $FeCO_3$
   - c $AgNO_3$
   - d $PbSO_4$
   - e Li_3PO_4
   - f AgCl
   - g $CaCl_2$
   - h Na_2S
4. Why do aqueous solutions of soluble salts conduct electricity?
5. Which carbonates do not decompose on heating?
6. Nitrates mostly decompose by heat to give metal oxide, nitrogen dioxide and oxygen. Which nitrates do not give these products on heating?
7. What reagents do you use to identify the presence of the following ions in salts?
   - a Halide ions?
   - b Fe^{2+} and Fe^{3+} ions?
   - c Sulphate, SO_4^{2-} ions?
8. An unknown salt when heated with a Bunsen flame produced a bright-yellow flame. An aqueous solution of this salt when reacted with dilute HCl released a gas that turns lime water milky. Upon addition of calcium chloride solution to an aqueous solution of this salt, a white precipitate is formed. What is the unknown salt?

Plant Nutrients

Essential nutrients

Activity 2.22

1. Form a group and list the kind of fertilizers you are familiar with. Which of the listed fertilizers are inorganic salts?

2. Plants need nitrogen for their growth, and there is plenty of nitrogen in the air. If this is so, why do we apply nitrogeneous fertilizers for plants?
3. Some people prefer to eat organic food that has been grown without fertilizers and pesticides. Does eating organic food overcome the problems caused by artificial fertilizers? Discuss in groups and present to the class.

The growth and development of plants is determined by various factors of soil, climate, and by factors inherent in the plants themselves. Minerals required by plants for their growth and development are called plant nutrients. For a soil to produce crops successfully, it must have an adequate supply of all the necessary nutrients that plants take from the soil. The required nutrient elements must be present in the soil in forms that plants can use and also there should be a rough balance among them in accordance with the amounts needed by plants. When any one of these elements is lacking or is in excess of the required proportion, the normal plant growth will not take place.

Elements required by plants for their growth and development are called essential nutrients. The elements considered as essential nutrients are carbon, hydrogen, oxygen, sulphur, nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, boron, copper, zinc, molybdenum, cobalt and chlorine. All these seventeen elements have their own roles in the growth and development of plants. Depending on the amount required by plants, these elements are classified as macronutrients and micronutrients.

Activity 2.23

Try to identify the (a) micronutrients, (b) macronutrients, required for the growth of wheat, maize, and rice crops, by consulting the books in your library. Share your findings with the class.

Macronutrients are the elements required in relatively large amounts by plants. These are nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, carbon, hydrogen and oxygen.

Micronutrients are the elements required by plants in relatively small (*trace*) amounts. These elements are iron, cobalt, zinc, manganese, molybdenum, copper, boron and chlorine.

The elements carbon, hydrogen and oxygen are obtained by plants from air and water. These are not considered as mineral nutrients. Nitrogen, phosphorous and potassium are said to be primary mineral nutrients. The roles of nitrogen, phosphorus and potassium in the plant growth are discussed below:

Nitrogen is a very important plant nutrient. It is absorbed by plants in the form of nitrate ions (NO_3^-). In the growth and development of plants, nitrogen is utilized in the synthesis of amino acids, proteins, coenzymes and nucleic acids. The proteins formed control the metabolic processes that occur in plant cells. Nitrogen is also involved in the synthesis of chlorophyll to produce a deep green colour.

Phosphorus is an important element without which the growth of plants is impossible. It facilitates early growth and root formation, quick maturity and promotes seed or fruit production. Phosphorus is absorbed by plants mainly in the form of $H_2PO_4^-$ and HPO_3^{2-} in small amounts. Phosphorus has a role in the formation of some amino acids and proteins, coenzymes, nucleic acids and high energy phosphate compounds like Adenosine Triphosphate (ATP).

Potassium is absorbed by plants in the form of the K^+ ion. It is a component of enzymes that facilitate the process of photosynthesis and protein synthesis. It also adjusts stomata movement. It is the most important ion in controlling the turgidity of plant cells. It increases in the solute potential (*sap concentration*) within the cells which leads to an increase in the amount of water that enters the cells osmotically.

Exercise 2.12

1. What is the importance of the following elements for the growth of food crops?
   a nitrogen b phosphorus c potassium
2. In what form do plants absorb these elements?

Fertilizers

During the growth and development of plants, the plants consume the essential nutrients from the soil. The concentration of these nutrients will decrease in the soil. If the plants are specially food crops, the nutrients can be lost from the soil when the plants are removed on harvest. So for the soil to be suitable for the growth of plants in the next round, the nutrients lost must be replaced.

How can we replace the nutrients lost from the soil? How can we increase the crop producing potential of soils? The nutrients lost from the soil can be replaced or the crop producing potential of soils can be increased by adding the appropriate fertilizers to the soil.

What are fertilizers? Fertilizers are materials that are added to soils to increase the growth, yield or nutrient value of crops. Fertilizers are usually classified as organic (*natural*) fertilizers and synthetic or artificial fertilizers.

Organic (natural) fertilizers are those derived from animals and plants. This includes animal dung, urine and substances obtained from the decay and decomposition of plants. These fertilizers provide readily available nutrients to plants after some period of decay and decomposition. These fertilizers can supply the elements nitrogen, phosphorus, potassium and various trace elements to the soil.

Synthetic or artificial fertilizers contain all three major plant nutrients i.e., nitrogen, phosphorous and potassium, and are known as complete fertilizers.

A mixed artificial fertilizer may contain nitrogen, phosphorus and potassium. Such a type of fertiliser is called a complete fertiliser. The term NPK is used to describe fertilizers containing the elements nitrogen, phosphorus and potassium.

Examples of artificial fertilizers are ammonium sulphate, $(NH_4)_2SO_4$, potassium nitrate (KNO_3), ammonium nitrate (NH_4NO_3), and diammonium hydrogen phosphate, DAP ($(NH_4)_2HPO_4$).

The most important mineral nutrients that need to be added to the soil are usually nitrogen, phosphorus and potassium. All the three elements are needed in large quantities. Commercial fertilizers are normally given a "grade", which reflects the percentages they contain of N, P and K by dry weight. For example, a NPK fertilizer may be described as 10:10:10 indicating that there is 10% of each element in the fertilizer. The suitable proportions are best determined in relation to the tested fertility of the soil and the requirements of the particular crop that is being grown on it. This means fertilizers of the same composition are not used for different purposes. In nitrogen deficient soil, a fertilizer containing a higher percentage of nitrogen than phosphorus and potassium must be used. In addition to this, all fertilizers are not used for treatment of all kinds of soil. For example, ammonium sulphate is more suitable for use in basic soils than in acidic or neutral soils.

Exercise 2.13

1. Classify the following as organic or synthetic fertilizers:

   a NH_4NO_3 b urea c $(NH_4)_2SO_4$

2. Can the same fertilizer be applied to all types of soil? Explain.

Pesticides

Pesticides are chemicals that can be applied to agricultural crops to kill pests which affect the growth and development of plants. Parasitic fungi, insects and animals like rodents, rabbits and birds reduce crop yields or even completely destroy crops.

Pesticides are used to overcome the damage caused by fungi and pests. The majority of the pesticides used in agriculture are organic compounds. However, there are some inorganic substances that serve as pesticides. These include fumigant insecticides that exist in the vapour phase. Examples of fumigants are hydrogen cyanide (HCN), sulphur dioxide (SO_2), carbon disulphide (CS_2) and phosphine (PH_3). These pesticides are mostly used in the treatment of empty transport containers, grain stores, warehouses, harvested products prior to or during storage and to destroy pests in the soil. The other inorganic pesticides are mostly copper compounds such as $CuCl_2$, $Cu(OH)_2$, $Cu(NO_3)_2$, $CuSO_4$, Cu_2O and $CuCO_3$. Among the inorganic compounds, $CuSO_4$ and Cu_2O are used as *fungicides* where as HCN, SO_2, PH_3, $CuCl_2$, $Cu(OH)_2$, $Cu(NO_3)_2$ and $CuCO_3$ are used as insecticides.

Herbicides

Herbicides are also called weed killers. They are used to control the damage caused by weeds. Inorganic compounds used as herbicides include ammonium sulphamate ($(NH_4)SO_3–NH_2$), borax ($Na_2B_4O_7·10H_2O$), sodium chlorate ($NaClO_3$) and ferrous sulphate ($FeSO_4·7H_2O$).

Check list

Key terms of the unit

- *acidic oxide*
- *amphoteric oxide*
- *Arrhenius acid*
- *Arrhenius base*
- *acid, basic and normal salt*
- *basic oxide*
- *Bronsted - Lowery acid*
- *Bronsted - Lowery base*
- *concentrated acid*
- *dilute acid*
- *deliquescent*
- *dissociation constant for water (kw)*
- *efflorescent*
- *electrolyte*
- *flame test*
- *hygroscopic*
- *indicator*
- *Lewis acid*
- *Lewis base*
- *litmus*
- *molarity*
- *neutral oxide*
- *neutralization*
- *non-volatile acid*
- *peroxide*
- *pH*
- *plant nutrient*
- *pOH*
- *salt*
- *strong acid*
- *strong base*
- *universal indicator*
- *weak acid*
- *weak base*

Unit Summary

- *Inorganic compounds are those compounds that originate from mineral constituents of the earth's crust.*
- *Inorganic compounds may be classified as oxides, acids, bases and salts.*
- *Oxides are binary compounds consisting of oxygen and any other element.*
- *Most common oxides are classified as acidic, basic, amphoteric, neutral oxides and peroxides.*
- *Acidic oxides are oxides of non-metallic elements.*
- *Basic oxides are oxides of metals. These metal oxides which dissolve in water are also called basic anhydrides.*
- *Amphoteric oxides are those oxides which show the properties of both acids and bases.*
- *Neutral oxides are those oxides which do not show basic or acidic properties.*
- *Peroxides are oxides containing a peroxide* (-O-O-) *link and the oxidation state of oxygen is -1.*
- *Arrhenius acids are substances that release hydrogen ions or protons in aqueous solution.*
- *Arrhenius bases are substances that release hydroxide* (OH^-) *ions in aqueous solution.*
- *A Brønsted-Lowery acid is a proton-donor.*
- *A Brønsted-Lowery base is a proton-acceptor.*
- *A Lewis acid is an electron-pair acceptor.*
- *A Lewis base is an electron-pair donor.*
- *Strong acids and strong bases ionize almost completely in aqueous solution.*
- *Weak acids and weak bases ionize only slightly in aqueous solution.*
- pH *is the negative logarithm of hydrogen ion concentration* $pH = -\log [H^+]$.
- pOH *is the negative logarithm of hydroxide ion concentration* $pOH = -\log [OH^-]$.
- $K_W = [H^+][OH^-] = 1 \times 10^{-14}$ *at 25°C.*
- $pK_w = pH + pOH = 14$ *at 25°C.*
- *A salt is an ionic compound containing a cation derived from a base and anion derived from an acid.*

- *Salts may be classified as acidic, normal and basic salts.*
- *An acid salt is formed when ionizable hydrogen atoms of an acid are replaced partly by a metal ion or ammonium ion.*
- *A normal salt is formed when all ionizable hydrogen atoms of an acid are completely replaced by a metal or ammonium ion.*
- *A basic salt is a salt containing ionizable hydroxide ion.*
- *Hygroscopic substances absorb water from the atmosphere.*
- *Deliquescent substances absorb water from the atmosphere and dissolve in the water absorbed to form solutions.*
- *Efflorescent substances lose their water of crystallisation to the atmosphere.*
- *Plant nutrients are minerals required by plants for their growth and development.*
- *The elements plants need for their growth and development are classified as macronutrients and micronutrients depending on the amount utilised by them.*
- *Fertilizers are natural products or synthetic chemicals that are added to the soil to increase its crop producing potential.*
- *Synthetic fertilizers are classified as nitrogen, phosphorus and potassium fertilizers.*
- *Pesticides are chemicals used in agriculture to kill pests that reduce crop yields.*

REVIEW EXERCISE ON UNIT 2

Part I: Write the missing words in your exercise book

Acidic	*litmus*	*salt*	*ammonia*	*Alkalis*
react	*acids*	*hydroxide*	*soluble*	

Most oxides of non-metals are _1_ oxides, acidic oxides react with _2_ to form a _3_ and water. Some acidic oxides _4_ with water to form solutions of acids. These solutions turn blue _5_ red. Alkalis are _6_ bases. Examples of alkalis are _7_ and sodium _8_. Alkalis react with _9_ to form a _10_ and water.

Part II: A Match the substances on the left with those properties stated on the right

1. Vinegar (pH ≈ 4.5)
2. dish-washing powder (pH ≈ 12)
3. soap (pH ≈ 7.5)
4. distilled water (pH ≈ 7)
5. concentrated hydrochloric acid

a strongly acid
b weakly alkaline
c neutral
d strong alkaline
e weakly acidic

Part II: B Match the ions or molecules on the left with the correct test reagent on the right

6. Iron (II) ion
7. Iodide ion
8. Sulphate ion
9. Carbon dioxide
10. Nitrate ion

a silver nitrate
b acidified barium nitrate
c heat with aluminium
d iron (II) sulphate and sulphuric acid
e sodium hydroxide
f limewater

Part III: Choose the correct answer from the given alternatives

11. A solution has a pH of 9. The solution is best described as:

    a strongly alkaline
    b weakly acidic
    c weakly alkaline
    d strongly acidic

12. Which one of these statements about magnesium oxide is true:

    a it reacts with hydrochloric acid to form a salt
    b it reacts with sodium hydroxide to form a salt
    c it reacts with water to form an acid
    d it reacts with basic oxide to form a base

13. Sodium hydroxide is added to solution M. A reddish-brown precipitate is formed, solution M contains:

    a iron (II) ions
    b iron (III) ions
    c copper (II) ions
    d silver (I) ions

14. Which one of these statements about fertilizers is true?

a ammonium nitrate can be used as a fertilizer
b primary fertilizers contain nitrogen, sulphur and iron
c fertilizers are added to the soil to make it more alkaline
d fertilizers are made by combining calcium with oxygen

15. Which of the following is not the characteristic of an acid:
a an acid changes the colour of an indicator
b an acid has a bitter taste
c an acid ionizes in water
d an acid produces hydronium ions in water

16. When an acid reacts with an active metal:
a hydronium ion concentration increases
b metal forms anions
c hydrogen gas is produced
d carbon dioxide gas is produced

17. Which of the following is the correct definition of a Brønsted-Lowry base?
a an electron pair donor
b an electron pair acceptor
c a proton donor
d a proton acceptor

18. The pH of a solution is 6.32. What is the pOH of the solution:
a 6.32
C 7.68
b 4.8×10^{-7}
d 2.1×10^{-8}

19. A neutral aqueous solution:
a has a 7.0 M H_3O^+ concentration
b contains neither hydronium ion nor hydroxide ion
c has an equal number of hydronium ions and hydroxide ions
d has an unequal number of hydronium ions and hydroxide ions

20. Which of the following solutions would have a pH value greater than 7:
a $[OH^-] = 2.4 \times 10^{-2}$ M
c 0.0001 M HCl
b $[H_3O^+] = 1.53 \times 10^{-2}$ M
d $[OH^-] = 4.4 \times 10^{-9}$ M

Part V: Give Short Answers

21. Write equations for the reaction of zinc oxide with:

    a hydrochloric acid

    b aqueous sodium hydroxide

22. Calcium oxide reacts with hydrochloric acid to form calcium chloride and water.

    a Write a balanced equation for this reaction.

    b Farmers often add calcium oxide to the soil. Explain why they do this.

23. Fertilizers are spread on fields by farmers.

    a Why do farmers use fertilizers?

    b State the names of three elements most commonly found in fertilizers.

    c Ammonium sulphate is a fertilizer. Describe how you can make ammonium sulphate in the laboratory from aqueous ammonia and sulphuric acid.

    d Ammonium nitrate is also a fertilizer. Write a word equation to show how ammonium nitrate can be produced.

24. State the names of a suitable acid and alkali you can use to make each of the following fertilizers:

    a ammonium sulphate

    b potassium phosphate

    c ammonium nitrate

25. A classmate states, "*All compounds containing H atoms are acids, and all compounds containing OH groups are bases.*" Do you agree? Give examples and explanations.

26. For the following three reactions, identify the reactants that are Arrhenius bases, Brønsted-Lowry bases, and/or Lewis bases. State the type(s) of bases in each case. Explain your answer.

    a $NaOH\ (s) \rightarrow Na^+\ (aq) + OH^-\ (aq)$

    b $HF\ (aq) + H_2O\ (l) \rightarrow F^-(aq) + H_3O^+\ (aq)$

    c $H^+\ (aq) + NH_3\ (aq) \rightarrow NH_4^+\ (aq)$

UNIT 3

Electrochemistry

Unit Outcomes

After completing this unit, you will be able to:

- *understand how a chemical reaction produces an electric current and how electricity brings about chemical reactions in electrochemical cells;*
- *understand the differences between metallic conduction and electrolytic conduction;*
- *develop skills in writing the oxidation half-reaction, reduction half-reaction and cell reaction for the electrolysis of molten electrolytes that occur in electrolytic cells;*
- *know three types of voltaic cell;*
- *understand the difference between electrolytic cells and voltaic cells;*
- *appreciate the industrial applications of electrolysis in the production of certain metals, non metals and chemicals and electroplating, and purification of metals;*
- *demonstrate scientific inquiry skills: observing, comparing and contrasting, measuring, asking questions, designing experiment, interpreting data, predicting, classifying, communicating and problem solving.*

MAIN CONTENTS

3.1 INTRODUCTION

Competencies

By the end of this section, you will be able to:

- explain electrochemistry;

Activity 3.1

Discuss the following in groups and one of your group members will present your ideas to the class.

Dry cells which we use in portable radios and flashlights are energy converters.

a Peel the external cover of a dry cell battery and observe the components. How many different components do you see? What are they?

b What type of energy do we get from dry cells? How does the cell generate this energy?

Electrochemistry is a field of chemistry that deals with the relationship between electrical energy and chemical energy. It is a field of chemistry concerned with processes that bring about chemical reactions (*changes*) using electricity or generating electrical energy from chemical reactions. Thus, electrical energy and chemical energy are inter-convertible.

The devices that convert chemical energy to electrical energy or electrical energy to chemical energy are called electrochemical cells. These cells can be classified as electrolytic cells and galvanic or voltaic cells. Electrolytic cells use electrical energy to bring about chemical changes that produce many desirable substances in our daily lives. Galvanic or voltaic cells convert chemical energy to electrical energy. The cells we use in flashlight batteries, wrist watches, cameras and car batteries are examples of Galvanic cells. The reactions between the chemicals in these cells are responsible for the generation of electricity.

Electrochemistry has practical applications in our modern world and in everyday life. Electrolysis is used to manufacture metals like sodium, aluminium; non-metals like chlorine, hydrogen and compounds like sodium hydroxide and sodium hypochlorite. Electrochemistry also has a role in the production of dry cells and lead storage batteries used in the automotive industry.

3.2 ELECTRICAL CONDUCTIVITY

Competencies

After completing this subunit, you will be able to:

- define electrical conductivity;
- explain metallic conductivity;
- explain electrolytic conductivity;
- distinguish between metallic and electrolytic conduction;
- distinguish between weak and strong electrolytes;
- use conductivity apparatus to test the conductivity of substances.

Why do metals conduct electricity? Do you know any non-metal, which conducts electricity? Electrical conductivity is the capacity of a substance to transmit electricity. The materials that allow the passage of electricity through them are called electrical conductors.

Conductivity apparatus is used to test the conductivity of different solid substances or that of aqueous solutions of different compounds. The basic components of conductivity apparatus include electric wires, electrodes, a d.c. source or dry cells, a switch and light bulb. The components of the apparatus can be connected to one another as shown in Figure 3.1.

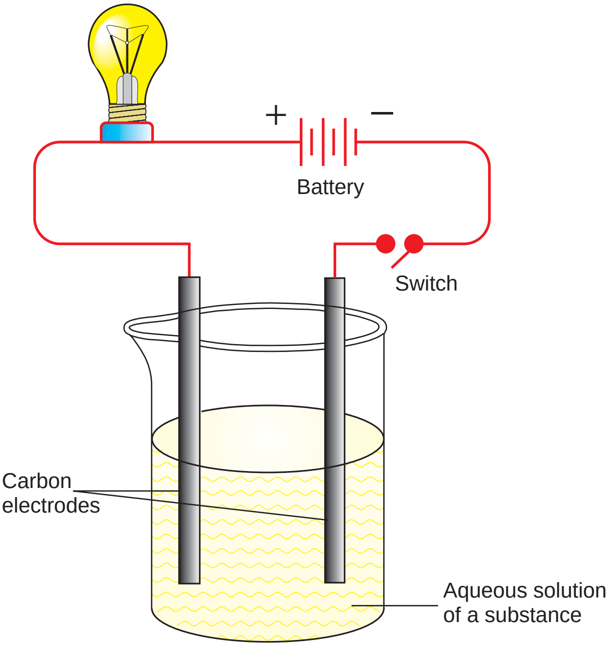


Figure 3.1 Conductivity cell.

Depending on the nature of the particles responsible for the flow of electric charges through conductors, electrical conductivity can be classified as metallic conductivity or electrolytic conductivity.

a) *Metallic conductivity*

Activity 3.2

1. With the help of your teacher collect pieces of iron bars, zinc metal, sodium chloride crystal, rubber stoppers, rubber bands, coins, stone, glass, pieces of dry wood, a spoon, a pencil, chalk and solid sulphur.
2. Identify the substances that conduct electricity and classify them as conductors and non-conductors.
3. From your observations above, (a) what type of solids conduct electricity, (b) why do you think some of the materials conduct electricity? (c) Does graphite have the same nature as the other conductors of electricity?

Discuss in groups and present it to the class

Why do metals transmit electric current? What are the charge carriers in metals? Metallic conductivity refers to the transmission of electric current through metals. This transmission is directly related to the structure of metals. In atoms of metals, the valence electrons are bounded very loosely to their respective nuclei and move very easily throughout the metal. This means metals contain electrons that do not have fixed positions and are relatively free to move. These electrons are called free electrons or mobile electrons or delocalized electrons. Thus, the structure of the metals can be regarded as a series of positively charged metal ions, or cations, in a sea of negatively charged electrons.

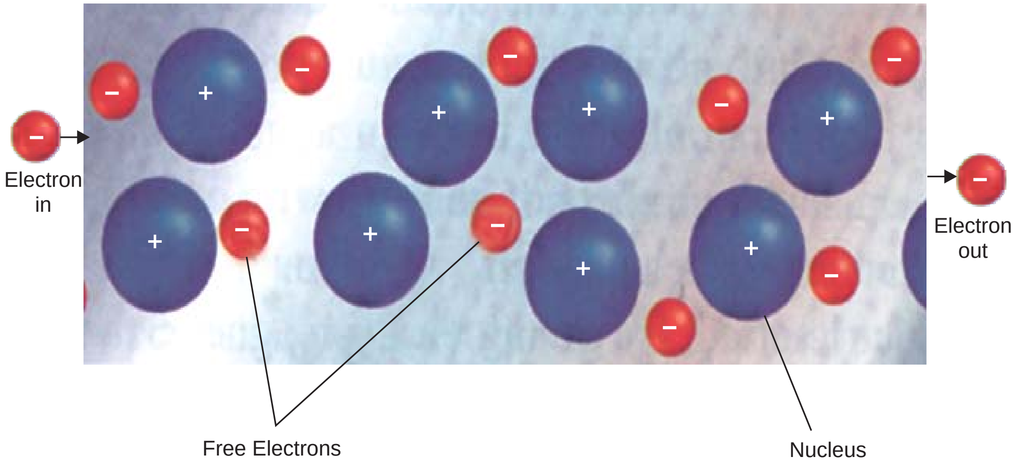


Figure 3.2 Electrical conductivity in metals.

The electrons entering the metal displace (repel) the freely moving electrons at the point of entry. The displaced electrons occupy new positions by pushing neighbouring electrons ahead. This will continue until electrons are forced out of the wire at the opposite end. So, metallic conductivity is caused by the flow of mobile electrons due to repulsion exerted on them from the electrons entering the metal from the source of electricity. The charge carriers in metallic conduction are electrons. Hence, metallic conductivity is also called electronic conductivity.

Non-metals are generally non-conductors of electricity, because they do not have freely moving electrons. Graphite is a form of carbon in which the carbon atoms are bonded in trigonal planar fashion to the three other carbon atoms, to form inter-connected hexagonal rings, as shown in Figure3.3. Electrons move freely through the hexagonal layers, making graphite a good conductor of electricity.

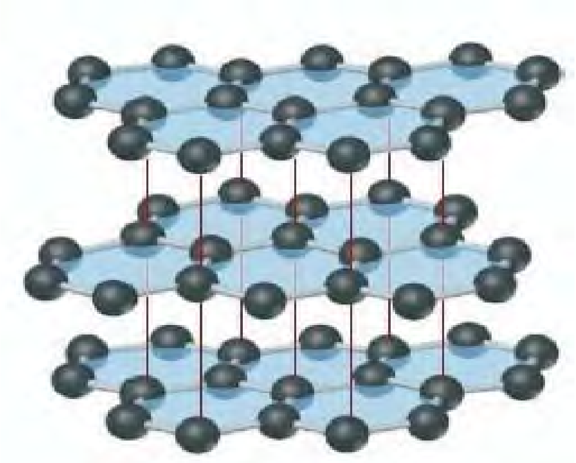


Figure 3.3 Structure of graphite (The blue colour is added to emphasize the planarity of the carbon layers.)

b) *Electrolytic conductivity*

Electrolytes are substances that transmit electricity in a molten state or in aqueous solution. Based on their degree of ionization or the extent to which they produce anions and cations, electrolytes can be classified as strong electrolytes or weak electrolytes. Strong electrolytes ionize almost completely in aqueous solutions. Weak electrolytes ionize only slightly. When electrical potential is applied through an electrolyte solution, the positive ions (*cations*) move in one direction and the negative ions (*anions*) move in the opposite direction. This movement of ions through the electrolyte, brought about by the application of electricity, is called electrolytic conductivity. Hence, the charge-carriers in electrolytic conductivity are ions (*anions and cations*).

Project 3.1

Construct a conductivity apparatus in your group. To construct the apparatus, you will need a light bulb, three dry cells, some electric wire, two graphite electrodes and a switch. You can get the graphite electrodes by peeling off two old dry cells. A graphite electrode is the long cylindrical black rod inside the cell. Ask your teacher for further assistance. Assemble the materials as shown in Figure 3.4. Demonstrate the experimental set-up to the class.

Experiment 3.1

Conductivity of electrolytes

Objectives: To test the conductivity of different electrolytes.

Materials required: Conductivity apparatus, distilled water, table salt, copper sulphate, hydrochloric acid, sodium hydroxide, acetic acid, ammonia solution, molten lead bromide and sugar solution.

Procedure:

1. Arrange the conductivity apparatus as shown in Figure 3.4.

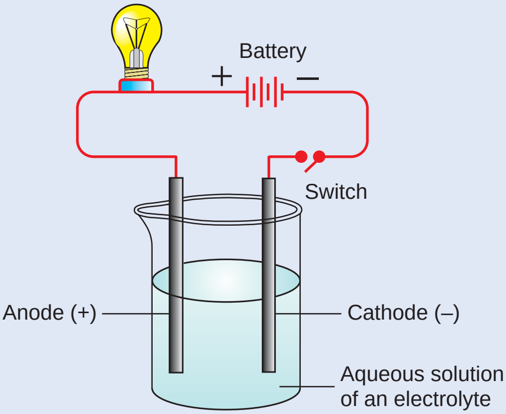


Figure 3.4 Conductivity of electrolytic solution.

2. Pour some distilled water in the beaker, dip the electrodes into the water and turn the switch on.
3. Repeat the experiment with separate solutions of table salt, copper sulphate, hydrochloric acid, sodium hydroxide, acetic acid, ammonia and sugar solutions (*use 1.0 M solutions of each*).

***Observations and Analysis*:**

- a Does the bulb glow when the switch is turned on?
- b Solutions of which substances make the bulb glow and not glow, when you turn on the switch?
- c Solutions of which substances make the bulb to glow with a:
  - i bright light?
  - ii dim light?
- d Classify the substances used in this experiment as strong conductors, weak conductors and non-conductors by completing the table below:

Strong conductors	Weak conductors	Non-conductors

- e Which substances in the experiment are used as:
  - i strong electrolytes
  - ii weak electrolytes

Write a laboratory report on what you have observed and submit to your teacher.

Exercise 3.1

1. Explain the difference between i) metallic and electrolytic conductivity ii) electrolyte and non-electrolyte.
2. Why do NaCl and $CaCl_2$ conduct electricity when they are dissolved in water or when they are in the molten form, but not in the solid state?
3. Why are solutions of strong electrolytes better conductors of electricity than weak electrolytes?

The substances that do not transmit electricity either in solution or in a molten state are called non-electrolytes. Ionic compounds are non-conductors of electricity in the solid state. This is because their ions are held at fixed positions and cannot move. Other examples of non-electrolytes include sugar, ethanol, oil, benzene, and liquid nitrogen.

3.3 ELECTROLYSIS

Competencies

After completing this section, you will be able to:

- define the term electrolysis;
- define the terms electrode, anode, cathode, electrolyte, anion and cation;

- describe an electrolytic cell;
- draw and label a diagram of an electrolytic cell;
- define the terms half-cell reaction and cell reaction;
- write the oxidation half-reaction, reduction half-reaction and cell reaction for the electrolysis of molten or fused electrolytes;
- perform an activity to show the electrolysis of molten electrolytes.

Activity 3.3

Give an opinion on the following questions and present your ideas to the class.

1. How do you identify whether an electrode is a cathode or an anode?
2. Can you suggest why positive and negative ions are named as cations and anions respectively?

Electrolysis is a process in which electrical energy is used to produce chemical changes. This process is carried out in an electrochemical cell known as an electrolytic or electrolysis cell. A typical electrolysis cell contains a source of direct electric current, an electrolyte and connecting wires that join the source to the electrodes.

Electrodes are strips of metal or graphite that allow electrons to leave or enter the electrolytes. They can be chemically active or inert. Active electrodes directly take part in reactions. Examples include zinc and magnesium. Inert electrodes do not directly take part in chemical reactions. They only serve to transfer electrons. Examples include platinum and graphite.

The electrode connected to the positive terminal of the source is positively charged and is called the anode. It is the electrode through which electrons leave the cell. The electrode connected to the negative terminal of the source is negatively charged and is called the cathode. It is the electrode through which electrons enter the cell.

During electrolysis, the ions of the electrolyte migrate to the electrodes of the opposite charge. The positive ions are attracted to the cathode and are called cations. Since the cathode has excess electrons, the cations will discharge by gaining electrons. This process of gaining electrons is called reduction. The negative ions are attracted by the positive electrode (*anode*) and are called anions. These ions are discharged by losing electrons at the anode. This process of losing electrons is called oxidation.

Thus, the cathode is the electrode at which reduction occurs and the anode is the electrode at which oxidation takes place.

The reaction that takes place at each electrode is known as a half-cell reaction. Oxidation half-reactions occur at the anode and reduction half reaction at the cathode. The net reaction that takes place in the electrolytic cell is known as a cell reaction. This overall reaction is also referred to as an oxidation-reduction reaction or redox reaction. So electrolysis is a process in which electric energy is used to bring about an oxidation-reduction reaction. It is also defined as the decomposition of an electrolyte, using electricity. The process of electrolysis includes electrolyzing aqueous solutions of electrolytes. However, at this level, electrolysis of molten electrolytes will be discussed.

Electrolysis of Molten (Fused) Electrolytes

When ionic solids melt, they dissociates into positive and negative ions that are not held in fixed positions. To understand the chemical reactions that occur during electrolysis, consider a hypothetical electrolyte, MX, that dissociate into M^+ and X^-.

$$MX \xrightarrow{\text{melting}} M^+ + X^-$$

During electrolysis, the cations, M^+ ions, move toward the cathode, gain one electron each and become M atoms. The anions, X^- ions, move toward the anode, lose one electron and become X atoms. The reaction at each electrode and the entire reaction in the electrolytic cell are represented by the following equations.

Cathode reaction: $M^+ + 1e^- \rightarrow M$ (*Reduction-half reaction*)

Anode reaction: $X^- \rightarrow X + 1e^-$ (*Oxidation half-reaction*)

Cell reaction: $M^+ + X^- \xrightarrow{\text{electrolysis}} M + X$ (*Oxidation-reduction*)

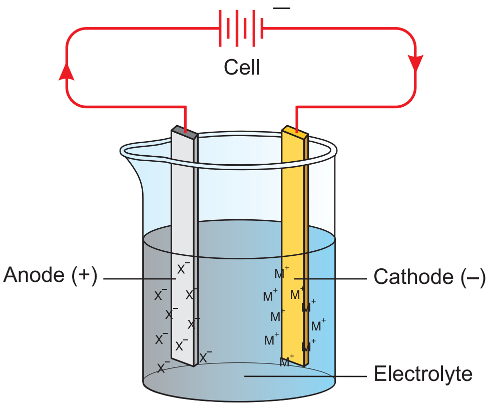


Figure 3.5 Electrolysis of fused Electrolyte, MX.

Here, it is very important to realize that the number of electrons gained by the cations at the cathode is exactly equal to the number of electrons lost by anions at the anode during electrolysis. This is true for any oxidation-reduction (*redox*) reaction. Moreover, oxidation and reduction reactions proceed simultaneously. Reduction and oxidation cannot occur separately. Oxidation is always accompanied by reduction and there cannot be reduction in the absence of oxidation, and vice versa.

Electrolysis of Molten (Fused) lead bromide

Experiment 3.2

Electrolysis of fused lead Bromide ($PbBr_2$)

Objectives: To observe substances produced at the electrodes during electrolysis.

Materials required: Stand and clamp, two graphite electrodes, wires, switch, light bulb, test tube (*bigger in size*), Bunsen burner, lead bromide crystals.

Precaution: Bromine causes very severe burn on the skin.

Procedure:

1. Assemble the materials as shown in Figure 3.6.

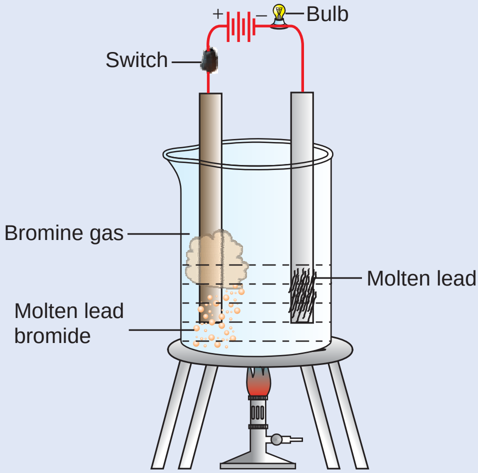


Figure 3.6 Electrolysis of Fused Lead Bromide.

2. Place small amount of lead bromide crystals in a beaker. Insert the two electrodes, as shown in Figure 3.6, until they are in contact with the lead bromide crystals. Then turn on the switch. Does the bulb glow?
3. Heat the lead bromide in a beaker gently, using a Bunsen burner. When the lead bromide melts, turn on the switch.

Observations and Analysis:

1. Does the bulb glow? If yes, what is the reason?
2. Write the dissociation reaction for $PbBr_2$.
3. Identify the ions which migrate to the respective electrodes.
4. Write the products formed at each electrode.
5. Identify the half reactions as oxidation and reduction.

Write a laboratory report on your observation and present to the class.

Exercise 3.2

Consider the electrolysis of KI and NaCl

a Identify ions which migrate towards the anode.

b Identify ions which migrate towards the cathode.

c Write down the half-reactions at the anode and cathode and cell reactions.

d Write the substances produced at the electrodes.

3.4 GALVANIC (VOLTAIC) CELLS

Competencies

After completing this section, you will be able to:

- construct a simple galvanic cell, using strips of zinc, copper, $ZnSO_4$ and $CuSO_4$ solutions;
- mention different types of voltaic cells;
- describe how voltaic cells can be used to make commercially useful batteries;
- distinguish between voltaic cell and an electrolytic cell;
- describe voltaic cells.

Activity 3.4

Discuss the following and present your ideas to the class:

1. Have you seen the expiry date written on dry cells? Can we get the expected amount of electric energy after the expiry date of the cell; why?
2. Do we throw away car batteries when they fail to generate electricity? Explain.
3. Galvanic cells available in the market have positive and negative terminals. Does this show that they also possess an anode and cathode?

In the previous section, electrolytic cells were defined as electrochemical cells in which electricity was used to bring about chemical reactions. The chemical reaction in an electrolytic cell is caused by electricity and is a non-spontaneous redox reaction. This means the reaction can proceed only in the presence of electricity. If we stop passing electricity through the electrolyte, the reaction will stop.

In a Galvanic cell, the reaction that occurs inside the cell is a spontaneous redox reaction. The reaction that occurs inside the cell will proceed on its own without any external influence. This reaction enables a galvanic cell to generate electricity. Therefore, Galvanic cells are electrochemical cells in which spontaneous redox reactions generate electricity. They convert chemical energy into electrical energy.

Galvanic or voltaic cells are classified into primary cells, secondary cells, and fuel cells. For this level, only primary and secondary cells will be discussed.

Primary Cells

Primary galvanic cells are those cells that are not rechargeable. This is because the electrode reaction as well as the entire cell reaction cannot be reversed on recharging. Once the chemicals in the cells that serve as reactants are completely used up, it is not possible to recover them by charging the cells. Examples of primary cells include Daniel's cell and zinc-carbon (*Leclanche*) dry cells. The common feature of all Galvanic cells is that they contain two electrodes in contact with an electrolyte. The electrolyte in a Galvanic cell can be in the form of a solution or a paste. The cells containing electrolytes in the form of solution are called wet cells, and those containing electrolytes in the form of paste are called dry cells.

An example of a wet primary cell is the Daniell cell. It consists of a zinc strip placed in $ZnSO_4$ solution in one compartment and a copper strip placed in copper sulphate, $CuSO_4$, solution in another compartment. Each compartment is called a half-cell, and the reactions occurring in each compartment are called half-cell reactions. The solutions in the two compartments are linked by a salt bridge as shown in Figure 3.7. The salt bridge consists of a delivery tube filled with warm mixture of conc. KCl solution and agar solution, which is then allowed to cool so that it sets in the form of a gel.

Alternately, a porous barrier is used to separate the solutions. The zinc atoms from the zinc electrode lose two electrons each and become zinc ions, Zn^{2+}. The ions enter into the solution, and the electrons remain on the electrode and flow through the external wire to the copper electrode. This situation causes the zinc electrode to be negative and the solution to have an overall positive charge.

On the other hand, in the compartment containing the copper electrode, copper ions, Cu^{2+}, from the solution move to the cathode and gain two electrons each, to become copper atoms and deposit on the surface of the copper electrode. This condition causes the electrode to be positive and the solution to have a negative charge.

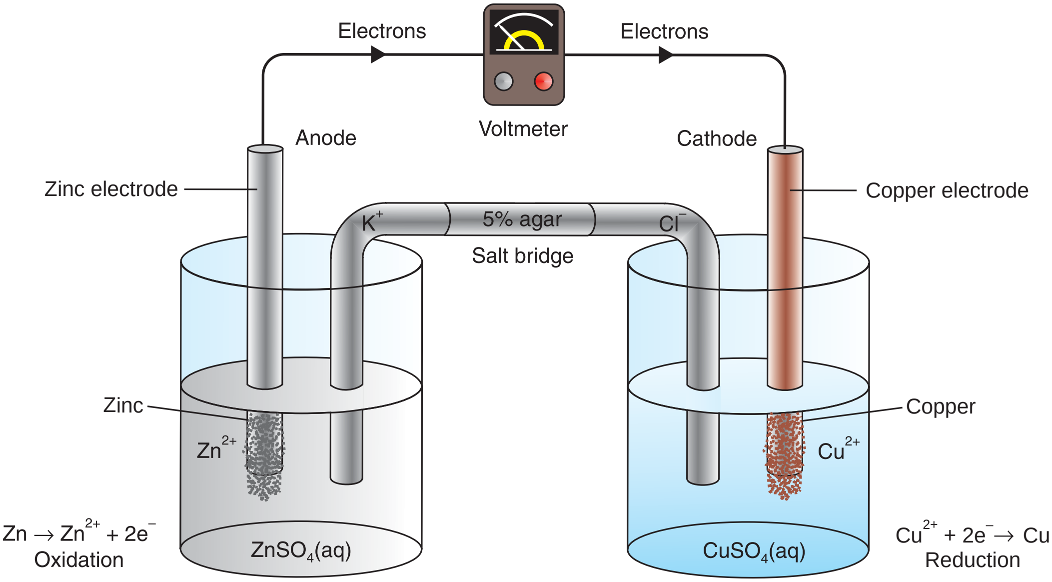


Figure 3.7 The Daniell Cell.

Note that the anode is the negative electrode and the cathode is the positive electrode in galvanic cells, as opposed to the situation in an electrolytic cell. But, it is always oxidation that occurs at the anode and reduction at the cathode.

The half-cell reactions and the cell reaction in Daniell cells are represented as

Anode reaction: $Zn\ (s) \rightarrow Zn^{2+}\ (aq) + 2e^-$

Cathode reaction: $Cu^{2+}\ (aq) + 2e^- \rightarrow Cu\ (s)$

Cell reaction: $Zn\ (s) + Cu^{2+}\ (aq) \rightarrow Zn^{2+}\ (aq) + Cu\ (s)$

Due to the oxidation-reduction reaction in the cell, the Daniell cell generates electricity.

What is the purpose of the salt bridge in Figure 3.7?

From the preceding discussion, it is clear that the solution in which the zinc electrode is placed has an overall positive charge while the solution in the copper compartment has a negative charge. Unless the two solutions are neutral, the cell cannot produce electricity. Thus, the purpose of the salt bridge is to:

a maintain electrical neutrality between the two solutions. In this process the anions (*negative ions*) from the salt bridge diffuse into the solution containing the zinc electrodes, and the cations (*positive ions*) diffuse into the solution containing the copper electrode to compensate for the excess positive and negative charges, respectively;

b allow electrical contact between the two solutions;

c prevent mixing of the electrode solutions.

Although, wet cells like the Daniell cell can serve as a source of electricity, they are not portable since they contain solutions. Due to this practical problem of using wet cells, dry cells were developed.

In a dry cell, a moist electrolyte paste is used instead of solutions. This cell was invented by Georges Leclanche, a French chemist.

A zinc-carbon dry cell, which is also called a Leclanche cell (Figure 3.8) is used in devices like portable radios and flashlights. The cell consists of a zinc cup that serves as the anode. The zinc cup is filled with a paste of manganese (IV) oxide, zinc chloride, ammonium chloride and powdered carbon. A graphite rod, immersed in this paste, serves as the cathode.

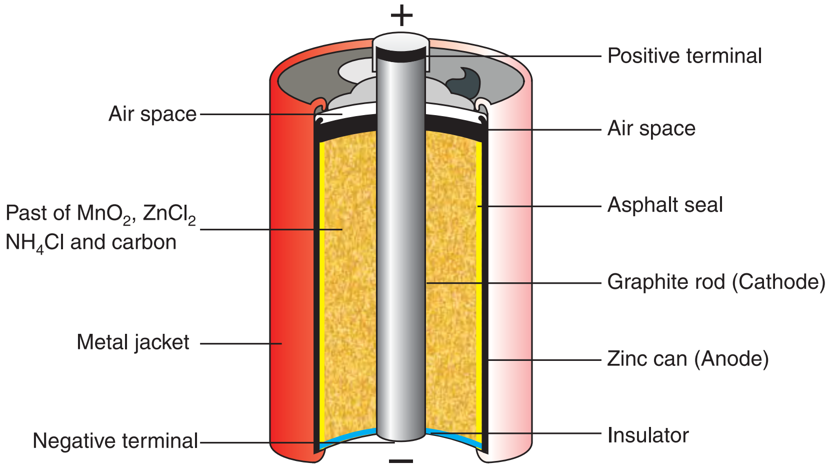


Figure 3.8 Zinc-carbon dry cell (Leclanche cell).

A zinc-carbon dry cell produces electricity as a result of a spontaneous redox reaction. Oxidation occurs at the zinc cup.

Oxidation: $Zn\ (s) \rightarrow Zn^{2+}\ (aq) + 2e^-$

Reduction takes place at the graphite (*carbon*) electrode.

$$2MnO_2\ (s) + 2NH_4^+\ (aq) + 2e^- \rightarrow Mn_2O_3\ (s) + 2NH_3\ (aq) + H_2O\ (l)$$

A build up of ammonia gas around the cathode may disrupt the current. However, this is prevented by the reaction between Zn^{2+} and NH_3 to form a complex ion, $[Zn(NH_3)_2]^{2+}$ which crystallizes as a chloride salt.

$$Zn^{2+}\ (aq) + 2NH_3\ (g) + 2Cl^-\ (aq) \rightarrow Zn(NH_3)_2\ Cl_2\ (s)$$

The overall reaction occurring in a Leclanche cell is:

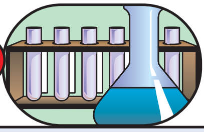
$$\mathrm{Zn\ (s) + 2MnO_2\ (s) + 2NH_4Cl\ (aq) \rightarrow Zn(NH_3)_2Cl_2\ (s) + Mn_2O_3\ (s) + H_2O\ (l)}$$

There are other examples of dry cells, such as the alkaline dry cell, silver oxide cell, and copper oxide cell.

Exercise 3.3

1. In a Daniell cell, copper and zinc are used as electrodes. Which metal serves as an anode and which one as a cathode? Is the anode the positive or the negative terminal in this cell?
2. Which electrode is negative and which one is positive in the Leclanche cell? Is the polarity of the electrodes in Galvanic cells similar to that of the electrodes in electrolytic cells?
3. Why do we refer to the redox reactions in electrolytic and voltaic cells as non-spontaneous and spontaneous, respectively?

Experiment 3.3



Constructing Simple Galvanic Cells

Objectives: To design and construct a simple Galvanic cell.

Materials required: 1.0 M solutions of $ZnSO_4$, 1.0 M solutions of $CuSO_4$, concentrated KCl solution, zinc and copper strips, electric wires, beakers, a salt bridge, a tomato or lemon, magnesium ribbon, zinc, iron and aluminium metals.

Procedure:

1. Put about 150 mL of 1.0 M $ZnSO_4$ solution in one beaker and the same amount of 1.0 M $CuSO_4$ solution in another beaker. Immerse a zinc strip in the beaker containing the $ZnSO_4$ solution, and immerse a copper strip in the copper sulphate solution. Attach electric wires to the electrodes and a voltmeter as shown in Figure 3.7. Connect the solutions in the two beakers by yarn (*thread used in kerosene stoves*). Soak the yarn in concentrated KCl solution.
2. Insert a magnesium ribbon and a copper strip into a raw tomato or lemon. The two metals should be at least 0.5 cm apart and should not touch each other. Attach magnesium and copper strips to the negative and positive ends of a voltmeter, respectively, using electric wires.

3. Repeat the same procedure using metals like Fe, Al, Zn in place of Magnesium and see which of the metals gives the greatest voltage and which one the least.

Observations and Analysis:

A For the cell in procedure 1

1. What do you observe at each electrode in this cell?
2. What is the direction of electron flow in the external circuit?
3. Which metal serves as the a) anode b) cathode
4. At which electrode does a) oxidation b) reduction occur?
5. Write the a) anode b) cathode and c) cell reaction

B For the cell in procedure 2

1. Do you observe deflection of the pointer in the volt meter?
2. Which of the metals has the greatest voltage and which one the least when coupled with copper?
3. Is there any relationship between the voltage produced and the reactivity of the metals?

Write a laboratory report and submit to your teacher.

Secondary Cells

Unlike primary cells, secondary cells are rechargeable. The electrode reactions can be reversed, and the original reactants can be regenerated. This can be achieved by passing a direct current through the cell. The process is called charging or recharging.

A secondary cell needs to be recharged when it stops producing electricity. A lead storage battery is an example of a secondary cell.

A lead Storage Battery is the common automobile battery that usually delivers either 6 or 12 volts, depending on the number of cells used in its construction. The inside of the battery consists of galvanic cells connected in series. A fully-charged lead-acid cell is made up of a stack of alternating lead and lead (IV) oxide plates isolated from each other by porous separators. The individual cells contain a number of lead anodes connected together, plus a number of cathodes composed of PbO_2, also joined together. These electrodes are immersed in 35% sulphuric acid, which serves as an electrolyte.

A single lead-storage cell delivers 2 volts. Therefore, a 12 V battery contains six cells connected in series.

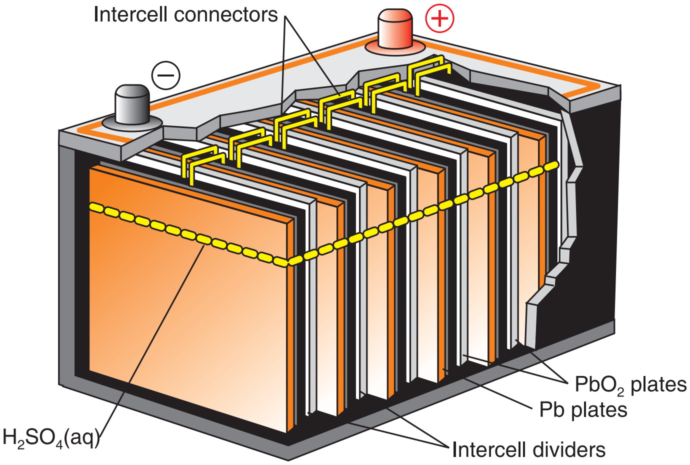


Figure 3.9 Lead - Storage Battery.

When a lead-storage battery is in operation (*on discharge*), the following reactions occur at the electrodes:

Anode reactions: $Pb\ (s) + SO_4^{2-}\ (aq) \rightarrow PbSO_4\ (s) + 2e^-$

Cathode reactions: $PbO_2\ (s) + 4H^+\ (aq) + SO_4^{2-}\ (aq) + 2e^- \rightarrow PbSO_4\ (s) + 2H_2O\ (l)$

and the overall reaction is:

$$Pb\ (s) + PbO_2\ (s) + 4H^+\ (aq)\ 2SO_4^{2-}\ (aq) \rightarrow 2PbSO_4\ (s) + 2H_2O\ (l)$$

From the electrode reactions it can be noticed that $PbSO_4$ is produced at both electrodes.

Unlike primary cells a lead-storage battery is rechargeable when the battery runs down. The electrode reactions can be reversed by placing a potential across the electrodes that is slightly larger than that which the battery can deliver. The reaction that takes place on recharging a lead storage battery is given by the following equation.

$$2PbSO_4\ (s) + 2H_2O\ (l) \rightarrow Pb\ (s) + PbO_2\ (s) + 2H_2SO_4\ (aq)$$

What are the differences between voltaic cells and electrolytic cells?

Activity 3.5

Compare and contrast between voltaic and electrolytic cells. List the differences between voltaic cells and electrolytic cells, and discuss with your classmates.

Exercise 3.4

1. Explain the differences between primary and secondary cells.
2. What substances are used as the anode, cathode and electrolyte in a lead storage battery?
3. What happens to the concentration of sulphuric acid when a lead storage battery is on discharge?
4. Write the overall reactions taking place in a lead storage battery when it is discharging.

3.5 INDUSTRIAL APPLICATIONS OF ELECTROLYSIS

Competencies

After completing this section, you will be able to:

- describe selected industrial applications of electrolysis;

Activity 3.6

1. The copper used for the transmission of electric current is supposed to be 100% pure. What happens if the copper is impure?
2. How many articles in your house are electroplated? Make a list. What is the purpose of electroplating?

Discuss in groups and share your opinions with your classmates.

Each day, our lives are touched directly or indirectly by the products of electrolysis. Electrolysis has important industrial applications. It is used for:

a) *The production of chemicals like sodium hydroxide, from electrolysis of brine (concentrated NaCl solution), using inert electrodes.*

The reactions that take place at the electrodes (*when graphite electrodes are used*) are as follows:

Anode reaction: $2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$

Cathode reaction: $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

The overall cell reaction is:

$$2NaCl(aq) + 2H_2O(l) \rightarrow 2Na^+(aq) + 2OH^-(aq) + Cl_2(g) + H_2(g)$$

b) *For the production of metals and non-metals.*

The non-metals like H_2, Cl_2, F_2 etc are manufactured on an industrial scale by the process called electrolysis. The metal aluminium is extracted industrially by the Hall Process. This process involves the electrolysis of molten alumina (Al_2O_3) mixed with some amount of cryolite, Na_3AlF_6. The role of cryolite is to reduce the melting point of alumina from 2000°C to 1000°C. The vessel holding the molten mixture (Figure 3.8) is made up of iron lined with carbon, which serves as the cathode. Carbon (*graphite*) rods that serve as the anode are inserted into the melt. When the molten mixture is electrolyzed, pure aluminium is produced. The reactions at the electrodes are:

Anode reaction: $6O^{2-}(l) \rightarrow 3O_2(g) + 12e^-$

Cathode reaction: $4Al^{3+}(l) + 12e^- \rightarrow 4Al(l)$

Overall reaction: $4Al^{3+}(l) + 6O^{2-}(l) \rightarrow 3O_2(g) + 4Al(l)$

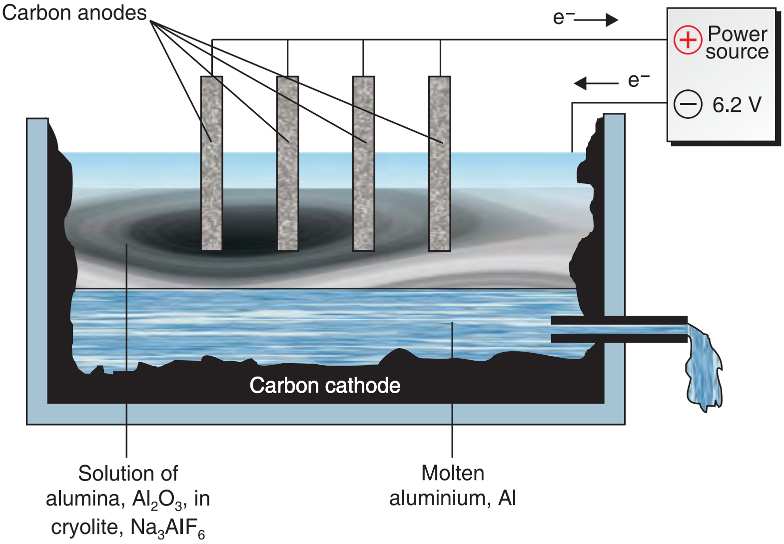


Figure 3.10 Production of Aluminium by Hall Process.

c) *For the Purification of Metals.*

Activity 3.7

For electrolytic and voltaic cells, the cell reaction is the sum of anode and cathode half-reactions. For electrolytic cell used to purify copper, there is no net (overall) reaction.

a Explain why this is so.

b Does this process mean wastage of time, labour and energy? Why? Discuss in groups and present your opinion o the rest of the class.

Another important application of electrolysis is the purification of metals like copper. When first separated from its ore, copper metal is about 99% pure with nickel, silver, gold and platinum as major impurities. In the refining process, the impure copper is used as the anode, copper metal of high purity used as cathode, and copper sulphate, $CuSO_4$ solution and aqueous H_2SO_4 as the electrolyte.

When electrolysis is carried out, copper and impurities that are more easily oxidized than copper, such as nickel, will go into the solution. Copper passes through the solution and deposits on the cathode, while the impurities remain in solution. Impurities like silver and gold are less easily oxidized and do not dissolve but fall away from the anode as 'sludge'. The electrode reaction in the purification of copper is the following:

Anode reaction: $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$

Cathode reaction: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

During the process, the size of the impure copper anode decreases and that of the pure copper cathode increases.

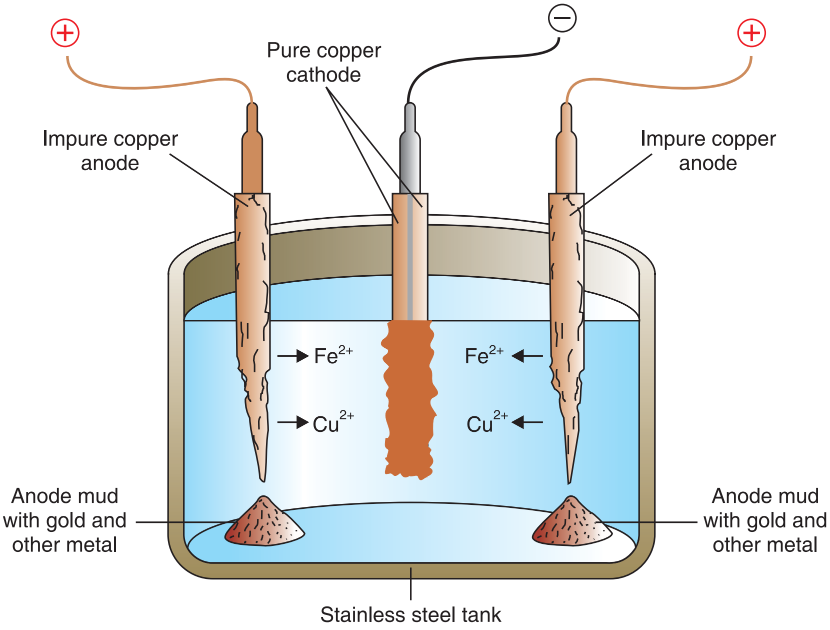


Figure 3.11 Purification of Copper by Electrolysis.

Always remember that, in the purification of metals by electrolysis, the impure metal should be used as the anode, the pure form of the metal as the cathode and an electrolyte should contain soluble salt (*ions*) of the metal to be purified. The process of purifying metals by electrolysis is called electrorefining.

d) *Electroplating*

Activity 3.8

When zinc electrode is dipped in copper sulphate solution, part of the electrode in the solution will be covered with a reddish brown layer of copper. Can this process be considered as electroplating? Explain. Discuss in groups and present your opinion to the class.

What is the purpose of electroplating?

Electroplating is a process of covering the surface of a metal (*metal article*) with a thin layer of another metal. Using this process, metals that easily corrode can be protected by a thin coating of another metal that resists corrosion. For example, tin cans are steel cans with a thin coating of tin, and chrome-plated bumpers are used for automobiles. Thus, the main objective of electroplating is to protect an article from corrosion and to give articles a beautiful appearance. In the process of electroplating, the pure plating metal should be used as the anode, the article (*metal*) to be plated the as cathode and a solution containing ions of the plating metal as the electrolyte. For example, to produce a silver-plated copper article, say, a medal, one should use silver as the anode, the copper medal as the cathode and silver nitrate solution as the electrolyte (Figure 3.12).

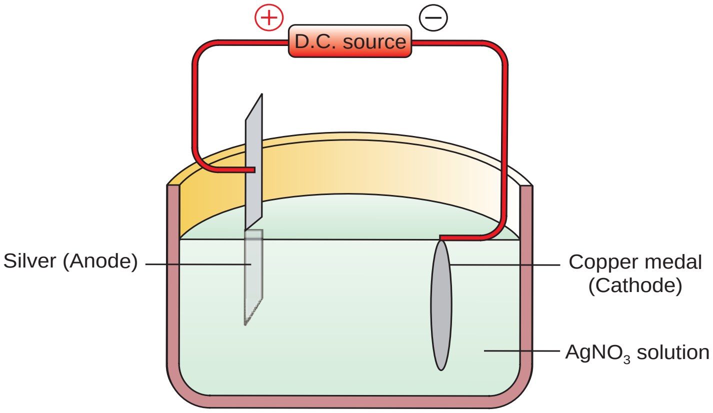


Figure 3.12 Electroplating Copper medal with Silver.

The reactions that occur at the electrodes during electroplating are:

Anode reaction: $Ag\,(s) \rightarrow Ag^{+}(aq) + 1e^{-}$

Cathode reaction: $Ag^{+}(aq) + 1e^{-} \rightarrow Ag\,(s)$

Check list

Key terms of the unit

- *anode*
- *cathode*
- *conductivity apparatus*
- *Daniel cell*
- *electrical conductivity*
- *electrochemical cell*
- *electrochemistry*
- *electrode*
- *electrolysis*
- *electrolyte*
- *electrolytic cell*
- *electroplating*
- *electrorefining*
- *half - cell*
- *half - reaction*
- *hall process*
- *primary cell*
- *salt bridge*
- *secondary cell*
- *voltaic (galvanic) cell*

Unit Summary

- *Electrochemistry is a field of chemistry that studies how chemical reactions produce electricity and how electricity is used to bring about chemical reactions in electrochemical cells.*
- *Electrochemistry deals with the relationship that exists between chemical energy and electrical energy.*
- *Electrochemical cells include electrolytic cells and Galvanic (voltaic) cells.*
- *Electrical conductivity is the ability of substances to conduct electricity.*
- *Metallic conductivity is the flow of electricity through metals, and the conduction of electricity through metals is due to the presence of freely moving (delocalized) valence electrons.*
- *Electrolytes are substances that conduct electricity, either in an aqueous solution or in a molten state.*
- *The conduction of electricity through electrolytes is due to the movement of anions and cations towards electrodes of opposite charge, and the charge-carriers in electrolytic conduction are ions.*
- *Electrolysis is a process in which electricity is used to bring about an oxidation- reduction reaction in an electrolytic cell.*
- *Electrolysis is also the process of decomposition of an electrolyte, using electrical energy.*

- *Electrodes are either metal strips or graphite rods.*
- *An anode is the electrode attached to the positive terminal of a direct current source, at which oxidation (loss of electrons) by anions occurs, and electrons leave the cell.*
- *A cathode is the electrode attached to the negative terminal of a dc source, the negative electrode at which reduction (gain of electrons) of cations occurs and electrons enter the cell (electric current enters the electrolyte).*
- *During electrolysis, anions move to the anode and cations move to the cathode.*
- *The reaction taking place at each electrode (cathode or anode) is said to be a half-cell reaction.*
- *Cell reaction is the reaction that takes place in the entire cell.*
- *Voltaic (Galvanic) cells are electrochemical cells in which a spontaneous redox reaction generates electricity. They convert chemical energy into electrical energy.*
- *Primary cells are voltaic cells that are not rechargeable, and the reactions taking place in them are irreversible.*
- *Secondary cells are voltaic cells that are rechargeable since the reactions taking place in them are reversible.*
- *Unlike electrolytic cells, the anode is negative and the cathode is positive in voltaic cells.*
- *Electrolysis has important industrial applications such as in the production of chemicals like NaOH, in the production of non-metals like Cl_2 and H_2, metals like Na, Al and in purification of metals and electroplating.*

REVIEW EXERCISE ON UNIT3

Part I: Choose the correct answer from the suggested options

1. Which one of the following solutions shows no current flow in an electrolytic cell?

   a water solution of table salt

   b molten sodium chloride

   c hydrochloric acid solution

   d sugar solution

2. Which of the following is not correct about voltaic cells?
   - a the anode is negative
   - b the cathode is positive
   - c oxidation takes place at the cathode
   - d redox reactions produce electricity in the cell
3. Which of the following conditions is not used to electroplate a tray made of iron with chromium?
   - a using chromium as the anode
   - b using an electrolyte containing iron (III) ions
   - c using the tray as the cathode
   - d using an electrolyte containing chromium ions
4. Electrolysis is not used for the:
   - a purification of metals
   - b production of metals
   - c electroplating of metals
   - d production of electricity
5. Which substance is not used in the Leclanche cell?
   - a H_2SO_4
   - b NH_4Cl
   - c MnO_2
   - d powdered carbon
6. Which one of the following is correct about automobile batteries?
   - a the electrodes in the battery are graphite electrodes
   - b each cell in the battery delivers 1.5 volts
   - c the electrolyte is aqueous H_2SO_4 solution
   - d lead (IV) oxide is used as anode
7. Which of the following occurs during electrolysis of the molten binary salt of a metal:
   - a the metal in the salt will deposit on the cathode
   - b reduction will take place at the anode
   - c oxidation will take place at the cathode
   - d no current will flow through the molten salt
8. Which substance does not conduct electricity?
   - a solid $CaCl_2$
   - b aqueous NaCl solution
   - c dilute aqueous solution of HCl
   - d molten $PbBr_2$

9. Two copper electrodes dipped in copper sulphate solution are connected to a 12 volt battery. The electrode connected to the end of the battery marked with a "–" is:

a anion
b cathode
c anode
d cation

10. The charge-carriers in electrolytic conduction are:

a anions only
b cations only
c cations and anions
d delocalized electrons

11. When electric current is applied externally, which of the following produces a redox reaction:

a wood
b electrolytic cells
c solid sugar
d diamond

12. During the electrolysis of fused sodium chloride, the anode half reaction involves:

a oxidation of sodium atoms to ions
b reduction of chlorine atoms to give chloride ions
c reduction of sodium ions to form free metal
d oxidation of chloride ions to elemental chlorine

13. Metals conduct electricity. This is because metals possess:

a freely moving ions
b all electrons held in fixed position
c delocalized electrons
d valence electrons that are strongly bound to the nucleus

14. Increasing the concentration of ions in an electrolyte solution:

a increases the extent of conduction of electricity through it
b decreases the extent of conduction of electricity through it
c has no effect on the conduction of electricity
d changes the direction of electron flow

15. Voltaic cells and electrolytic cells are similar in that:

a the anode is positive and cathode is negative in both types of cells
b oxidation half-reaction occurs at the cathode in both types of cells
c both types of cells contain two electrodes in contact with electrolytes
d reduction half-reaction occurs at the anode in both types of cells

16. The conduction of electricity through each of the following substances is caused by the migration of ions except in one case; the exception is:

a fused lead bromide
b aqueous solution of NaCl
c molten KCl
d graphite

17. Four different solutions of equal volume (1 L) were prepared by dissolving one mole of each of the following substances. The conduction of electricity is least in the solution containing:

a	HCl	c	HNO_3
b	CH_3COOH	d	KCl

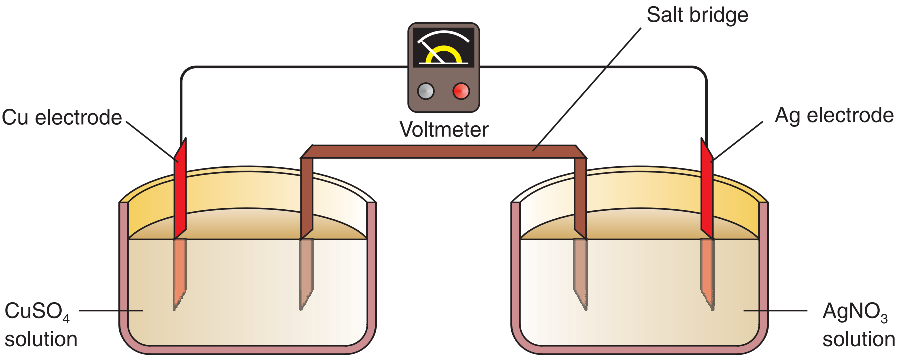
18. Strong electrolytes differ from weak electrolytes in that strong electrolytes:
    - a are poorer conductors than weak electrolytes
    - b ionize to a smaller extent than weak electrolytes
    - c produce greater numbers of ions in aqueous solution as compared to weak electrolytes
    - d do not conduct electricity in aqueous solutions

19. Which of the following is a wet voltaic cell:
    - a Leclanche cell
    - b cells used in electronic wrist watches
    - c cells used in mobile telephones
    - d lead-storage cell

Part II: Write the missing words in your exercise book

20. The type of electrical conductivity caused by the flow of freely moving electrons is known as__________________.

21. Consider the following galvanic cell:



Half-reaction: $Cu\,(s) \rightarrow Cu^{2+}(aq) + 2e^{-}$

Half-reaction: $Ag^{+}(aq) + 1e^{-} \rightarrow Ag\,(s)$

According to the information given in the above figure, a The anode of the galvanic cell is ________________.

b The cathode of the galvanic cell is _______________.

c The negative electrode is ______________________.

d The positive electrode is ______________________.

e The overall cell reaction is _____________________.

22. _________________ means two metal strips or graphite rods through which electrons enter and leave an electrolyte in electrolytic cells.

23. In an electrolytic cell, positive ions move to the ______________ and negative ions move to the _____________ and electrons flow from the _____________ to the __________ in the external circuit during electrolysis.

24. The process of covering one metal with a thin layer of another metal, using electricity, is known as _______________.

Part III: Give short answers to each of the following questions

25. Explain the differences between the following pairs of terms.

a Anode and cathode

b Metallic conduction and electrolytic conduction

c Inert and active electrodes

d Galvanic cell and electrolytic cell

e Cation and anion

f Wet cell and dry cell

g Primary and secondary voltaic cells

h Strong and weak electrolytes

26. Why are ionic compounds like NaCl, KCl, $CaCl_2$, $PbBr_2$, etc. non-conductors in the solid state but conductors in aqueous solutions?

27. During electrolysis of fused $CaCl_2$,

a Which ions are responsible for the conduction of electricity through the molten salt?

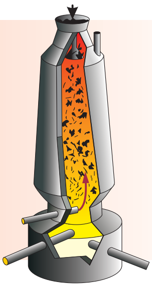
b What half-cell reactions occur at the anode and cathode?

28. How can a salt bridge maintain electrical neutrality in the solutions of the two half-cells of a galvanic cell?

29. A chemistry teacher in a chemistry laboratory asked two students, A and B, to perform an experiment. The teacher told student A to refine impure silver and told student B to produce a gold-plated medal from a medal made of copper. How can these students accomplish the tasks given to them?

30. What is the purpose of a salt bridge in a voltaic cell?

UNIT 4



Chemistry in Industry and Environmental Pollution

Unit Outcomes

After completing this unit, you will be able to:

- *know the renewable and non-renewable natural resources and appreciate their importance to industry as raw materials;*
- *know the extraction, chemical properties and uses of aluminium, iron, copper, nitrogen, phosphorus, oxygen, sulphur and chlorine;*
- *know the production and chemical properties of nitrogen, phosphorus, oxygen, sulphur and chlorine;*
- *know some chemical and related industries in Ethiopia;*
- *understand the important steps in the production of glass, ceramics, cement, sugar, paper and pulp;*
- *know how tanning is carried out and how food is packed and preserved;*
- *know the three types of environmental pollution and the names of the pollutants;*
- *understand the causes and effects of air, water and land pollution and know the main methods to reduce them; and*
- *demonstrate scientific inquiry skills such as observing, classifying, communicating, asking questions, applying concepts and problem-solving.*

MAIN CONTENTS

4.1 INTRODUCTION

Competencies

After completing this section, you will be able to:

- list general characteristics of chemical industries;

Activity 4.1

1. What do you understand by the statement that, "life would have been very much harder without the chemical industry."?
2. Name major raw materials used by chemical industries for the production of chemicals.
3. Prepare a list of many products which are manufactured by chemical industries? Discuss in groups and give a presentation to the class.

A chemical industry is an institution involved in the production of chemical products. The chemical industry involves the use of chemical processes such as chemical reactions and refining methods to produce a wide variety of materials with desirable properties and quality to satisfy social needs. Most of these products, in turn, can be used by other chemical industries to manufacture other items or can be used directly by consumers. Generally, chemical industries:

- use naturally-available raw materials to produce the desired products,
- involve chemical reactions to transform raw materials into finished and semi-finished products,
- consume relatively large quantities of energy during the manufacturing process,
- use safe operation methods in their manufacturing processes, and

- test their products during and after manufacture in their quality control laboratories to ensure that the products meet the required specifications.

4.2 NATURAL RESOURCES AND INDUSTRY

Competencies

After completing this section, you will be able to:

- define natural resources;
- list natural resources;
- classify natural resources as renewable and non-renewable;
- define the chemical industry as a firm that involves the taking of raw materials from the environment and turning them into usable products by chemical means;
- describe the applications of minerals in industry.

Activity 4.2

1. Can fossil fuels be renewed?
2. How can animals and plants be replaced once they die?
3. What are natural resources?
4. Explain the importance of natural resources for chemical industries with examples. Discuss in group and present your opinion to the class.

Natural resources can be classified as renewable and non-renewable resources. Renewable resources are resources that can be replenished (*replaced*) by natural processes. These resources can be renewed at the same rate at which they are used. Plants, animals, soil and water are examples of renewable resources. Non-renewable resources are resources that are found in a fixed amount in nature and cannot be replenished. These resources can be completely used up within some decades and cannot be replaced easily. Examples of non-renewable resources include natural gas, and coal. Generally, any chemical industry utilizes either natural resource as starting materials, or other substances obtained from natural resources after processing, as a raw material, for its manufacturing activity.

Exercise 4.1

Classify the following natural resources as renewable and non-renewable:

a petroleum
b minerals
c fire wood
d biomass
e plants
f coal

4.3 PRODUCTION OF SOME IMPORTANT METALS AND NON-METALS

Competencies

After completing this section, you will be able to:

- outline the extraction of aluminium by the Hall process;
- describe the main physical and chemical properties of aluminium;
- describe the uses of aluminium;
- outline the extraction of iron by the blast furnace;
- briefly describe the conversion of pig iron in steel;
- describe wrought iron;
- describe the main chemical properties of iron;
- describe the uses of iron;
- outline the extraction of copper;
- describe the main chemical properties of copper;
- describe the uses of copper;
- outline the production of nitrogen;
- describe the main chemical properties of nitrogen;
- outline the production of phosphorus;
- describe the main chemical properties of phosphorus;
- outline the production of oxygen;
- describe the main chemical properties of oxygen;
- outline the production of sulphur;
- describe the main chemical properties of sulphur;
- outline the production of chlorine; and
- describe the chemical properties of chlorine.

Activity 4.3

Discuss the following issues in groups:

1. Steel-cored aluminium cables are used for conducting high-voltage electricity over long distances.
   i) Give two reasons why aluminium is used for these cables.
   ii) What is the purpose of the steel core?

2. Can you mention materials, in your home or outside, that are made of aluminium? What are their properties for example weight, rusting, shape etc? Discuss in groups and give presentation to the class.

4.3.1 Production of Some Important Metals

A. Aluminium

Occurrence and extraction

Aluminium is the most abundant metal and the third most plentiful element after oxygen and silicon in the earth's crust. About seven percent of the earth's crust is aluminium. It is the second-most important metal, after iron, in terms of consumption. Aluminium does not occur as a free metal in nature. Its principal ore is bauxite ($Al_2O_3{\cdot}2H_2O$). Other minerals containing aluminium are orthoclase ($KAlSi_3O_8$), cryolite (Na_3AlF_6), corundum (Al_2O_3), beryl ($Be_3Al_2Si_6O_8$) and china clay ($Al_2Si_2O_7{\cdot}2H_2O$).

Aluminium is extracted industrially principally, from bauxite, $Al_2O_3{\cdot}2H_2O$, by the Hall–Héroult process or simply the Hall process. In this process, first the bauxite needs to be purified since it is frequently contaminated with silica (SiO_2), iron oxides and titanium (IV) oxide. To isolate pure Al_2O_3 from bauxite, the powdered ore is first heated with sodium hydroxide solution to convert silica into a soluble silicate.

$$SiO_2(s) \quad + \quad 2NaOH\,(aq) \quad \rightarrow \quad Na_2SiO_3(aq) \quad + \quad H_2O\,(l)$$

At the same time aluminium oxide is converted to soluble sodium aluminate.

$$Al_2O_3(s) \quad + \quad 2NaOH\,(aq) \quad \rightarrow \quad NaAlO_2(aq) \quad + \quad H_2O\,(l)$$

The impurities like iron oxides and titanium (IV) oxide remain unaffected by the base and are filtered off. Why are they not affected?

Then the solution is treated with acid to precipitate aluminium hydroxide.

$$AlO_2^-\,(aq) + \quad H_3O^+(aq) \quad \rightarrow \quad Al(OH)_3(s)$$

Aluminium hydroxide is collected by filtration, washed, dried, and then heated strongly in a furnace to get Al_2O_3.

$$2Al(OH)_3 \xrightarrow{\text{heat}} Al_2O_3 \quad + \quad 3H_2O$$

Pure aluminium oxide is mixed with some cryolite, Na_3AlF_6, and then melted. Cryolite is added to Al_2O_3 to reduce its melting point from 2045°C to 1000°C. The molten mixture is then electrolyzed to obtain aluminium. The electrolytic cell, in which the molten mass is electrolyzed, contains graphite electrodes as both anode and cathode.

Activity 4.4

1. Write the balanced chemical equation for the dissociation of aluminium oxide in the molten state.
2. Identify the ions that move to the cathode and the anode during the electrolysis of molten aluminium oxide? Write the half-reactions at the anode, cathode and overall cell reactions.
3. At which electrode will aluminium be produced during the process?

Discuss in groups and give a presentation to the class.

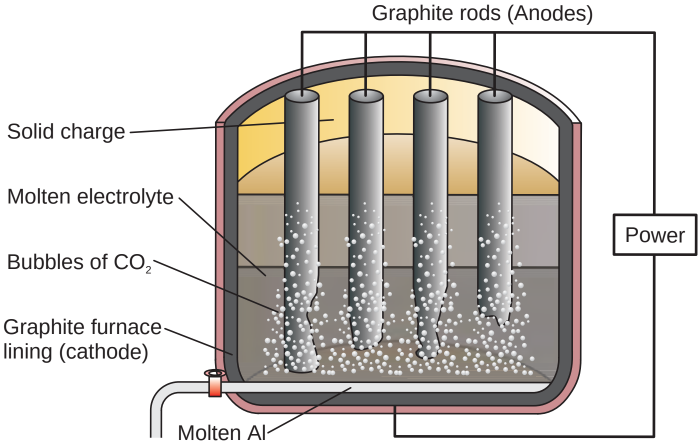


Figure 4.1 Electrolytic cell for aluminium production

Al_2O_3 is converted to Al, by electrolysis. *We do not use reducing agents for reduction of aluminium from aluminium oxide; why?*

Physical Properties: Aluminium is a soft silvery-white metal having a density of 2.7 g/cm^3. It melts at 660°C. It can be shaped into wires, rolled, pressed or cast into different shapes. It is a good conductor of heat and electricity.

Chemical Properties: Aluminium is a reactive metal, even though its reactions are not vigorous in comparison with those of sodium, potassium, calcium and other metals of group IA and IIA. It undergoes the following reactions:

a Reaction with Oxygen:

Aluminium has affinity for oxygen and reacts with atmospheric oxygen to form a thin film of aluminium oxide on its surface.

$$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$$

This thin film of oxide inhibits further reaction with oxygen. The thin film can be removed by rubbing with mercury or mercury (II) chloride solution.

What type of oxide is Al_2O_3?

b *Reaction with dilute acids:*

Aluminium reacts with dilute acids like HCl and H_2SO_4, forming salts and liberating hydrogen gas.

$$2Al(s) + 3H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$$

$$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(s) + 3H_2(g)$$

Aluminium does not react with dilute or concentrated HNO_3 due to the formation of a protective oxide layer on its surface.

c *Aluminium burns in chlorine gas to form aluminium chloride:*

$$2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s)$$

d *Aluminium reacts with sodium hydroxide solution:*

$$2Al(s) + 2NaOH(aq) + 6H_2O(l) \rightarrow 2NaAl(OH)_4(aq) + 3H_2(g)$$

Uses: Aluminium is lightweight and corrosion resistant, so it is used to make light alloys like duralumin (*mixture of* Al, Cu and Mg). Alloys of aluminium are extensively used in the transport industry to make aircraft, ships and cars. It is used in the manufacture of household cooking utensils due to its high thermal conductivity and resistance to corrosion. It is also used to make door and window frames and roofing for buildings, as packaging material in food industries, and for electrical transmission lines.

In the thermite welding process, powdered aluminium when mixed with iron (III) oxide and ignited, produces a temperature of about 3000°C. This temperature is quite sufficient for welding metals. The reaction in this process is as follows:

$$2Al(s) + Fe_2O_3(s) \rightarrow 2Fe(l) + Al_2O_3(s)$$

The mixture of powdered aluminium and iron oxide is called thermite.

Research and writing

1. Make a list of materials made of aluminium you encounter at home, and in the city or town where you live.
2. What property of aluminium makes it useful in the construction industries?
3. Regarding the manufacturing of aluminium by electrolysis, answer the following questions.
   a The electrolyte does not need heating to keep it in its molten state; why?
   b The graphite anode gradually disappear during the electrolysis. What is it turning into? (*Think about the product that is given off at the anode*).

Present your findings to the class.

Activity 4.5

1. Iron is the cheapest among all metals. Give reasons for this.
2. What is the difference between stainless steel and iron?
3. What do you understand by the term alloy? Is stainless steel an alloy?

Discuss in groups and give a presentation to the class.

B. Iron

Occurrence and Extraction

Iron is the second-most abundant metal next to aluminium, in the earth's crust and it is the fourth most abundant element. It constitutes about 4.7% of the earth's crust by weight. It is never found as a free metal in nature. It occurs in nature only in the form of compounds, such as oxides, carbonates and sulphides. The chief ores of iron are hematite (Fe_2O_3), limonite ($Fe_2O_3 \cdot H_2O$), magnetite (Fe_3O_4), and siderite ($FeCO_3$). It is also found in the form of iron pyrites (FeS_2) which is commonly called fool's gold.

Iron is generally extracted from hematite (Fe_2O_3), magnetite (Fe_3O_4) and siderite ($FeCO_3$). The extraction of iron from its ores is carried out in a blast furnace. The raw materials for the extraction of iron are iron ore, coke, limestone and hot air. The furnace is charged with a mixture of iron ore, limestone and coke at the top and a blast of hot air is blown in at the bottom. The coke burns to form carbon dioxide and the temperature approaches 2000°C near the bottom. As the carbon dioxide rises up, the coke reduces it to carbon monoxide. The carbon monoxide then reduces the iron oxide to iron metal. The overall reactions in the blast furnace can be summarized as follows:

1. Oxidation of coke to carbon dioxide:

   $C(s) + O_2(g) \rightarrow CO_2(g) + \text{heat}$

2. Reduction of carbon dioxide to carbon monoxide:

   $CO_2(g) + C(s) \rightarrow 2CO(g)$

3. Reduction of iron oxides to metallic iron by carbon monoxide:

   $3Fe_2O_3(s) + CO(g) \rightarrow 2Fe_3O_4(s) + CO_2(g)$

   $Fe_3O_4(s) + CO(g) \rightarrow 3FeO(s) + CO_2(g)$

   $FeO(s) + CO(g) \rightarrow Fe(l) + CO_2(g)$

4. Decomposition of the limestone by heat in the blast furnace serves as a flux to *remove impurities*:

$$CaCO_3\,(s) \xrightarrow{\text{heat}} CaO\,(s) + CO_2\,(g)$$

5. Reaction of calcium oxide with impurities like silica (SiO_2) to form calcium silicate which is a glass-like material called slag.

$$CaO + SiO_2 \rightarrow CaSiO_3$$

The molten iron flows to the bottom of the blast furnace. The slag is less dense and floats on the surface of the molten iron. Thus, the molten iron and the molten slag are tapped off separately. The slag is used mostly for the manufacture of cement

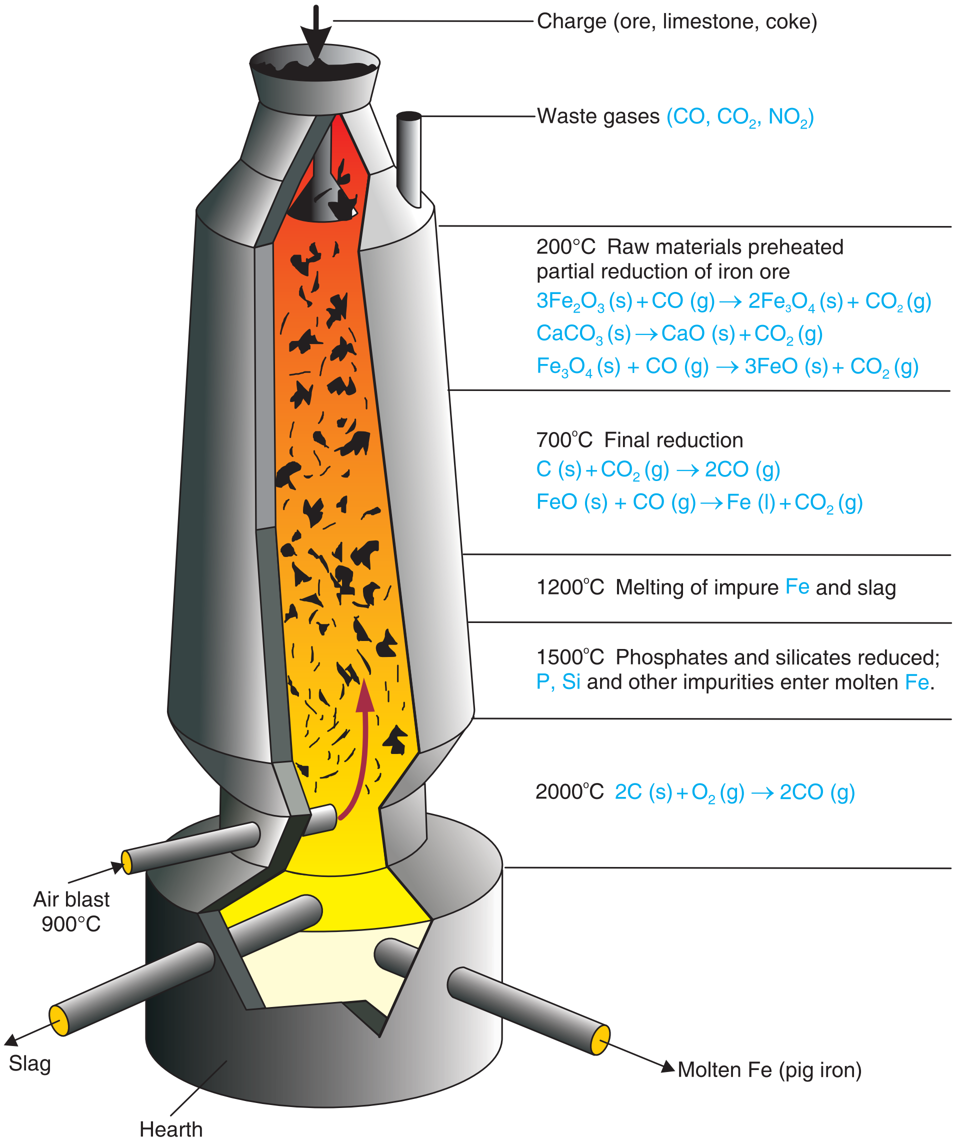


Figure 4.2 Blast furnace.

The *iron* obtained directly from the blast furnace is called pig iron. It is impure and contains about 2% silicon, up to 1% phosphorus and manganese, and traces of sulphur. These impurities make pig iron brittle. When pig iron is re-melted with scrap iron and cast into moulds, it forms cast iron.

Wrought iron: is the purest form of commercial iron. It is obtained by removing most of the impurities from pig iron. It is manufactured by heating impure iron with hematite and limestone in a furnace. This increases the purity of the iron to 99.5%. Wrought iron is a tough, malleable and ductile form of iron.

PROJECT 4.1

Form a group and construct a model of the blast furnace from locally available materials.

Conversion of Pig Iron to Steel

The relatively high carbon-content of the iron recovered from the blast furnace (*pig iron*) makes it very hard and brittle. The conversion of pig iron to steel is essentially a purification process in which impurities are removed by oxidation. This purification process is carried out in a furnace at high temperatures. In the conversion of pig iron to steel, three different methods are used. These are the Bessemer Converter, Open-hearth Furnace and the Basic Oxygen Process.

a **The Bessemer Converter:** In the process of converting pig iron to steel, molten pig iron from the blast furnace is transferred to a cylindrical vessel containing a refractory lining of $MgCO_3$ and $CaCO_3$. A blast of hot air is blown through the molten metal from a set of small holes at the bottom of the vessel. The oxygen passing through the molten metal converts silicon, phosphorus and sulphur to their oxides, which then react with the lining to form a slag. The carbon in the pig iron is also oxidized to carbon monoxide, so its concentration is also reduced. The conversion of the pig iron to steel by this process requires only 15 minutes. However, the reaction is difficult to control and the quality of the steel produced can be quite variable.

b **The Open-hearth Furnace:** It has a large, shallow hearth, which is usually lined with a basic oxide refractory (MgO and CaO). The furnace is charged with a mixture of pig iron, Fe_2O_3, scrap iron and limestone. A blast of hot air and burning fuel is directed over the surface of the charge to maintain it in the molten state. Impurities in the pig iron are oxidized by the Fe_2O_3 and air. Carbon dioxide, and sulphur dioxide formed by the oxidation of the carbon and sulphur, respectively, in the pig iron bubble out of the mixture as waste gases.

The SiO_2 and other acidic oxides like P_4O_{10} combine with CaO (*from limestone*) and the refractory lining to form a slag.

The impurities in pig iron are oxidized in the following way:

$$C + O_2 \rightarrow CO_2$$

$$S + O_2 \rightarrow SO_2$$

$$12P + 10Fe_2O_3 \rightarrow 3P_4O_{10} + 20Fe$$

$$3Si + 2Fe_2O_3 \rightarrow 3SiO_2 + 4Fe$$

Calcium oxide, formed by the decomposition of limestone, reacts with oxides of silicon and phosphorus to form slag.

$$P_4O_{10} + 6CaO \rightarrow 2Ca_3(PO_4)_2$$

$$SiO_2 + CaO \rightarrow CaSiO_3$$

This entire process takes 8 to 10 hours to complete and the quality of the steel is much more easily controlled. A calculated amount of various elements can be added to the steel to form steel alloys with desired properties.

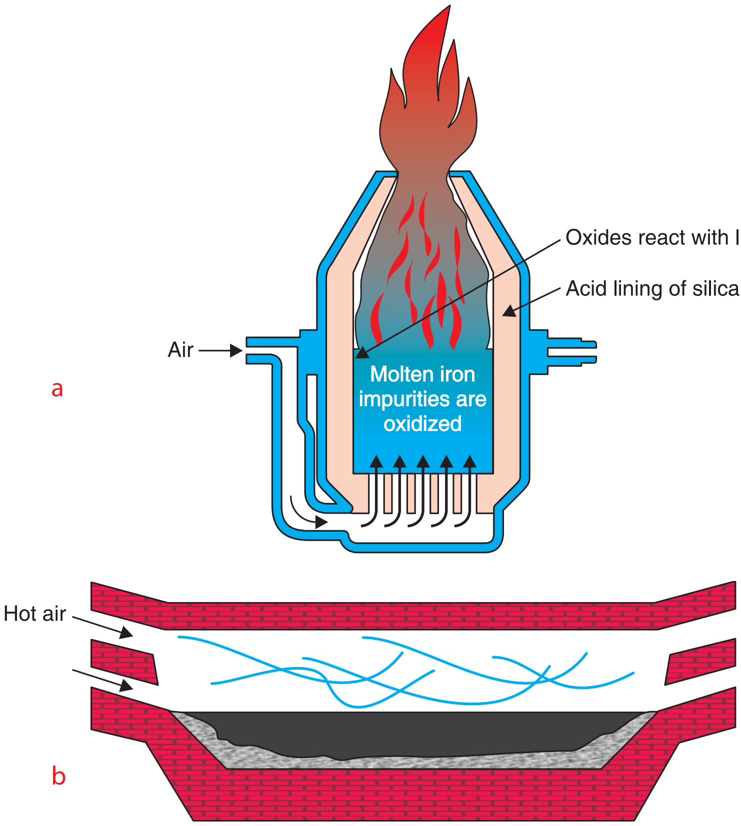


Figure 4.3 a) Bessemer converter b) Open-hearth furnace.

c **Basic Oxygen Process:** This newer procedure has largely replaced the open hearth, because of its high speed. It involves forcing a mixture of powdered calcium oxide, CaO, and oxygen gas directly into the surface of the molten pig iron. The oxygen reacts exothermically with carbon, sulphur, silicon, phosphorus and impurity metals. Carbon and sulphur are oxidized to CO_2 and SO_2, respectively, and are released as exhaust gases. The oxides of silicon (SiO_2), phosphorus, (P_4O_{10}) and impurity metals combine with lime (CaO), forming slag. The charge in the converter is maintained in the molten state by the energy released in these oxidation reactions. The converter is tilted to remove the slag. After a second blow of oxygen, the converter is tilted once again and the molten steel is poured out. This process takes only about 20 to 25 minutes.

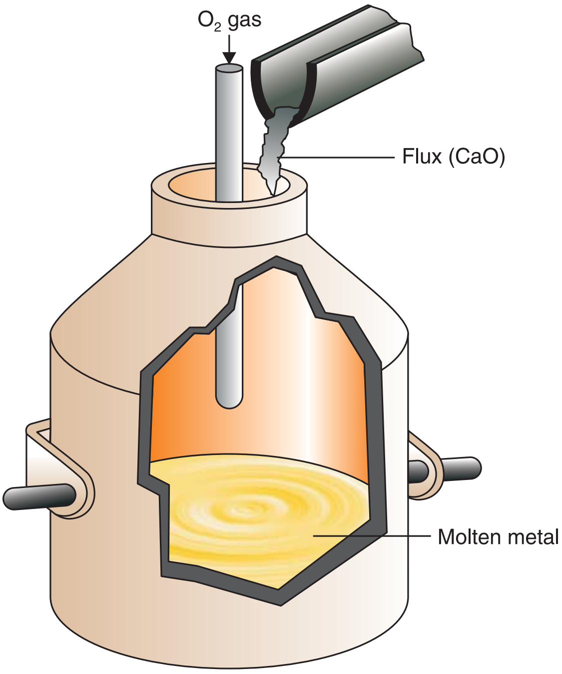


Figure 4.4 The basic oxygen converter.

Activity 4.6

Prepare a list of materials which are made of steel and describe their uses. Discuss in groups and give a presentation to the class.

Physical Properties of Iron

Do you remember physical properties of iron? Can you mention some of them?

Iron is a grey, lustrous, malleable and ductile metal. It is a good conductor of heat and electricity. It has a high melting point (1580°C) and a high density (7.87 g/cm^3). It is a ferromagnetic metal, which means it can be permanently magnetized.

Chemical Properties of Iron

Have you ever noticed the formation of a reddish thin film on the surface of an iron object? Do you know the chemical nature of this thin film? From your observations, what do you conclude about the reactivity of iron?

Iron is a reactive metal. Its reactivity is very slow, compared to group IA and IIA metals.

Iron rusts in the presence of air and moisture to form hydrated iron (III) oxide.

$$4Fe(s) + 3O_2(g) \xrightarrow{\text{moisture}} 2Fe_2O_3.xH_2O(s)\ (\text{rust})$$

Iron reacts with dilute acids, like HCl and H_2SO_4, forming iron (II) salts and liberating hydrogen gas.

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

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

Like other transition metals, iron also exhibits different oxidation states. It commonly exists as the ferrous (Fe^{2+}) and ferric (Fe^{+3}) ions. Iron (II) and iron (III) compounds are coloured. Aqueous solutions of iron (II) compounds are pale-green and solutions of iron (III) compounds are yellowish brown.

Aqueous solutions of some iron (II) compounds are rapidly oxidized to the corresponding iron (III) compounds. For example, iron (II) hydroxide, $Fe(OH)_2$, on exposure to air, oxidizes to iron (III) hydroxide.

$$4Fe(OH)_2(s) + O_2(g) + 2H_2O(l) \rightarrow 4Fe(OH)_3(s)$$

Heated iron reacts with hydrogen chloride gas, forming iron (II) chloride and hydrogen gas.

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

Heated iron reacts with chlorine and sulphur to form the chloride and sulphide, respectively.

$$2Fe(s) + 3Cl_2(g) \rightarrow 2FeCl_3(s)$$

$$Fe(s) + S(s) \rightarrow FeS(s)$$

Iron has the ability to displace less active metals from solutions of their salts. For example, when a piece of iron is placed in a solution of $CuSO_4$, it is oxidized to Fe^{2+} and a reddish brown deposit of copper metal forms on the surface of the iron.

$$Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$$

Uses of Iron

Iron is the most widely used metal and takes first position in worldwide consumption. It is used as a structural metal in the construction of buildings and bridges. In the form of pig iron, it is used to make domestic boilers, hot-water radiators, railings, water pipes, castings, and mouldings. As wrought iron, it is used in making nails, sheets, horseshoes, ornamental gates, door knockers, farm machinery etc. Iron is also used in the manufacture of alloys such as carbon steels and alloy steels. Carbon steels can be classified as mild steel, medium steel and high-carbon steel, based on the amount of carbon.

Mild Steel: contains up to 0.2% carbon and is used in making screws, motors, car batteries, railway lines, ships, bridges, nuts and bolts.

Medium Steel: contains 0.3–0.6% carbon and is used to make springs and chains.

High-Carbon Steel: contains 0.6–1.5% carbon and is used to make drill bits, knives, hammers and chisels.

Alloy Steel: contains iron and a relatively higher percentage of other metals. For example, stainless steel contains chromium (14–18%) and nickel (7–9%). Tool steels include tungsten steel and manganese steel. These metals give the alloy hardness, toughness and heat resistance. They are used in rock drills, cutting edges and parts of machinery that are subjected to heavy wear.

Activity 4.7

1. You have learned about the purification of metals, including copper in unit 3. Describe the electrolytic process used for the purification copper metal.
2. Prepare a list of items made of copper.
3. In the refining process of copper, zinc does not deposit on the cathode. Why?

Discuss in your group and give a presentation to the class.

C. Copper

Occurrence and extraction

Copper is occasionally found as native copper. However, it is found mainly in compounds such as sulphides, oxides and the carbonates. The most important sulphide ores are chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS) and bornite (Cu_5FeS_4). The principal oxide ores are cuprite (Cu_2O) and tenorite (CuO). In the carbonate form, it exists as malachite ($CuCO_3{\cdot}Cu(OH)_2$).

Copper is principally extracted from chalcopyrite. Since the amount of copper in the ore is very small, the crushed and ground sulphide ore is first concentrated by froth flotation. This treatment changes the concentration of the ore from 2 % copper to as high as 30% copper. The concentrated ore is then roasted with a limited supply of air (*oxygen*).

$$2CuFeS_2(s) + 4O_2(g) \rightarrow Cu_2S(s) + 2FeO(s) + 3SO_2(g)$$

The roasted mixture is smelted by adding limestone and sand to form a molten slag that removes many of the impurities. FeO present in the roasted mixture can also be removed as slag in the form of iron silicate ($FeSiO_3$), and silica in the form of calcium silicate ($CaSiO_3$).

$$CaCO_3(s) + SiO_2(s) \rightarrow CaSiO_3(l) + CO_2(g)$$
$$FeO(s) + SiO_2(s) \rightarrow FeSiO_3(l)$$

The Cu_2S obtained by roasting chalcopyrite is then reduced by heating it in a limited supply of oxygen.

$$Cu_2S(s) + O_2(g) \rightarrow 2Cu(l) + SO_2(g)$$

The copper produced by the above process is called blister copper and it has 98.5 – 99.5 % purity. Blister copper contains iron, silver, gold and sometimes zinc as impurities. So it is refined further by electrolysis as shown in Figure 4.5. Copper obtained by electrolytic refining is 99.99% pure.

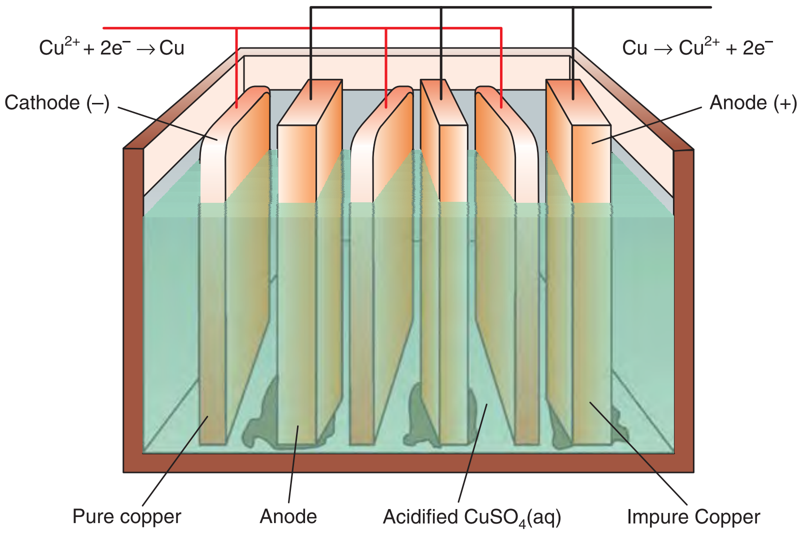


Figure 4.5 Electrolytic refining of copper.

Physical Properties of Copper

Copper is a soft, ductile, malleable, reddish-brown metal with a density of 8.96 g/cm^3. It is second to silver in electrical conductivity. It melts at 1086°C and boils at 2310°C.

Chemical properties of copper

Copper is less reactive metal, that is why it is found in the native state. Although it is not very reactive, it undergoes the following reactions:

Powdered copper, when heated in air forms a black powder of copper (II) oxide, CuO.

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

Copper does not react with dilute acids like HCl and H_2SO_4. It cannot displace hydrogen from acids. However, it can be oxidized by oxidizing acids such as dilute and concentrated nitric acid and hot concentrated sulphuric acid, H_2SO_4.

$$3Cu\ (s) + 8HNO_3\ (aq) \xrightarrow{\text{dilute}} 3Cu(NO_3)_2\ (aq) + 2NO\ (g) + 4H_2O\ (l)$$

$$Cu\ (s) + 4HNO_3\ (aq) \xrightarrow{\text{concentrated}} Cu(NO_3)_2\ (aq) + 2NO_2\ (g) + 2H_2O\ (l)$$

$$Cu\ (s) + 2H_2SO_4\ (aq) \xrightarrow{\text{Hot and concentrated}} CuSO_4\ (aq) + 2SO_2\ (g) + 2H_2O\ (l)$$

Copper corrodes in moist air over a long period of time as a result of oxidation caused by a mixture of water, oxygen and carbon dioxide. It turns green, due to the formation of verdigris: a basic copper carbonate ($CuCO_3{\cdot}Cu(OH)_2$) or $Cu_2(OH)_2CO_3$.

$$2Cu\ (s) + H_2O\ (l) + O_2\ (g) + CO_2\ (g) \rightarrow CuCO_3{\cdot}Cu(OH)_2$$

Basic copper carbonate is responsible for the green layer that forms on the surface of copper and bronze objects. This layer adheres to the surface and protects the metal from further corrosion.

Copper is a transition metal and exhibits different oxidation states. It exists as cuprous (Cu^+) and cupric (Cu^{2+}) ions. Compounds containing copper in the +1 oxidation state are stable in insoluble compounds. Cu^{1+} is unstable and cannot exist in aqueous solution since it reduces and oxidizes (*disproportionates*) itself as follows:

$$2Cu^+\ (aq) \rightarrow Cu^{2+}\ (aq) + Cu\ (s)$$

Soluble compounds containing Cu^+, such as CuCl, CuI and CuBr, are all colourless solids. The most stable oxidation state of copper is +2. Aqueous solutions of many copper (II) compounds are blue, thus copper forms coloured compounds in the oxidation state of +2. For example, hydrated copper sulphate, $CuSO_4{\cdot}5H_2O$, consists of blue crystals, and its aqueous solution is also blue.

Uses of Copper

Copper is used to manufacture alloys. For example, bronze is an alloy of copper and tin, and it is used to make coins, medals, bells, machinery parts, etc. Brass is an alloy of copper and zinc, and it is used for hardware tops, terminals and pipes. Copper is widely used in the electrical industry in the form of electric wires, cables etc. Copper compounds, such as copper chloride, copper carbonate and copper hydroxide, are used as pesticides.

Exercise 4.2

1. Describe the occurrence and extraction of the following metals; aluminium, iron, and copper.
2. Which of the three metals, Al, Fe and Cu is produced by electrochemical reduction?
3. Explain how Al, Fe and Cu behave in dry air, moisture and acidic solutions.
4. Suggest the main chemical reactions involved in the conversion of pig iron to wrought iron.
5. Discuss the main areas of applications of Al, Fe and Cu in home and industry.

4.3.2 Production of Some Important Non-metals

A. Nitrogen

Activity 4.8

1. Draw the structure of a nitrogen molecule. How many bonds are present in it? Why does nitrogen form triple bond?
2. Which form of nitrogen is absorbed by green plants?

Discuss in group and give a presentation to the class.

Occurrence and Production

Nitrogen occurs in nature in the elemental form. It also exists in the form of compounds. In the elemental state, it exists as a diatomic molecule, N_2, in atmospheric air. It constitutes about 80% by volume of the atmosphere. In the form of compounds, it exists as sodium nitrate (*Chile salt peter*, $NaNO_3$) and potassium nitrate (KNO_3) also called saltpetre. It is also found in DNA molecules and proteins of all living things.

In the industrial production of nitrogen, the first step is to remove impurities like dust and other particles from air. The air is then compressed under high pressure and low temperature to remove carbon dioxide and water vapour since they solidify at a relatively high temperatures compared to nitrogen and oxygen. As the temperature continues to decrease, the air containing mainly nitrogen and oxygen condenses to give a pale-blue liquid. Nitrogen is thus separated on an industrial scale by fractional distillation of liquid air. When liquid air is fractionally distilled, nitrogen is collected and stored in steel cylinders under pressure. The second fraction consists of argon, which distils off the mixture at –186°C, leaving behind a blue liquid of oxygen that boils at –183°C.

In the laboratory, nitrogen is prepared by warming an aqueous solution containing ammonium chloride and sodium nitrite.

$$NH_4Cl\,(aq) + NaNO_2\,(aq) \rightarrow NaCl\,(aq) + N_2\,(g) + 2H_2O\,(l)$$

Physical Properties of Nitrogen

Nitrogen is colourless, odourless and tasteless gas. It is inert under ordinary conditions, and that is why it is found in atmospheric air as N_2. The inertness of nitrogen at low temperatures is directly related to the strength of the triple bond, which requires high energy to break.

Chemical Properties of Nitrogen

Is nitrogen a reactive or unreactive non-metal? Can you suggest a proof for your answer?

However, nitrogen reacts with metals of group IA and IIA as well as oxygen at higher temperatures. When heated with reactive metals like lithium, calcium and magnesium, it forms compounds, known as nitrides.

$$6Li\,(s) + N_2\,(g) \rightarrow 2Li_3N\,(s)$$
$$3Ca\,(s) + N_2\,(g) \rightarrow Ca_3N_2\,(s)$$
$$3Mg\,(s) + N_2\,(g) \rightarrow Mg_3N_2\,(s)$$

Nitrogen combines with oxygen at elevated temperatures or in an electric arc to form oxides.

$$N_2\,(g) + O_2\,(g) \rightarrow 2NO\,(g)$$
$$N_2\,(g) + 2O_2\,(g) \rightarrow 2NO_2\,(g)$$

Nitric oxide, also called nitrogen monoxide, NO, is a colourless and reactive gas. It forms nitrogen dioxide (NO_2), a reddish brown gas, when it comes into contact with oxygen.

$$2NO\,(g) + O_2\,(g) \rightarrow 2NO_2\,(g)$$

This reddish brown gas dimerizes at low temperatures to give a colourless gas of dinitrogen tetraoxide, N_2O_4.

$$2NO_2\,(g) \rightarrow N_2O_4\,(g)$$

Nitrogen also forms oxides, like dinitrogen monoxide, N_2O, (commonly called laughing gas), dinitrogen trioxide (N_2O_3) and dinitrogen pentoxide (N_2O_5).

Nitrogen reacts directly with hydrogen in the Haber process to form ammonia. In this process, a mixture of N_2 and H_2 gas, at a pressure of 200-300 atm and a temperature of 400-600°C, is passed over a catalyst of finely divided iron.

$$N_2(g) \quad + \quad 3H_2(g) \quad \underset{400-600^\circ C}{\overset{Fe/200-300atm}{\rightleftarrows}} \quad 2NH_3(g)$$

The ammonia produced by this method is primarily used in the manufacture of fertilizers. It is also used for the production of nitric acid (HNO_3).

Uses of Nitrogen

Nitrogen is used in food packaging to prevent oxidation, and to create an inert atmosphere in the production of semiconductors. Liquid nitrogen is used as a refrigerant to preserve bulls' semen and blood. Its major use is in the production of ammonia.

Activity 4.9

Have you ever observed glowing worms? Why do they glow? Anyone who has observed them should explain to the class.

B. Phosphorus

Occurrence and Extraction

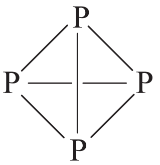
Does phosphorus exist in the pure form (elemental state) as does nitrogen? If not, why? Phosphorus is a relatively abundant element, ranking 12th in the earth's crust. It exists naturally only in the combined state, such as in rock phosphate, $Ca_3(PO_4)_2$, fluoroapatite, $Ca_{10}(PO_4)_6F_2$ or $3Ca_3(PO_4)_2.CaF_2$. It is also found in teeth, bones and DNA.

What is allotropy? What are the two common allotropes of phosphorus?

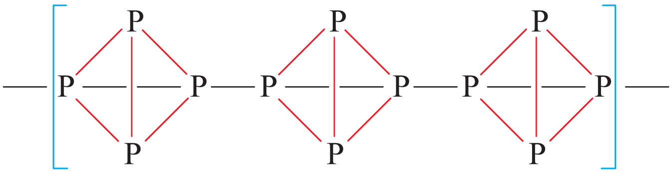
Allotropes are different forms of the same element with the same physical state but with different physical properties. This is due to the difference in the arrangement of atoms.

The two common allotropic forms of phosphorus are white phosphorus and red phosphorus. White phosphorus is a very poisonous, white waxy-looking substance that melts at 44.1°C and boils at 287°C. Its density is 1.8 g/cm^3. It consists of individual tetra-atomic (P_4) molecules and is an unstable form of phosphorus.

Red phosphorus is denser (2.16 g/cm^3) and is much less reactive than white phosphorus at normal temperatures. It consists of P_4 molecules linked together to form a polymer (*large molecule*) as shown below.



White phosphorus



Red phosphorus

Industrially, white phosphorus is manufactured by heating a mixture of crushed rock phosphate, $Ca_3(PO_4)_2$, silica, SiO_2, and coke in an electric furnace. The reaction in the furnace is:

$$2Ca_3(PO_4)_2\,(s) + 6SiO_2\,(s) + 10C\,(s) \rightarrow 6CaSiO_3\,(l) + P_4\,(g) + 10CO\,(g)$$

The vaporized phosphorus (P_4) is condensed, collected and stored under water. Red phosphorus is prepared by heating white phosphorus in sunlight for several days. White phosphorus is stored under water because it spontaneously ignites (bursts into flames) in the presence of oxygen. Red phosphorus is much less reactive than white phosphorus and does not need to be stored under water.

Physical Properties of Phosphorus

Activity 4.10

Use reference books available in your school library and write down the main properties of white and red phosphorus.

Chemical Properties of Phosphorus

Phosphorus exhibits the following common chemical reactions. Phosphorus reacts with limited and excess supplies of oxygen to form tetraphosphorus hexoxide (P_4O_6) and tetraphosphorus decoxide (P_4O_{10}) respectively.

$$P_4\,(s) + 3O_2\,(g) \rightarrow P_4O_6\,(s)$$
$$P_4\,(s) + 5O_2\,(g) \rightarrow P_4O_{10}\,(s)$$

P_4O_6 and P_4O_{10} dissolve in water to form phosphorous acid, H_3PO_3, an orthophsophoric acid, H_3PO_4 respectively.

$$P_4O_6\,(s) + 6H_2O\,(l) \rightarrow 4H_3PO_3\,(aq)$$
$$P_4O_{10}\,(s) + 6H_2O\,(l) \rightarrow 4H_3PO_4\,(aq)$$

Phosphorus also reacts with limited and excess supplies of chlorine to form phosphorus (III) chloride (PCl_3) and phosphorus (V) chloride (PCl_5) respectively.

$$P_4(s) + 6Cl_2(g) \rightarrow 4PCl_3(s)$$

$$P_4(s) + 10Cl_2(g) \rightarrow 4PCl_5(s)$$

Activity 4.11

1. Write the chemical reactions for photosynthesis and respiration. What are the products formed in photosynthesis and respiration?
2. What are the uses of oxygen in hospitals?
3. How do astronauts breathe while in space?

Discuss all the above points in groups and give a presentation to the class.

C. Oxygen

Occurrence and Production

Oxygen is the most abundant element on earth. It constitutes about 46.6% by weight of the earth's crust in the form of compounds such as oxides, silicates, carbonates, phosphates etc. It exists in nature in the elemental state in atmospheric air constituting about 20% by volume. Oxygen is manufactured industrially by the fractional distillation of liquid air in a way similar to that of nitrogen.

Chemical Properties of Oxygen

Oxygen is relatively reactive and combines directly with most elements to form oxides. Oxygen combines with metal to form metal oxides (*basic oxides*). For example,

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

$$2Ca(s) + O_2(s) \rightarrow 2CaO(s)$$

Oxygen combines with non-metals to form acidic oxides; for example:

$$S_8(s) + 8O_2(g) \rightarrow 8SO_2(g)$$

$$P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(g)$$

Oxygen supports combustion and is necessary for the burning of substances like charcoal, hydrocarbon fuel, etc.

$$C\,(s) + O_2\,(g) \rightarrow CO_2\,(g)$$

$$CH_4\,(g) + 2O_2\,(g) \rightarrow CO_2\,(g) + 2H_2O\,(g)$$

Activity 4.12

Have you observed the colour of sulphur? What is the use of sulphur in your area?

D. Sulphur

Occurrence and Extraction

Sulphur is found in nature and in the form of compounds such as galena (PbS), pyrites (FeS_2) (*fool's gold*), cinnabar (HgS), sphalerite (ZnS), gypsum ($CaSO_4{\cdot}2H_2O$), barite ($BaSO_4$), and as hydrogen sulphide (H_2S) in natural gas and crude oil.

Sulphur is extracted from underground deposits of elemental sulphur by the Frasch process (Figure 4.6). In this process, three concentric pipes are sent down to the sulphur deposit. Superheated water at about 170°C is pumped through the outermost pipes. Hot air is compressed in the innermost tube. A froth of sulphur, air and water come out to the surface of the earth forced by hot compressed air in the middle tube. The molten sulphur is then cooled and solidified.

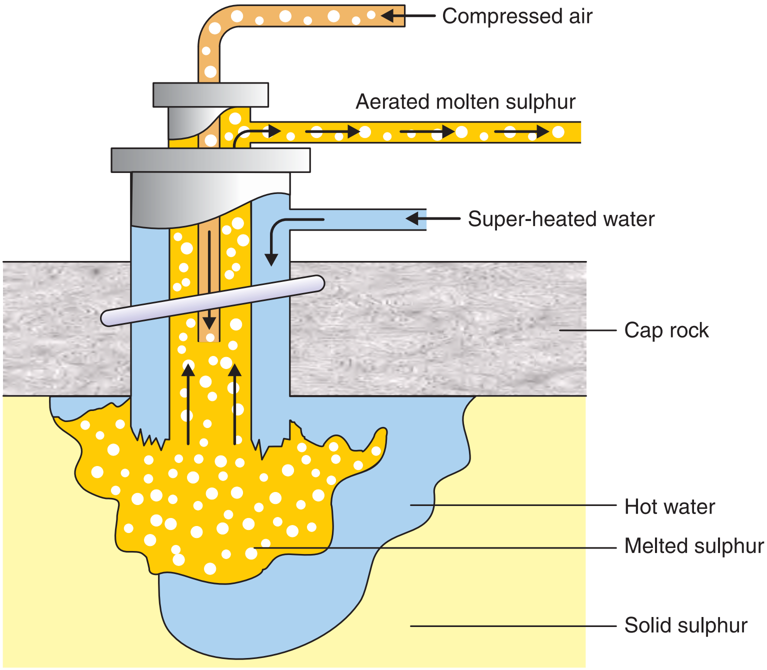


Figure 4.6 Frasch Process for the production of sulphur.

Uses: Nearly one-half of the sulphur needed by chemical industries is obtained as a waste product of other industrial processes. For example, sulphur can be obtained in the form of hydrogen sulphide (H_2S) from natural gas and during the purification of crude oil. It can also be obtained in the form of sulphur dioxide from the roasting of sulphide ores during the manufacture of metals. The use of sulphur obtained from waste products of other industries reduces the demand for the element from natural deposits. This also reduces the pollution of atmospheric air and the formation of acid rain.

Sulphur exhibits allotropy. The most important allotropes of sulphur are rhombic and monoclinic sulphur. Rhombic sulphur is the most stable form of sulphur consisting of S_8 molecules.

Chemical Properties of Sulphur

Sulphur is relatively stable and unreactive at room temperature. However, it reacts with metals and non-metals when heated.

Sulphur combines with metals when heated to form sulphides.

$$8Fe\ (s) + S_8\ (s) \rightarrow 8FeS\ (s)$$

Sulphur burns in oxygen to form oxides.

$$S_8\ (s) + 8O_2\ (g) \rightarrow 8SO_2\ (g)$$

Sulphur is the raw material for the production of sulphuric acid (H_2SO_4) by the Contact Process. This process of sulphuric acid production involves the following steps.

Step 1: Sulphur is first oxidized to produce sulphur dioxide:

$$S_8\ (s) + 8O_2\ (g) \rightarrow 8SO_2\ (g)$$

Step 2: Sulphur dioxide is converted to sulphur trioxide at high temperatures in the presence of a catalyst:

$$2SO_2\ (g) + O_2 \xrightarrow{V_2O_5} 2SO_3\ (g)$$

Step 3: Sulphur trioxide is absorbed into concentrated sulphuric acid to produce oleum ($H_2S_2O_7$).

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

Step 4: The oleum is then diluted with water to produce the desired concentration of sulphuric acid. Commercially used concentrated sulphuric acid is 98% H_2SO_4.

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

E. Chlorine

Activity 4.13

1. When we turn on the water tap, the water coming out of the tap sometimes appears white and turns normal after a few minutes. Many people say that the white colour we see is due to chlorine. Do you agree? Discuss in group and present your opinion to the class.
2. What is the purpose of adding chlorine to drinking water?

Occurrence and Extraction

Chlorine belongs to group VIIA, known as the halogens. It is the most abundant element among the halogens. It is found in nature in the form of compounds only. Chlorine is found in nature chiefly in the form of chlorides of sodium, potassium, calcium and magnesium. Sodium chloride is the chief source of chlorine, and it is obtained from seawater or as deposits of rock salt.

Commercially, chlorine is manufactured by the electrolysis of a concentrated aqueous solution of sodium chloride. During electrolysis of the concentrated solution, chlorine is formed at the anode and the reduction of water occurs at the cathode, producing hydrogen gas and hydroxide ions (OH^-). The electrode and the overall cell reactions are as follows:

Oxidation at anode: $2Cl^- (aq) \rightarrow Cl_2 (g) + 2e^-$

Reduction at cathode: $2H_2O (l) + 2e^- \rightarrow H_2 (g) + 2OH^- (aq)$

Cell reaction: $2NaCl (aq) + 2H_2O (l) \rightarrow 2NaOH (aq) + Cl_2 (g) + H_2 (g)$

Although NaOH forms at the cathode compartment and Cl_2 at the anode, the two substances must be kept apart from one another. This is because, if they come into contact with each other, they can react according to the following equation.

$$NaOH (aq) + Cl_2 (g) \rightarrow NaOCl (aq) + HCl (aq)$$

What is the oxidation number of chlorine in NaOCl?

Physical Properties of Chlorine

Activity 4.14

1. In urban area, tap water possesses a peculiar smell, which disappeares after a few minutes. Many people say that the smell is due to chlorine. Do you agree? Discuss in group and present your opinion to the class.

Some of its physical properties are the following:

- Chlorine is a greenish-yellow gas at room temperature.
- It melts at –102°C and boils at –34°C.
- It is fairly soluble in water.
- It is extremely poisonous, causing inflammation of the lungs and mucous membranes if inhaled, even in very small amounts. It is fatal if inhaled in higher amounts.

Chemical Properties of Chlorine

Chlorine is a highly reactive non-metal. It reacts directly with almost all elements except the noble gases, carbon and nitrogen. It is a powerful oxidizing agent and oxidizes most of the elements with which it reacts. The following are the main reactions of chlorine.

Chlorine reacts with heated metals to form chloride salts

$$2Fe\,(s) \quad + \quad 3Cl_2\,(g) \quad \rightarrow \quad 2FeCl_3\,(s)$$

$$2Al\,(s) \quad + \quad 3Cl_2\,(g) \quad \rightarrow \quad 2AlCl_3\,(s)$$

Chlorine reacts smoothly with hydrogen, in the presence of a charcoal as a catalyst, at room temperature to form hydrogen chloride.

$$H_2\,(g) \quad + \quad Cl_2\,(g) \quad \rightarrow \quad 2HCl\,(g)$$

Chlorine displaces less reactive halogens (Br_2 and I_2) *from aqueous solutions of their compounds*.

$$Cl_2\,(g) \quad + \quad 2KBr\,(aq) \rightarrow \quad 2KCl\,(aq) \quad + \quad Br_2\,(l)$$

$$Cl_2\,(g) \quad + \quad 2KI\,(aq) \quad \rightarrow \quad 2KCl\,(aq) \quad + \quad I_2\,(aq)$$

Can bromine displace chlorine in a chemical reaction?

Chlorine dissolves in water and reacts with it, forming an acidic solution containing hydrochloric acid (HCl) and hypochlorous acid (HOCl).

$$Cl_2\,(g) \quad + \quad H_2O\,(l) \quad \rightarrow \quad HCl\,(aq) \quad + \quad HOCl\,(aq)$$

This type of reaction is called a disproportionation reaction, where chlorine is itself reduced and oxidized.

Chlorine is commercially used as a bleaching agent and disinfectant (kills germs). As elemental chlorine or as chlorine water, it is strong enough to oxidize dyes and to bleach coloured materials. For example, it can be used to remove yellow or brown colours from wood pulp, paper and cotton.

Exercise 4.3

1. What are the main natural sources of N, P, O, S, and Cl?
2. Describe the main processes involved in the production (extraction) of N, P, O, S and Cl.
3. How do N, P, and S behave when heated in air?
4. Write an equation for the reaction of chlorine with water.
5. Consult the books present in your library and describe with the aid of labelled diagrams the laboratory preparation of following molecules:

   a N_2 b Cl_2

4.4 SOME INDUSTRIES IN ETHIOPIA

Competencies

After completing this section, you will be able to:

- define industry;
- list some industries in Ethiopia;
- describe the general characteristics of industries;
- outline the important steps in the productions of ceramics;
- mention some uses of ceramics;
- outline the important steps in the production of cement;
- outline the important steps in the production of sugar;
- outline the important steps in the production of pulp and paper;
- explain how tanning is carried out;
- describe the application of the chemical preservation of skin and hides;
- mention some uses of skin and hides;
- explain the process of food packing and preservation; and
- present a report to the class after visiting a nearby food factory.

Activity 4.15

1. Define industry.
2. What are the general characteristics of chemical industries?
3. List some common chemical industries in Ethiopia, mention products manufactured by them in tabular form.

PROJECT 4.2

1. Have you ever wondered how glass retains different colours? Consult books in your library and make list of the compounds added to impart colour to the glass.
2. Can glass be recycled; how?

Submit your findings to your teacher.

Glass

Glass is an amorphous or non-crystalline solid material. Almost all glass contains silica as the main component. Quartz glass is made by melting pure silica, $SiO_{2,}$ at a temperature of about 2300°C and then pouring the molten viscous liquid into moulds. It is of high strength, low thermal expansion and highly transparent.

Soda-lime glass is ordinary glass which is a mixture of sodium silicate and calcium silicate. It is made by heating a mixture of silica sand, sodium carbonate or sodium sulphate and limestone. The reactions that take place in forming soda-lime glass are the following:

$$Na_2CO_3 + SiO_2 \rightarrow Na_2SiO_3 + CO_2$$
$$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$$

Soda-lime glass accounts for about 90% of manufactured glass. This type of glass is widely used for window panes, bottles, dishes etc.

Borosilicate glass is commonly known as Pyrex. It is manufactured using boron (III) oxide, B_2O_3, instead of limestone or calcium oxide. This glass has high resistance to chemical corrosion and temperature changes and is widely used to make ovenware and laboratory equipment such as flasks, beakers, and test tubes.

Steps in glass production

i) **Batch preparation:** refers to the preparation of the raw materials according to the appropriate combinations. The raw materials are mixed in a proportion of 60% sand, 21% sodium carbonate and 19% limestone.

ii) **Glass melting:** The raw materials and recycled glass (according to their colour) are fed into a glass-melting furnace. The materials are then heated to a temperature of about 1600°C to form a molten viscous liquid. Why are glasses is separated according to the colour?

The furnace operates continuously, producing glass 24 hours a day. Substances that give the glass different colours or improved chemical and physical properties such as transparency, thermal and chemical stability and mechanical strength are added during this process.

iii) **Glass forming:** This is the stage in which the melted glass is made into a required shape.

iv) **Annealing:** This is a process that involves the removal of internal stresses by reheating the glass followed by a controlled slow-cooling cycle during which the stresses are relieved.

v) **Inspection:** It involves testing of the glass product to check whether it fulfils desired quality requirements or not.

vi) **Packing and dispatching** is the final stage before distribution.

Ceramics

Activity 4.16

1. Are you familiar with the pottery industry? Do you know any ceramic factories in Ethiopia?
3. Prepare a list of ceramic products used in daily life.

Discuss in groups and give presentation to the class.

Ceramic is an inorganic, non-metallic solid prepared by the action of heat and subsequent cooling. Traditional ceramics, such as porcelain, tiles and pottery are formed from minerals such as clay, talc and feldspar. Most industrial ceramics, however, are formed from extremely pure powders of specialty chemicals, such as silicon carbide, alumina, barium titanate, and titanium carbide.

Manufacturing of ceramics

The minerals used to make ceramics are dug out of the earth and are then crushed and ground into a fine powder. Manufacturers often purify this powder by mixing it in a solution and allowing a chemical precipitate (*a uniform solid that forms within a solution*) to form. The precipitate is then separated from the solution. The powder is heated to drive off impurities including water.

The processes of manufacturing ceramics include:

A **Moulding:** After purification, small amounts of wax are often added to bind the ceramic powder and make it more workable. Plastics may also be added to the powder to give the desired pliability and softness. The powder can then be shaped into different objects by various moulding processes.

B **Densification:** The process of densification uses intense heat to condense a ceramic object into a strong, dense product. After being moulded, the ceramic object is heated in an electric furnace to temperatures between 1000°C and 1700°C. As the ceramic heats, the powder particles coalesce, much as water droplets join at room temperature. As the ceramic particles merge, the object becomes increasingly dense, shrinking by up to 20 percent of its original size. The goal of this heating process is to maximize the strength of ceramic by obtaining an internal structure that is compact and extremely dense.

In general, most ceramics are hard and wear-resistant, brittle, refractory, thermal and electrical insulators, non-magnetic, oxidation-resistant, and chemically stable.

Due to the wide range of properties of ceramic materials, they are used for a multitude of applications.

- **Well-known uses of ceramics**: They are commonly found in art sculptures, dishes, platters and other kitchenware, kitchen tiles and bath room structures.
- **Lesser-known uses for ceramics:** They are used as electrical insulators, computers parts, tools, dental replacements, engine parts, and tiles on space shuttles and to replace bones such as the bones in hips, knees and shoulders.
- **Future uses of ceramics:** In future, the ceramics might be used to remove impurities from the drinking water, and to replace diseased heart valves.

Cement

Activity 4.17

1. How many cement factories do you know in Ethiopia? Name the regions where they are found and share these with your classmates.
2. Why are cement factories located in rural areas of Ethiopia? Give your reasons to the class.

Cement is made by heating limestone (*chalk*), alumina (Al_2O_3) and silica-bearing materials such as clay to 1450°C in a kiln using a process known as calcination. The resulting hard substance called ‘clinker’ is then ground with a small amount of gypsum into a powder to make “ordinary Portland cement” (OPC).

Cement mainly consists of calcium silicate ($CaSiO_3$), calcium aluminate ($CaAl_2O_4$), iron (III) oxide (Fe_2O_3) and magnesium oxide (MgO).

Portland cement is a very important building material, and was first discovered in England. It received its name because, on setting, it hardens to a stone-like mass and was compared to the famous Portland Rock of England. It is a mixture of calcium and aluminium silicates with gypsum.

Raw Materials: Limestone and clay are the chief raw materials used in the manufacture of Portland cement.

Manufacturing Process: First, limestone and clay are crushed separately. They are then mixed in the required quantities and finally mixed and ground together, which can be done either by the dry or wet process. The wet process is suitable if the limestone and clay are soft. If the raw materials are hard, the dry process is preferred. The dry process is cost-effective because fuel consumption is less when the raw materials are burnt in a rotary kiln.

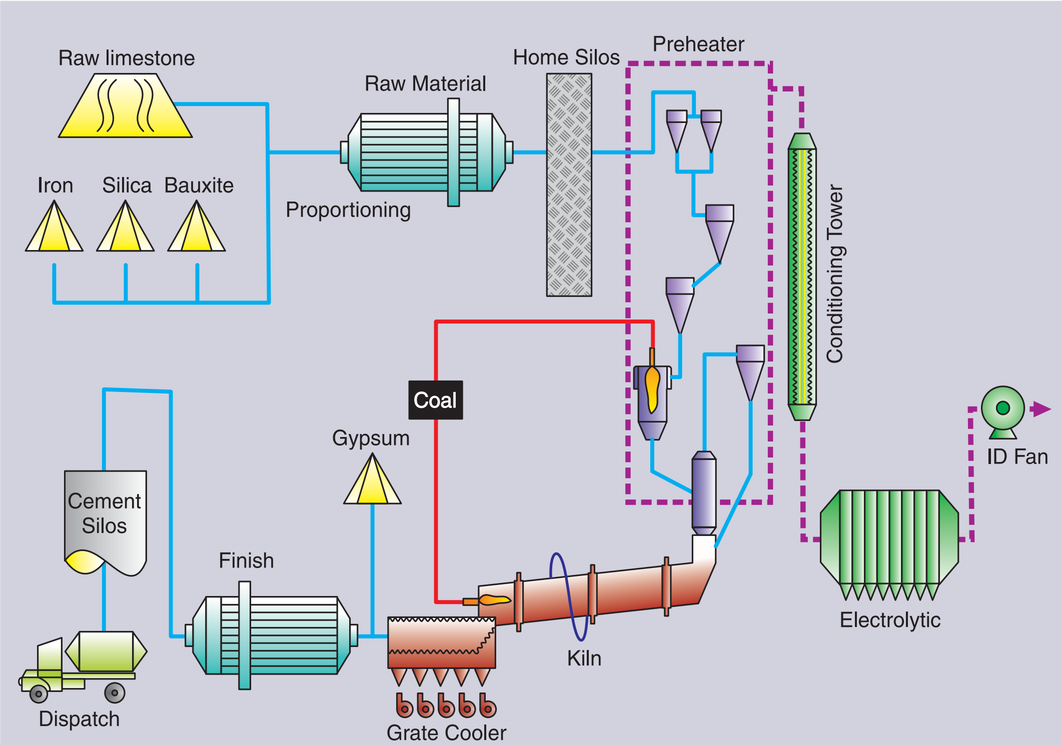


Figure 4.7 Cement manufacturing process.

– *Upper Part of the Kiln*

Raw material heated $\xrightarrow{\Delta}$ complete elimination of moisture

– *Middle Part of the Kiln*

Limestone decomposes to calcium oxide.

$$CaCO_3\,(s) \xrightarrow{\Delta} CaO\,(s) + CO_2\,(g)$$

– *Lower End of the Kiln*

In this part, the temperature reaches about 1600°C; the partly fused and sintered mixture undergoes a series of chemical reactions to form calcium aluminates and silicates.

$$2CaO + 2SiO_2 \rightarrow 2CaO{\cdot}SiO_2\ (\textit{di-calcium silicate})$$

$$3CaO + 3SiO_2 \rightarrow 3CaO{\cdot}SiO_2 \text{ (\textit{tri-calcium silicate})}$$

$$3CaO + 3Al_2O_3 \rightarrow 3CaO{\cdot}Al_2O_3 \text{ (\textit{tri-calcium aluminate}).}$$

$$4CaO + 4Al_2O_3 + 4Fe_2O_3 \rightarrow 4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3 \text{ (\textit{tetra-calcium aluminium ferrate})}$$

$$MgO + SiO_2 \rightarrow MgSiO_3 \text{ (\textit{magnesium silicate})}$$

The resulting mixture of all these silicates and aluminates is called cement clinker. After cooling, it is mixed with 2-3% gypsum (calcium sulphate) and ground to a fine powder. Gypsum slows down the rate of setting of cement, so that the cement hardens adequately.

Table 4.3 The approximate composition of cement.

Component	Percentage
Calcium oxide (CaO)	50-60 %
Silica (SiO_2)	20-25 %
Alumina (Al_2O_3)	5-10 %
Magnesium Oxide (MgO)	2-3 %
Ferric oxide (Fe_2O_3)	1-2 %
Sulphur trioxide(SO_3)	1-2 %

Setting of Cement

When mixed with water cement first forms a plastic mass that hardens after sometime. This is due to the formation of three-dimensional cross-links between –Si–O–Si– and –Si–O–Al– chains.

The first setting occurs within 24 hours, whereas, the subsequent hardening requires about two weeks. In the hardening process of cement, the transition from plastic to solid state is called setting.

PROJECT 4.3

Take a 0.5 kg of cement and mix it with correct proportion of sand and water. Mix the compoment well till a palstic mass is formed. Take this plastic mass and construct a model of any object. Start pouring water on the model starting from the second day onwards. Report the changes to the class after 24 hours and after two weeks.

Sugar Manufacturing

Activity 4.18

1. Prepare a list of foods and drinks used at your home in which sugar is an ingredient.
2. Is sugar made only from sugar cane? If no, what are the other sources? Discuss in group and give a presentation to the class.

Sugarcane is a perennial herb belonging to the grass family. Native to tropical and subtropical regions of the world, this tropical grass is about 3 metres tall.

Planting: Sugarcane is planted in fields by workers or mechanical planters. Typical cane soil is made from the mixture of silts, clay particles and organic matter. Fertilizers are applied from the time of planting up until the beginning of the ripening period, depending on the region where the crop is planted. Cane seasons last from 8-22 months.

1. **Collecting the Harvest:** Mature canes are gathered by a combination of manual and mechanical methods. The cane is cut at ground level, the leaves are removed, the top is trimmed off (*by cutting off the last mature joint*) the canes and transported to a sugar factory.
2. **Cleansing and Grinding:** The stalks are thoroughly washed and cut at the sugar mill. After the cleaning process, a machine led by a series of rotating knives, shreds the cane into pieces. This is known as "grinding". During grinding, hot water is sprayed onto the sugarcane to dissolve the remaining hard sugar. The shredded cane is then spread out on a conveyer belt.
3. **Juicing:** The shredded sugarcane travels on the conveyor belt through a series of heavy-duty rollers, which extract juice from the pulp. The pulp that remains, or "*bagasse*", is dried and used as a fuel. The raw juice moves on through the mill to be clarified.
4. **Clarifying:** Carbon dioxide and milk of lime are added to the liquid sugar mixture, which is heated until boiling. The process of clarifying begins at this stage. As the carbon dioxide moves through the liquid, it forms calcium carbonate, which attracts non-sugar debris (*fats*, *gums* and *waxes*) from the juice, and pulls them away from the sugar juice. The juice is then pushed through a series of filters to remove any remaining impurities.
5. **Evaporation:** The clear juice that results from the clarifying process is put under a vacuum, where the juice boils at a low temperature and the water in it begins to evaporate. It is heated until it forms into thick, brown syrup.
6. **Crystallization:** Crystallization is the process of evaporating the water from the sugar syrup. Pulverized sugar is fed into a sterilized vacuum pan. As the liquid evaporates, crystals form. The remaining mixture is a thick mass of large crystals. These crystals are sent to a centrifuge that spins and dries them. The dried product is *raw sugar*, which is edible.
7. **Refinery:** Raw sugar is transported to a cane sugar refinery for the removal of molasses, minerals and other non-sugars that contaminate it. This is known as the purification process. Raw sugar is mixed with a solution of sugar and water to loosen the molasses from the outside of the raw sugar crystals, producing a thick matter known as "magma". Large machines then spin the magma, separating the molasses from the crystals. The crystals are promptly washed, dissolved and filtered to remove impurities. The golden syrup that is produced is then sent through filters, and SO_2 is

passed through it to remove the colour and water. The process of removing colour is known as bleaching. What is left is concentrated, clear syrup which is again fed into a vacuum pan for evaporation.

8. **Separation and packaging:** Once the final evaporation and drying process is done, screens separate the different- sized sugar crystals. Large and small crystals are packaged and labelled as white refined sugar.

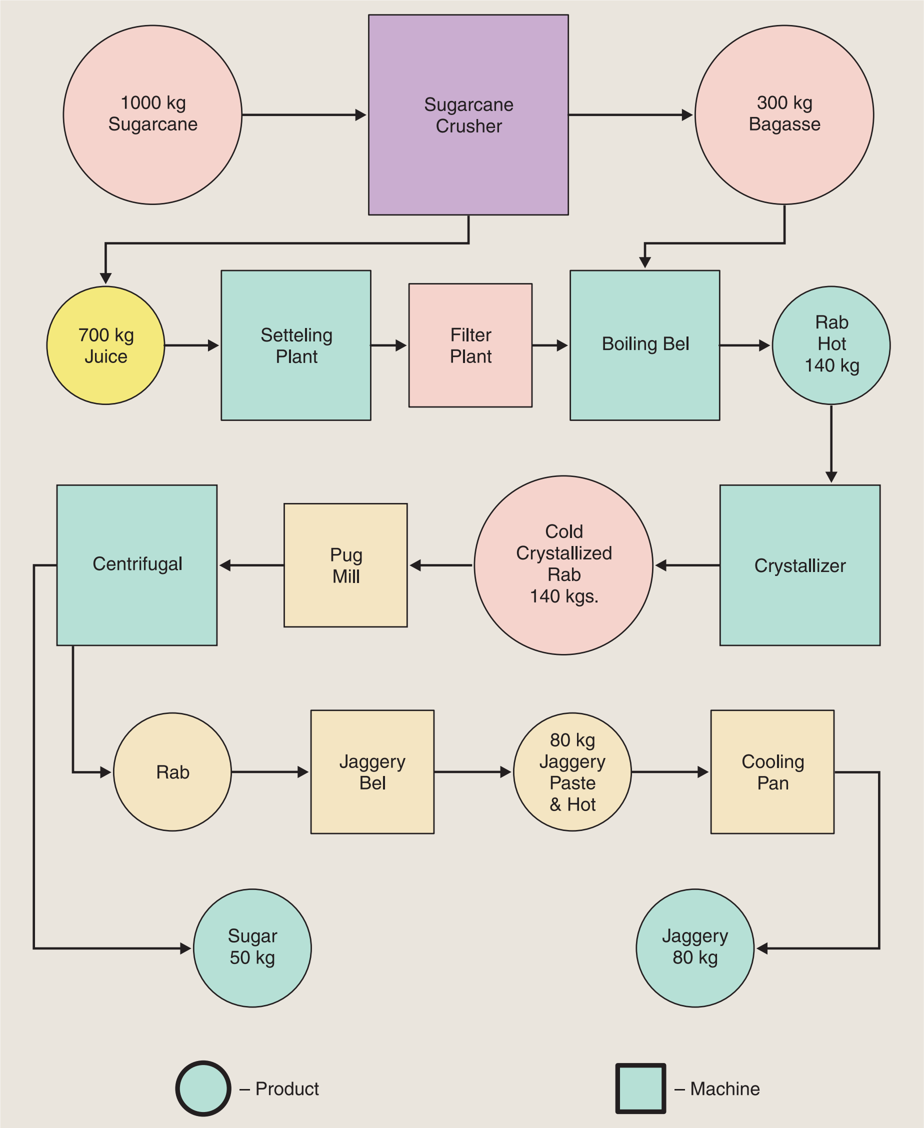


Figure 4.8 Steps involved in sugar production.

Paper and Pulp

Activity 4.19

Discuss the following issues in the group and give a presentation to your class:

1. Wasting paper is like chopping down trees. Comment.
2. Some papers are relatively cheap. The paper used for this grade 10 text book, for example, is expensive. Are different types of paper manufactured by different processes?

Wood is the raw material for making wood pulp and paper. Wood pulp is a dry fibrous material used for making paper. The timber resources used to make wood pulp are referred to as pulp wood. Wood pulp is made from soft-wood trees, such as spruce, pine, fir, larch and hemlock, and from hard woods, such as eucalyptus, aspen and birch.

Wood is composed of cellulose, lignin, oils and resins. Lignin is used to bind fibres of cellulose together. To provide wood pulp, the cellulose must be separated from the lignin.

Manufacturing of pulp and paper involves the following steps:

1. **Harvesting** trees involves the cutting down of trees from their growing areas and transporting the timber to the paper and pulp industry.
2. **Preparation for pulping** is a step in which the bark of the tree is removed and then the wood is chipped and screened to provide uniform sized chips (*pieces*).
3. **Pulping** is a step used to make wood pulp from the chipped wood pieces. This can be accomplished by either mechanical or chemical means depending on the strength and grade of paper to be manufactured.
   a **Mechanical pulping:** It utilizes steam, pressure and high temperatures instead of chemicals to tear the fibres. The fibre quality is greatly reduced because mechanical pulping creates short, weak fibres that still contain the lignin that bonds the fibres together. Paper used for newspapers are a typical product of mechanical pulping.

   b **Chemical pulping:** Chemical pulp is produced by combining wood chips and chemicals in large vessels called digesters. Heat and the chemicals break down the lignin which binds the cellulose fibres together without seriously degrading the cellulose fibres. Chemical pulp is manufactured using the Kraft process or the Sulphite Process.

      i) **The Kraft Process** is the dominant chemical pulping method. It is the most widely used method for making pulp from all types of trees. The process uses aqueous sodium hydroxide and sodium sulphide as a digestion solution. After digestion for about four hours at a temperature of 170°C, the pulp is separated by filtration. This process uses a basic digestion medium.

ii) **The Sulphite Process** uses a cooking liquor (*digestion*) solution of sodium bisulphate or magnesium bisulphate digester at pH of about 3 in a pulp. The action of the hydrogen sulphide ions at 60°C over 6 to 12 hours dissolves the lignin and separates it from the cellulose. After the process is complete, the pulp is recovered by filtration.

The wood pulp achieved from the Sulphite or Kraft processes is washed to remove chemicals and passed through a series of screens to remove foreign materials.

4. **Bleaching:** It is the process of removing colouring matter from wood pulp and increasing its brightness. The most common bleaching agents are strong oxidizing agents such as chlorine, chlorine oxide, ozone and hydrogen peroxide.
5. **Making paper from pulp:** After bleaching, the pulp is processed into liquid stock that can be transferred to a paper mill. The suspension is poured onto a continuously moving screen belt and the liquor is allowed to seep away by gravity to produce paper sheet. The continuous sheet then moves through additional rollers that compress the fibres and remove the residual water to produce fine paper.

Tannery

Activity 4.20

1. The leather products of Ethiopia are durable and relatively cheaper than the same products imported from outside. Why do people prefer to buy imported products? What can you suggest to change this attitude? Discuss this matter in class in relation to quality and availability of resources.
2. Why are leather products being replaced by synthetic products?

Discuss in groups and present to the class.

Tanning is a process of converting raw animal hides and skin to leather, using tannin. Leather is a durable and flexible material created by the tanning of animal hides and skin. Tannin is an acidic chemical that permanently alters the protein structure of a skin so that it can never return to rawhide or skin again.

Leather production involves various preparatory stages, tanning, and crusting

1. **Preparatory stages** are those in which the hide or skin is prepared for tanning. This stage includes curing, soaking, flesh removal, hair removal, scudding, and deliming.

a **Curing:** This process involves salting or drying the hide once it has been removed from the animal. Curing is employed to prevent putrefaction of the protein substance, collagen, from bacterial infection. Curing also removes excess water from the hide and skin. Brine curing is the simplest and fastest method.

b **Soaking**: In this process, cured hides are soaked in water for several hours to several days to remove salt, dirt, debris, blood and excess animal fat from the skin.

c **Flesh removal:** In this process, animal hides are moved through a machine that strips the flesh from the surface of the hide.

d **Hair removal:** In this step, the soaked hides and skins are transported to large vats where they are immersed in a mixture of lime and water. This process is called liming. It loosens the hair from the skin and makes hair-removal easier. After 1–10 days soaking, the hair is mechanically removed from the hide by a hair-removing machine.

e **Scudding:** This is the process in which hair and fat missed by the machines are removed from the hide with a plastic tool or dull knife.

f **Deliming:** This process involves the removal of lime from the skin or hide in a vat of acid. After this preparatory process, the skin or hide is ready for tanning.

2. **Tanning** is a process that converts the protein of the raw hide or skin into a stable material. There are two main types of tanning:

a **Vegetable or natural tanning:** The skin is placed in a solution of tannin. Tannins occur naturally in the barks and leaves of many plants. The primary barks used in modern times are chestnut, oak, tanoak, hemlock, quebracho, mangrove, wattle (acacia) and myrobalan. Naturally tanned hide is flexible and is used for making shoes, luggage and furniture.

b **Mineral tanning:** In this process, the skin is placed in solutions of chemicals such as chromium sulphate and other salts of chromium. Chrome tanning is faster than natural (*vegetable*) tanning and requires only twenty four hours. The leather is greenish-blue in colour derived from the chromium. This process produces stretchable leather that is used for making garments and handbags.

3. **Crusting**: This is the final stage in leather manufacturing and includes dyeing, rolling the leather to make it strong, stretching it in a heat-controlled room and performing a process that involves covering the grain surface with chemical compounds such as wax, oil, glazes etc. to make the leather very attractive.

Food Processing and Preservation

Activity 4.21

1. The rate of spoilage of food is faster in open air in comparison to foods kept inside the refrigerator. Explain. Discuss in group and present your findings to the class.

Food preservation is the process of treating and handling food to stop or greatly reduce spoilage, loss of quality, edibility or nutritive value caused or accelerated by micro-organisms.

Preservation usually involves preventing the growth of bacteria, fungi and other micro-organisms, as well as reducing the oxidation of fats, which causes rancidity.

Activity 4.22

1. What are the traditional methods used to preserve food for a long time without spoilage at your home?
2. What modern methods of food preserving and processing do we use in Ethiopia?

Discuss in groups and give a presentation to the class.

Modern methods of food preservation are:

a **Freezing:** This is one of the most commonly used processes, commercially and domestically, for preserving a very wide range of foods such as potatoes, as well as prepared foodstuffs that would not require freezing in their normal state.

b **Freeze-drying:** Water vapour has easier access through the cell structure of any product compared to water-penetrating the product and evaporating from the surface of the product as is the case of other drying methods. The gentle escape of water vapour in the freeze-drying process leaves the product close to its original shape, taste, and colour and there is no loss of aroma or flavour.

For example, liquids such as coffee, tea, juices and other extracts, vegetables, segments of fish and meat products. Freeze-drying is a superior preservation method for a variety of food products and food ingredients.

c **Vacuum-packing:** Stores food in a vacuum environment, usually in an air-tight bag or bottle. The vacuum environment strips bacteria of the oxygen needed for survival, slowing down the rate of spoiling. Vacuum-packing is commonly used for storing nuts to reduce loss of flavour from oxidation.

Exercise 4.4

1. What is the basic difference in the composition of glass and cement?
2. What is ceramics?
3. Write the main chemical equations involved in the production of cement.
4. Describe the refinery processes involved in sugar production.
5. Explain the difference between chemical and mechanical pulping.
6. How does natural tanning differ from mineral tanning?
7. Point out the modern methods of food preservation.

4.5 ENVIRONMENTAL POLLUTION

Competencies

After completing this section, you will be able to:

- define pollution;
- list the three types of pollution;
- list the names of common air pollutants;
- describe the effects of air pollutants;
- describe some of the main methods used to reduce air pollution;
- describe the different types of industrial water pollutants;
- explain some of the factors involved in water pollution and their effects;
- describe some of the methods used to reduce water pollution;
- explain some of the factors involved in land pollution;
- describe some of the main methods used to reduce land pollution; and
- carry out a project on the effects(s) of an industry on environment.

Activity 4.23

1. The Copenhagen summit was a popular international climate change summit. What was the role played by Ethiopia? What were the major issues of the summit?
2. Mention any activity in your area to bring awareness of air pollution and global warming.

Discuss in your group and present to the class.

Pollution is any discharge of a solid, liquid or gaseous substance or radiation (*energy*) into an environment that causes unwanted changes. Pollution causes short-term or long-term harm that affects the earth's ecological balance and lowers the quality of life in the environment. A pollutant is any substance that changes air, water or any other natural resource in a way that impairs the use of the resource.

Pollutants are discharged into the environment as a result of natural events (like a volcanic eruption) and as a result of human activities (such as the operation of chemical industries, agriculture, etc.). Pollutants can be classified by the type of pollution they cause: air pollution, water pollution, and land pollution.

Air Pollution

Activity 4.24

1. Based on the situation of your locality, discuss the following issues in groups and present the findings to the class:
   - a List some human activities which contribute to air pollution.
   - b How these activities contribute to air pollution?
   - c What solutions do you recommend to overcome these problems?
   - d What could be your contribution to reduce air pollutions?
2. Give your suggestions on the statement, 'Air pollution any where is a potential threat elsewhere.'

Air pollution is caused by the presence of contaminant gaseous substances in the air that affect the lives of plants and animals on earth. Some common air pollutants are sulphur dioxide, nitrogen oxides, carbon monoxide, ozone, hydrocarbons, particulates, chlorofluorocarbons (CFCs), and lead compounds.

Sulphur dioxide (SO_2): This enters the atmospheric air from the combustion of coal and petroleum, and during extraction of metals from their sulphide ores. It causes coughing, chest pains and shortness of breath. It is thought to be a cause for bronchitis and lung diseases. It slowly oxidizes to SO_3 by reacting with the oxygen in the air.

Oxides of nitrogen: These can be formed in the atmosphere by natural processes like thunderstorms. Combustion of fossil fuel containing nitrogen compounds as impurities and exhaust gases from furnaces and engines increase the amount of nitric oxide, NO, and nitrogen dioxide, NO_2, in the atmosphere. Nitric oxide, NO, catalyzes the decomposition of ozone in the upper layer of the atmosphere to oxygen, thus decreasing the ozone layer.

$$2O_3(g) \xrightarrow{NO} 3O_2(g)$$

Nitric oxide is oxidized by oxygen to nitrogen dioxide in the presence of ultraviolet light.

$$2NO\ (g) \quad + \quad O_2\ (g) \quad \rightarrow \quad 2NO_2\ (g)$$

SO_2, SO_3 and NO_2 react with rainwater and form sulphurous acid (H_2SO_3), sulphuric acid (H_2SO_4) and nitric acid (HNO_3), respectively and cause acid rain. Acid rain accelerates corrosion and the deterioration of metals, buildings, statues and also causes tree defoliation, release of heavy metal ions from soil into water courses and drop in the pH of water in rivers and lakes.

Hydrocarbons and ozone are responsible for photochemical smog. It is characterized by a reddish-brown haze containing substances irritating to the eye, nose, and lungs, and causes extensive damage to vegetation. Considerable amounts of hydrocarbons are released into the atmosphere by the evaporation of gasoline as unburnt hydrocarbons in auto exhaust. These substances react with ozone to give compounds that contribute to the oxidizing nature of photochemical smog.

Carbon monoxide: Most of the carbon monoxide escapes into the atmosphere due to the incomplete combustion of fuel. Prolonged exposure to carbon monoxide impairs vision, produces headaches, and exerts strain on the heart. It also reduces the oxygen-carrying capacity of the blood by reacting with haemoglobin.

Particulates: Dust storms, forest fires, volcanic eruptions and human activities such as mining and burning coal and oil increase the amount of solid particles in the air. Industrial areas contain particles of limestone, fertilizers, coal, stones, cement and silica. These particulates irritate the lungs and deleteriously affect breathing.

Chlorofluorocarbons (CFCs): Chlorofluorocarbons are used as refrigerants, solvents and plastic foam-blowing agents. When entering the atmosphere, they penetrate into the upper layers and interact with ultraviolet radiation as follows.

$$CF_2Cl_2 \xrightarrow{UV} CF_2Cl\cdot \quad + \quad \cdot Cl$$

The free chlorine, Cl, reacts with ozone to form chlorine monoxide and oxygen.

$$\cdot Cl \quad + \quad O_3 \quad \rightarrow \quad ClO\cdot \quad + \quad O_2$$

These reactions result in the conversion of ozone to molecular oxygen and contribute to depletion of the ozone layer. This situation in the upper atmosphere allows dangerous ultraviolet radiation to reach the earth's surface. This radiation causes skin cancer in human beings.

Excess carbon dioxide: The combustion of coal and petroleum to generate electricity, move our vehicles, heat our homes and supply power to our industrial machinery causes a significant increase in the concentration of carbon dioxide in the atmosphere. Combustion of these fuels releases about 20 billion tonnes of CO_2 annually. The increase in the concentration of CO_2 in the atmosphere has resulted in a rise in the average global temperature, owing to the greenhouse effect. Carbon dioxide and water vapour absorb infrared radiation, re-radiated from the earth, behaving like the glass in a green house. Since CO_2 and water vapour absorb heat they are called green-house gases. Due to the absorption of heat by the green house gases in the atmosphere, the overall effect is global warming (*an increase in the average temperature of our planet*). This rise in global temperature causes melting of polar ice and thus additional water flowing into the oceans. This situation, in turn, results in the rising of the levels of seas and oceans, flooding of coastlines and lowland areas, which can submerge these areas.

Heavy metals: Lead contamination in the atmosphere is a result of vehicle engines that use fuels containing tetraethyl lead which is added to the fuel to reduce engine knocking. The use of lead paints also contributes towards lead contamination. High levels of lead cause damage to the brain, kidneys and liver.

What are the potential air pollutants in and around your home?

Methods of Reducing Air Pollution:

Activity 4.25

1. Name the major air pollutants.
2. What methods do you recommend to reduce air pollution? Discuss in groups and present your idea s to the class.

Research and writing

Investigating the effects of air pollution on the environment by:

a consulting experts working on environmental protection, and

b referring materials available in you school library. Write a report about your findings and give a presentation to the class.

Water Pollution

Activity 4.26

1. In your community,
   a What are the major sources of drinking water?
   b What are the principal sources of contamination of surface water and ground water?
   c What could be done to reduce these problems?

Discuss in groups and present to the class.

Water pollution is the degradation of the quality of water brought about by the discharge into it of untreated sewage, industrial and agricultural waste, and oil spillage. In general, water is said to be polluted if it contains matter that affects the health of living things or causes damage to property. The major water pollutants are nitrate and phosphate fertilisers washed out of the soil, phosphate detergents, untreated sewage, insecticides and herbicides, and the heavy metal ion, acidic and/or basic residues released by industrial processes.

Phosphate and nitrate fertilisers washed out of the soil and phosphate detergents from untreated water, enter natural water systems, such as streams, rivers, lakes, and seas. These dissolved minerals are valuable nutrients for plants, and their discharge into the water systems accelerates the growth of surface-water plants, such as algae. As a result, less light reaches the bottom-living plants, which reduces the photosynthesis they need to live, and they die. When these aquatic plants die, they rot under the action of bacteria which multiply greatly and consume the oxygen dissolved in the water at a rate faster than natural aeration or photosynthesis can replenish. Thus, the amount of oxygen in the water decreases. This depletion of oxygen kills aquatic animals like fish. This sequence of events is called eutrophication.

Insecticides (pesticides) and herbicides applied in agriculture may also be washed into lakes, rivers, streams and seas. Some of the insecticides and herbicides do not decompose easily and are persistent in the environment. Residues of these insecticides and herbicides may enter the food chains and accumulate in an organism that is consumed by the next organism. The increasing amount of insecticide and herbicide residue in the bodies of animals causes health and behavioural problems.

The release of heavy metal ions, acidic and/or basic residues from industrial processes into natural water systems, such as lakes and rivers, causes pH changes in the water. Water organisms need specific ranges of water pH to survive, so these changes in pH can kill them. In the same way, increasing concentrations of toxic metal ions kills some aquatic organisms.

The release of untreated sewage to natural water systems can spread water-borne diseases such as cholera, typhoid, hepatitis, and polio.

Methods of Reducing Water Pollution:

1. Treatment of water before discharge into rivers and lakes.
2. To avoid unnatural temperature changes in natural water systems, industries should not discharge heat-ladened water into them.
3. Recycling industrial and agricultural wastes.
4. Using moderate amounts of agricultural chemicals and increasing the use of organic fertilizers and biological methods to control pests.

PROJECT 4.4

Develop a water conservation plan for your school and submit it to your teacher.

Land Pollution

Activity 4.27

Discuss the following issues and present your answer to your class.

1. Do you observe any pollution of land in your environment?
2. What are the causes of land pollution?
3. Do you observe soil erosion in your area? What three major things do you believe elected officials should take to decrease soil erosion in the region you live?
4. What should be your responsibility in solving the land pollution problems?

Land pollution is caused by things we put into it. It results from the spillage of oil, leaching of harmful chemicals and heavy metal ions, and dumping of non-biodegradable wastes such as plastics.

Factors involved in land pollution include:

- Spillages of oil from leaking pipelines.
- Harmful heavy metal ions from buried waste leaching into water systems.
- Leaching of harmful chemicals from corroded metal drums which have been buried underground.
- Dumping of non-biodegradable (*do not decompose by the action of bacteria*) wastes like plastics which remain unchanged in the soil for decades or hundreds of years. Their accumulation in the soil hinders air and water movement and affects the growth of plants.
- Excessive use of synthetic fertilisers in agricultural activities also contributes towards land pollution.

What are the contributions of commercial inorganic fertilizers to land pollution?

Methods of Reducing Land Pollution:

Activity 4.28

What methods should be practiced globally to reduce land pollution? Discuss in groups and present your opinion to the class.

Research and writing

Investigating the effects of an industry on the environment

This project work will develop your skills in identifying problems that an industry can cause in your environment and help you to seek solutions to overcome the problem.

Select an industry close to your school or home. Try to identify the following

1. What are the products manufactured by the industry?
2. What are the raw materials used by the industry?
3. What is the manufacturing process involved?
4. What are the waste products generated?
5. What happens to the waste products? (*How does the industry discharge wastes*)
6. How is the environment affected by the industrial waste product?
7. How could the environmental impact of waste product be reduced?

Write a report in groups and give a presentation to the class.

Exercise 4.5

1. Describe the main agents of:

   a air pollution b water pollution c land pollution

2. What are the main methods of reducing:

   a air pollution b water pollution c land pollution

Check list

Key terms of the unit

- allotrope
- alloy
- Basic – oxygen process
- bauxite cryolite
- Bessmer converter
- blast furnace
- blister copper
- ceramics
- chemical industry
- Chile salt peter
- chlorine
- Contact process
- flotation
- fluoroapatite
- flux
- food preservation

- fractional distillation
- Frasch process
- glass
- Haber process
- Hall process
- nitrogen
- Occurrence
- Open – hearth fumace
- ore
- paper and pulp
- pollutants
- pollution
- redphosphorus
- rock phosphate
- slag
- steel
- sugar
- sulphur
- tanning
- thermite process
- verdigris
- white phosphorus

Unit Summary

- *A chemical industry is any institution involved in the production of chemicals.*
- *A chemical industry is characterized by using raw materials available in nature and transforming them into desired products by chemical means.*
- *Most of the materials used by the industries are present in nature.*
- *Natural resources are classified as renewable and non-renewable.*
- *Aluminium is the most abundant metal in the earth's crust. It is manufactured by the electrolysis of molten aluminium oxide mixed with cryolite using the Hall process.*
- *Aluminium is used to make light-weight alloys that can be used for aircraft and similar constructions.*
- *Aluminium resists corrosion due to the formation of a thin film of an oxide on its surface.*
- *Iron is the second-most abundant metal in the earth's crust.*
- *Iron is extracted in a blast furnace. The furnace is charged with iron ore, coke and limestone, and hot air is blown up from the bottom.*
- *Limestone is used in the blast furnace to remove impurities like sand (silica) in the form of slag.*
- *The type of iron obtained directly from the blast furnace is called pig iron and it is impure.*
- *Wrought iron is the purest form of iron obtained from pig-iron by removing most of the impurities.*

- *Steel is an alloy of iron containing definite amounts of carbon and other metals like chromium, nickel, tungsten, vanadium, manganese etc.*
- *Steel is manufactured by the Bessemer Converter, Open-Hearth Furnace and Basic Oxygen Processes.*
- *Copper is extracted by roasting chalcopyrites* ($CuFeS_2$).
- *Copper that is obtained by roasting chalcopyrites is called blister copper. It is impure, and it is refined further by electrolysis.*
- *Copper is malleable and ductile, a good conductor of heat and electricity and is used to make electric wires and in the manufacture of alloys.*
- *Nitrogen constitutes about 80% by volume of atmospheric air.*
- *Nitrogen is manufactured by the fractional distillation of liquefied air.*
- *Nitrogen is relatively inert. However, its reactivity increases when heated and combined with metals of group IA and IIA to form nitrides and with oxygen to form oxides like NO and* NO_2.
- *Phosphorus is manufactured by heating a mixture of rock phosphate, coke (carbon) and silica in an electric furnace.*
- *Phosphorus has two common allotropes, white and red phosphorus. White phosphorus is highly reactive, while red phosphorous is relatively stable.*
- *White phosphorus is stored under water.*
- *Phosphorus reacts with oxygen and chlorine.*
- *Oxygen makes up about 20% by volume of air. It is manufactured by the fractional distillation of liquid air.*
- *Oxygen is the most abundant element in the earth's crust.*
- *Sulphur exists in the elemental state in underground deposits from which it is extracted by the Frasch process.*
- *Sulphur reacts with oxygen to form sulphur dioxide and sulphur trioxide.*
- *Sulphur is used for the manufacture of sulphuric acid by the Contact Process.*
- *Chlorine is manufactured by the electrolysis of brine.*
- *Chlorine is a powerful oxidizing agent and reacts with heated metals to form chlorides.*
- *Chlorine and chlorine water are used to bleach coloured materials and as disinfectant.*
- *Glass is a mixture of two or more silicates.*
- *Pyrex is a glass containing boron. It resists high temperatures.*

- *Ceramics are materials that are baked or fired at very high temperatures.*
- *Cement is made by heating a ground mixture of sand and clay. It contains calcium oxide, silicon dioxide, aluminium oxide, iron (III) oxide, and magnesium oxide.*
- *Sugar is manufactured from sugarcane in a series of steps.*
- *Paper and pulp are manufactured from trees in a series of steps. Bleaching agents such as chlorine, chlorine oxide, ozone or hydrogen peroxide are used in paper and pulp production.*
- *Tanning is a process of converting skin to leather.*
- *The methods used in food processing and preservation are salting, pickling, sugaring, smoking, drying, canning etc.*
- *Pollution is the discharge of harmful waste material into the environment.*
- *The three types of pollution are air, land and water pollution.*
- *Air pollution is caused by the release of sulphur dioxide, oxides of nitrogen, carbon monoxide, hydrocarbons, particulates, CFCs, and lead compounds etc. into the atmosphere.*
- *Water pollution is caused by the discharge of untreated sewage, industrial and agricultural waste and oil spillage.*
- *Land pollution results from the spillage of oil, leaching of harmful chemicals and heavy metal ions, and dumping of non-biodegradable wastes such as plastics.*

REVIEW EXERCISE ON UNIT 4

Part I: Write the missing words in your exercise book

air *blast* *coke* *haematite* *oxide* *reduces*

1. We extract iron from iron ore in _a_ furnace. The commonest ore of iron is_b_. The other raw materials used are _c_, limestone and_d_. Inside the blast furnace, carbon monoxide _e_ the iron (III)_f_ to iron.

Part II: Multiple choices type questions

2. Which of the statements about the extraction of iron in the blast furnace is true?
   - a limestone is added to combine with excess carbon dioxide
   - b a slag of iron oxide forms at the bottom of the furnace
   - c hot air is blown in at the top of the furnace
   - d carbon monoxide reduces iron (III) oxide to iron
3. Calcium oxide is added to a steel making furnace to:
   - a oxidize basic oxides
   - b oxidize carbon to carbon dioxide
   - c react with acid impurities
   - d react with silicon to form silicon dioxide
4. Which of the following statements about fertilizers is true?
   - a ammonium nitrate can be used as a fertilizer
   - b fertilizers contain nitrogen, sulphur and iron
   - c fertilizers are added to the soil to make it more alkaline
   - d fertilizers are made by combining calcium with oxygen
5. The chemical name for quicklime is:
   - a calcium carbonate
   - c calcium hydroxide
   - b calcium sulphate
   - d calcium oxide
6. Ordinary glass is chiefly composed of:
   - a $Al_2SiO_6(OH)$ and SiO_2
   - c Na_2SiO_3 and $CaSiO_3$
   - b Al_2O_3 and K_2SiO_3
   - d Na_2CO_3 and SiO_2
7. The purpose of using brine in the process of tanning is to:
   - a remove unwanted flesh from the skin
   - b dehydrate the skin and kill bacteria
   - c remove hair from the skin
   - d make the skin soft
8. In the sugar industry, sulphur dioxide is used as:
   - a a disinfectant
   - c a preservative
   - b a bleaching agent
   - d an oxidizing agent

9. In the tanning process, the purpose of putting the skin into slaked lime solution is to:
   - a facilitate the removal of unwanted flesh
   - b dehydrate the skin
   - c facilitate the removal of hair
   - d soften the skin

10. Which of the following is the purpose of treating the crude bauxite ore with hot aqueous sodium hydroxide in the extraction of aluminium?
    - a to lower the melting point of crude bauxite
    - b to dissolve impurities like iron oxides
    - c to decrease the solubility of crude bauxite
    - d to obtain pure aluminium oxide

11. Which of the following is not a raw material in the manufacture of ordinary glass?
    - a boron oxide
    - b limestone
    - c silica sand
    - d soda ash

12. Of the following, a light metal is:
    - a Au
    - b Ag
    - c Hg
    - d Al

13. Aluminium metal has the following properties with the exception that:
    - a it occurs in nature in the combined form as bauxite
    - b it is a conductor of heat and electricity
    - c it is ductile and malleable
    - d it is a heavy metal

14. Aluminium is used for:
    - a kitchen utensils
    - b electric wires
    - c making alloys
    - d all of the above

15. Which of the following is the purest form of iron?
    - a cast iron
    - b pig iron
    - c wrought iron
    - d limonite

16. Which of the following is used for the extraction of copper?
    - a haematite
    - b chalcopyrite
    - c cryolite
    - d siderite

17. The highest quality steel is produced by using:
    - a Contact Process
    - b Open-hearth Process
    - c Basic Oxygen Process
    - d Bessemer Process

18. Which of the following elements possess allotropes?
    a carbon
    b sulphur
    c phosphorus
    d all

19. The product obtained by combining a material rich in lime, CaO with other materials such as clay, which contains silica, SiO_2, along with oxides of aluminium, iron and magnesium is:
    a glass
    b steel
    c cement
    d fertilizer

20. Which of the following is not a specific characteristic of chemical industries:
    a using naturally available raw materials
    b providing transport services to customers
    c involving chemical reactions
    d consuming energy

21. Which of the following is a non-renewable resource:
    a soil
    b water
    c petroleum
    d plants

22. Which of the following elements does not react with nitrogen:
    a Li
    b Ca
    c Fe
    d Mg

23. Which of the following is not a use of nitrogen:
    a making matches
    b making fertilizers
    c production of ammonia
    d as a refrigerant

24. The most abundant element in the earth's crust is:
    a silicon
    b oxygen
    c iron
    d aluminium

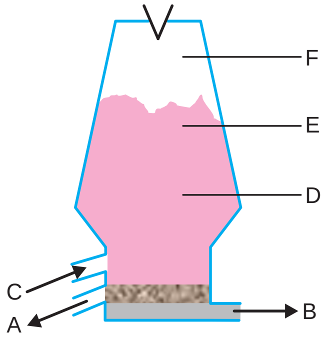
25. Which of the following elements is not found as a free element in nature:
    a sulphur
    b copper
    c oxygen
    d chlorine

Part III: Match the following items

26.	sulphur dioxide and nitrogen oxides	a	destroy the ozone layer
27.	hydrocarbons and ozone	b	poisonous substances
28.	particulates	c	acid rain
29.	CFC's	d	smog
30.	excess carbon dioxide	e	green house effect
31.	lead compounds and carbon monoxide	f	irritate the lungs

Part IV: Answer the following questions

32. Why is it important to ban the use of CFC's as refrigerants?
33. Mention three pollutants that can be released from the exhausts of motor vehicles.
34. What is the difference between carbon monoxide and carbon dioxide in polluting the environment?
35. What is the impact of using fertilizers and pesticides on the pollution of water?
36. What is the green-house effect? And what is its relationship to global warming?
37. What is the effect of heavy metals like Pb, Cd, and Hg on the body?
38. Mention three diseases that are caused by drinking water polluted by untreated sewage.
39. Mention two methods of converting potentially dangerous waste into harmless substances.
40. Explain at least two factors involved in land pollution.
41. What are the important properties of aluminium that make it useful in transport and construction?
42. Aluminium is one of the most reactive metals. How could it be corrosion resistant?
43. Iron is extracted in a blast furnace as shown below:



    a Name the four raw materials used in the extraction of iron from its ore.

    b Which letter in the diagram of blast furnace indicates:

    - *i)* The region where solid raw materials are put into the furnace.
    - *ii)* The hottest region of the furnace.
    - *iii)* The region where slag is collected.

44. Write balanced chemical equations for the given reactions, which take place in the blast furnace during the extraction of iron:

    a The reaction of iron (III) oxide with carbon monoxide.

    b The reaction of calcium oxide with silicon (IV) oxide.

45. Why is limestone added to the blast furnace?
46. Explain why aluminium is used to make cooking utensils.
47. Describe the advantages of using steel alloys instead of pure iron.