CHEMISTRY

A Textbook for Grade 12

C12TB

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Ministry of Education
Monrovia, Republic of Liberia

Star Educational Books Distributors (P) Ltd.
Delhi, India

ISBN : 978-93-95626-32-3

NOT TO BE SOLD

Printed on 80 gsm Maplitho paper in Times New Roman 12 pt.
Typeset and Cover designed by Shri Ganpati Enterprises, Delhi - 110 052

Published and Printed at:
Star Educational Books Distributors (P) Ltd., 4736/23, Ansari Road, Darya Ganj, New Delhi - 110002, India for Ministry of Education, Monrovia, Republic of Liberia

Email: info@estar-bk.com, Website: www.estar-bk.com

Foreword

Liberia, having gone through a period of utmost turmoil till 2003, due to the civil wars, is still reeling under its effect and the added trauma of Ebola in 2014 and effects of the COVID-19 outbreak in 2020. The Liberian government, in the past decade, has made valiant efforts to bring order to the lives of its people. In one such effort, the Ministry of Education (MoE) brought changes to the National Curriculum Framework which are relevant to the present generation, and which would prepare them to meet the challenges of the changing trends of the world. The National Curriculum Framework (NCF) 2018 recommends a change in basic assumptions in the teaching learning process from behaviorist to constructivist approach — moving from hardcore print material to the digital world. Keeping in consideration the sociocultural context and varied experiences of learners as laid down in the Framework, our Teaching Learning Materials are expected to be competent to use multiple methods and techniques like e-learning resources, energized textbooks, and readily available reference material to engage the learners.

As a first initiative, the MoE, through its World Bank-funded Improving Results in Secondary Education (IRISE) project, has adapted textbooks for Grades 10 to 12 in five subjects — English Language and Literature, Mathematics, Biology, Physics and Chemistry.

The National Curriculum Framework, 2018, recommends that children's learning at school is a reflection of their life outside the school and shows them the path to become a responsible citizen who makes knowledge-based choices.This principle marks a departure from the legacy of teacher centered learning to student centered learning. The syllabi and textbooks developed on the basis of the NCF indicate a serious attempt to implement the idea of Activity Base Learning (ABL). We hope these measures will take us ahead in the direction of building a system of education as outlined in the NCF.

Combined with the efforts by the school principals and teachers this will encourage children to reflect on their own learning and to pursue imaginative activities and questions.With this in mind, perhaps for the first time in our country, we are able to provide separate subject specific textbooks accompanied with guides for teachers for 10–12 grades. Not only have these been developed, adapted and modified to the Liberian context, each of the eight Minimum Learning Competencies (MLCs) have been included in each textbook. So as to reach every high school student, for the first time in the country's history we have included the digitized form of the textbook accessible by a Quick Response (QR) code given in each book. Not only does it have the digitized textbook, but it provides additional learning materials for use by students, teachers and interested persons. The links to these e-resources and digitized material is being made available on the MoE's website.

The Textbooks and Teacher Guides have reached the hands of the students after a rigorous quality evaluation by carefully handpicked subject specialists by the MoE, to whom the Ministry expresses gratitude. For the success of this project, I acknowledge the contributions of the IRISE Project Team in the World Bank, and in particular, the Task-Team Leaders; the Project Implementation Team in Liberia headed by its Coordinator Abraham A. Kiazolu II, supported by the Executive Director of the Center of Excellence for Curriculum Development and Textbooks Research, Mrs. Julia K. Sandiman-Gbeyai and her technical working group (TWG), and the International Textbook Consultant and Advisor, Dr Shveta Uppal engaged by the MoE. These notwithstanding would not have been possible without the guidance of the Senior Management Team (SMT) of the Ministry of Education, and in particular, the Deputy Ministers for Instructions, Administration, and Planning, Research and Development, respectively.

Professor Dao Ansu Sonii, Sr.
Minister of Education
Republic of Liberia

Monrovia, Republic of Liberia
January 24, 2023

Acknowledgments

The development of textbooks contributes to the quality of teaching and learning that go on in the classroom.

The Ministry of Education (MoE) has aligned its Curriculum for Grades 10–12 to the National Curriculum Framework (NCF) of 2018. To ensure the provision of Teaching Learning Materials (TLMs) that support the revised curriculum, the Ministry has sought, reviewed and adapted a new set of textbooks and teacher guides along with digitized contents and e-learning resources for the five core subjects taught at the Senior Secondary education level, namely English Language and Literature, Mathematics, Biology, Chemistry and Physics, through an internationally competitive bidding process from the market supported by the World Bank funded Improving Results in Secondary Education (IRISE) Project.

With profound gratitude and honor, we recognize the Senior Management Team of the Ministry, headed by the Coach, Professor D. Ansu Sonii, Sr., for the strategic decision to make teaching learning materials available and accessible to all in the Liberian Senior Secondary School System, and for providing directions through the process of securing these textbooks and other teaching learning materials for our students and teachers. Our special thanks and appreciation to the World Bank for the financial support towards this policy intervention, and its education task-team including Alonso Sanchez, Oni Lusk-Stover and Binta B. Massaquoi for all their technical inputs offered throughout the process to ensure the kind of quality TLMs the Liberian students deserve are made available for improved learning outcomes.

We would like to specifically recognize the invaluable contributions of the 15 subject experts selected by the MoE from across the various education systems and the West African Examinations Council (WAEC) to evaluate, review and sign off on these teaching learning materials. They didn't just deliver according to our expectations, but also ensured the contextual relevance of the materials

to the Liberian Secondary Education Curriculum and its minimum learning competencies (MLCs). These subject experts include Professor Isaac Saye-Lakpoh Zawolo – *Superintendent* of the Monrovia Consolidated School System (MCSS), Mr. Matthew V.Z. Darblo, Sr. – *Mathematics Instructor* at the University of Liberia (UL), Mr. Charles Tieh Bropleh – *Mathematics Specialist* (MoE), Mrs. Linda Y. Dean – *English Specialist*, Mr. Hassan M. Bangura – *English Language and Literature Expert*, Mr. J. Emmanuel Milton – *English Specialist* (MoE), Mr. Moses K.M. Togbah – *Physics Specialist*, Mr. Prince A. Dossen – *Physics Specialist*, Mr. Benjamin Koryah – *Physics Instructor* at the University of Liberia (UL), Mr. Dominic Dugbe Doe – *Chemistry Specialist*, Mr. Patrick A. Anderson, Sr. – *Director o*f the Division of Technical and Vocational Education (MoE), Mr. Kandakai Massaquoi – *Chemistry Specialist*, Ms. Patricia N. Doe – *Head* of Biology Department, African Methodist Episcopal University (AMEU), Mr. Job Carpenter – *Biology Specialist* and Mr. Prince Philip K.A. Aderibigbe – *Biology Specialist*.

The MoE is sincerely grateful to Dr Shveta Uppal, the *International Textbook Consultant* engaged by the IRISE Project to provide technical guidance and quality assurance support to the revising of the Textbooks Management Guidelines (TMG) and the procurement process leading to the provision of textbooks, teacher guides, digital contents and e-learning resources for the Senior Secondary School System in Liberia in accordance with the revised TMG. Heartfelt thanks and appreciations also to the *Executive Director* for the Center of Excellence for Curriculum Development and Textbooks Research, Mrs. Julia K. Sandiman-Gbeyai, and members of her Technical Working Group (TWG) for taking up the responsibility to lead the process of making textbooks and other TLMs available to Liberian students and teachers.

Lastly, we acknowledge the IRISE Project Delivery Team led by Mr. Abraham A. Kiazolu, II – *Project Coordinator*, Mr. Fuseini A. Abu – *International Procurement Specialist* and Mr. Lawrence S. Taylor – *Project Control Specialist* who coordinated the entire process.

We remain grateful to you all!

Hon. Alexander N. Duopu, Sr.,
Deputy Minister for Instruction
Ministry of Education, Republic of Liberia
#The Teacher

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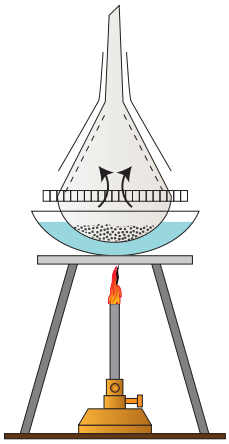
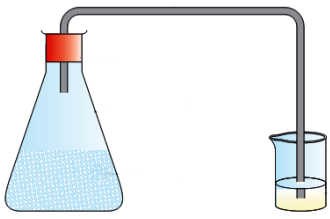
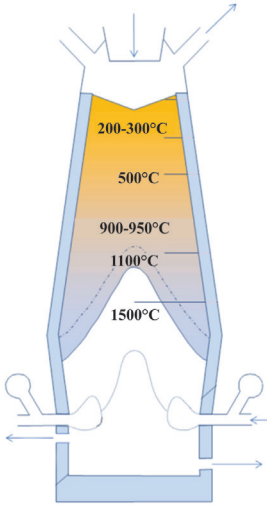
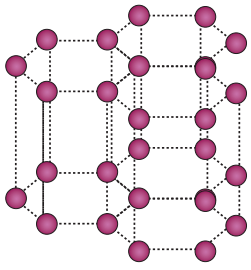
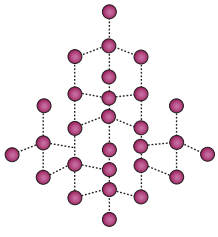










C12CH01

CHAPTER 1

INTRODUCTION TO ORGANIC CHEMISTRY

Chapter Contents

Chapter Outcomes

After completing this chapter, you will be able to:

- discuss general characteristics, laboratory techniques, as well as writing and naming hydrocarbons.
- discuss hydrocarbon derivatives together with their preparation, testing Polymerization processes as well as basic concepts of biochemistry.
- identify members of the homologous series.
- discuss the classes of isomers.
- discuss the general properties of hydrocarbons.
- discuss aromatic hydrocarbons.
- discuss hydrocarbon derivatives.
- demonstrate techniques for laboratory preparation and testing of hydrocarbon derivatives.
- demonstrate practical knowledge about the production of soap.

1.1 General Characteristics of Organic Compounds

Upon Completion of this topic, the learners will be able to:

- discuss the general characteristics of organic compounds,
- demonstrate practical knowledge about methods for separation and purification of methods of organic compounds,
- identify the various functional groups in organic compounds,

Do you recall what you have learnt about the branches of chemistry in grade 10? Can you name these branches? What is organic chemistry?

The term organic compound was first used to describe compounds of carbon derived from plants and animals. This is due to the fact that the sources of organic compounds were plants and animals. However, at the beginning of the 19th century (in 1828) a German scientist, ***FreidrichWohler***, synthesized the first man-made organic compound, ***urea.*** After the synthesis of urea by Wohler many carbon compounds were made artificially in chemical laboratories.

At present the term organic compound is used to describe compounds of carbon derived from living organisms as well as those made artificially in laboratories.

Organic chemistry is the study of carbon compounds with the exception of *oxides of carbon, carbonates and hydrogen carbonates, carbides of metals, cyanides,* etc.

Organic compounds have the following general characteristics. Organic compounds:

- are volatile (evaporate easily) and combustible (burst into flame in presence of oxygen and heat). They have low melting point and boiling points.
- are non-polar compounds and insoluble in polar solvents like water, but soluble in non-polar solvents like benzene, ether, etc.
- of the same class have similar chemical properties.
- have complex structures. This is due to the capacity of carbon atoms to link with one another to form long open or closed chains.
- exhibit isomerism. Most organic compounds have more than one structural formula.
- contain only few other elements besides carbon such as hydrogen, oxygen and sometimes nitrogen, sulfur, phosphorus and halogens.

(A) Classification of Organic Compounds

ACTIVITY 1

Form groups of four or five students and discuss on the following points for some minutes.

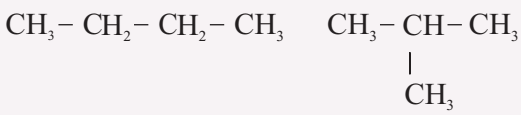
1. Do you know methods for the classification of organic compounds other than those mentioned below?
2. What are these methods?

After completing the your discussion, share the opinion of your group with the rest of the class.

There are different ways of classifying organic compounds. The classification of organic compounds is based on structural similarity and properties of group members. Based on structural similarity organic compounds are classified as i) ***acyclic organic compounds*** and ii) ***cyclic organic compounds.***

(i) ***Acyclic organic compounds:*** Compounds in which the carbon atoms are joined to one another in such a manner to form open chain structure. Thus, they are also called open chain organic compounds or aliphatic organic compounds.These open chain compounds may have straight or branched chain of carbon atoms.

Examples



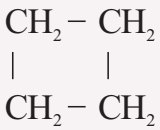
n-Butane (straight chain) *iso*-Butane (branched chain)

(ii) ***Cyclic organic compounds:*** Compounds in which the carbon atoms are linked to each other in a manner to form closed chain or ring structure. These class of compounds are further classified as ***alicyclic*** and ***aromatic compounds.***

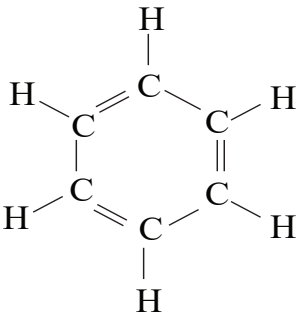
Alicyclic organic compounds: Compounds possess a ring structure made up of carbon atoms and behave like aliphatic compounds.

Aromatic compounds: Compounds contain benzene ring made up of six carbon atoms. They may contain one or more benzene rings.

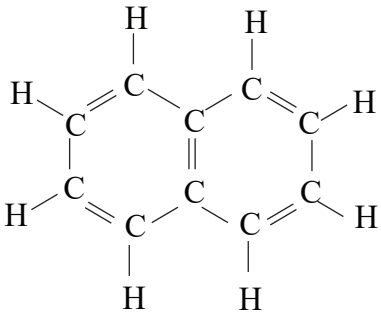
Examples



Cyclobutane (Alicyclic)



Benzene



Naphthalene

(B) **Separation and Purification of Organic Compounds**

Purification means the removal of unwanted impurities present in an organic compound. The method of purification of organic compounds depends mainly on the nature of the compounds and the impurities present.

The general methods of purification are:

- Sublimation
- Crystallization
- Distillation
- Differential Extraction
- Chromatography

Sublimation

Some solids can directly pass to the vapor state without going through the liquid phase. The purification technique which exploits this property is called sublimation. It is helpful in separating sublimable compounds from non-sublimable ones.

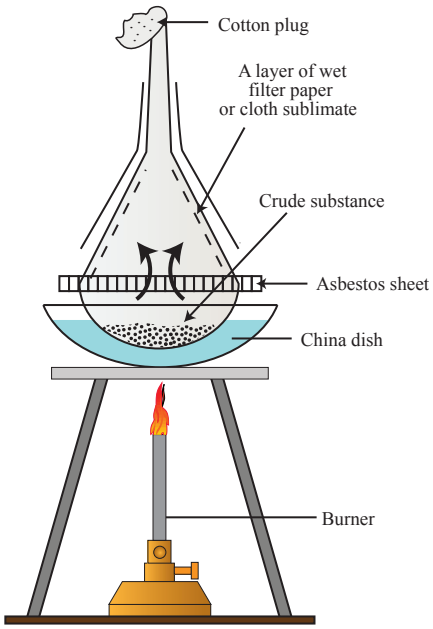


Figure 1. Purification by Sublimation

The substance is heated in a china dish above which an inverted funnel is kept to collect the sublimable compounds. The funnel is kept cooled by covering it with wet cloth or wet filter paper so as to fasten the process. Vapors of the substance solidify on the interior surface of the funnel.

Experiment 1

Separation of benzoic acid from sucrose by sublimation

Objective: To separate Benzoic acid from sucrose by sublimation.

Materials required: Benzoic acid, sucrose, balance, sand bath, Bunsen burner or candle, match box, 400 mL and 100 mL beakers, tripod stand and wire gauze.

Procedure

1. Weigh 1.0 g benzoic acid and 5.0 g sucrose and mix thoroughly.
2. Place a mixture of 1 g of benzoic acid and 5 g of sugar in a 400 mL beaker.
3. Place the beaker on a sand bath and cover the beaker with a round bottom flask filled with cold water.
4. Heat the beaker placed on a sand bath with Bunsen flame. You can also heat the beaker directly with a low flame and observe what is going on.

Observation and analysis

(a) Do you observe formation of crystals of a substance at the bottom of the cold round bottom flask and on the side walls of the beaker?

(b) What is the color of crystals of the substance formed?
(c) Is sucrose or benzoic acid the subliming substance?
(d) Scrap the sample of sublimed material from the bottom of the flask and beaker and place the sample in a beaker containing 5 mL of cold water and stir with glass rod. Is it highly or slightly soluble in water?

Crystallization

The principle here is that the compound and the impurities have different solubility in a solvent. A solvent is chosen where the compound to be purified is sparingly soluble, at lower temperature and more soluble at a higher temperature. The solution is heated up to a given temperature by adding more amount of the compound to be purified followed by stirring until a ***saturated solution*** is obtained. On cooling the saturated solution, the crystals of the solid settle down and the compound is removed via filtration.

Some organic substances do not crystallize readily, even from supersaturated solutions. A small crystal of the pure material may be added to induce the crystallization process, a technique known as "seeding". Crystallization can be induced also by scratching the sides or bottom of the container with a glass rod.

The microscopic scratches in the glass surface provide sharp edges upon which crystal growth may start.

If the mixture contains impurities that have the same solubility as of the compound to be purified, repeated crystallization is performed.

Experiment 2

Purification of benzoic acid by crystallization

Objective: To purify benzoic acid by crystallization

Materials required: Benzoic acid, water, 500 mL beaker, tripod and wire gauze, Bunsen burner, match, glass rod, filter papers, Buchner funnel.

Procedure

1. Weigh 10 g of benzoic acid and add it to a 500 mL beaker.
2. Place the beaker on wire gauze, add water gradually with constant stirring and heating the mixture with a Bunsen flame until a clear solution is formed.
3. Set aside the solution to cool until crystallization is complete.
4. Filter through suction filtration, collect the crystals after drying.
5. Weigh the dry crystal and calculate the % yield of purified crystals.

Observation and analysis

(a) Is the solubility of benzoic acid higher in cold water or hot water?

(b) What mass of benzoic acid is crystallized?

(c) What % of the dissolved benzoic acid is crystallized?

Distillation

The underlying principle behind distillation is that the mixture of liquids can be separated by the difference in their boiling points.

Boiling point is defined as the temperature at which the vapor pressure of the liquid is equal to the atmospheric pressure. This method separates volatile liquids from non-volatile liquids. The setup is given below for simple distillation.

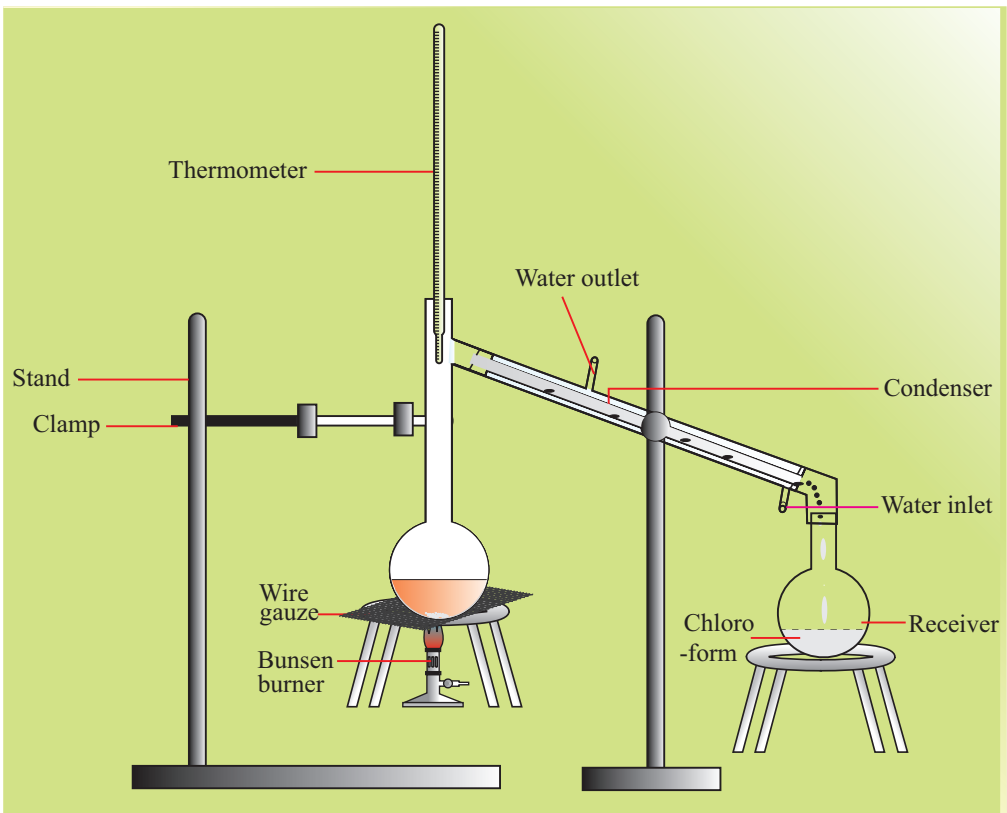


Figure 2. Purification of Liquids by Distillation

The mixture is taken in the distillation flask and boiled. The more volatile or the component with lower boiling point evaporates first and is collected in a separate container. A condenser is used to hasten the process of condensation.

Experiment 3

Separation of chloroform by distillation

Objectives: To separate chloroform by distillation from mixture of organic liquids

Materials required: Chloroform, aniline, measuring cylinder, distillation flask, condenser, Pneumatic trough, conical flask, thermometer, stand, clamp, rubber stopper, tripod stand and wire gauze.

Procedure

1. Take a mixture of 10 mL of chloroform and 10 mL of aniline and pour it into the distillation flask.
2. Arrange the setup as shown in Figure 2 above.
3. Heat the mixture with a Bunsen flame gently until the thermometer reading stays constant for some time.
4. After collecting about 5–8 mL of the first distillate stop heating and determine the boiling point of this liquid.

Observation and analysis

(a) What is the boiling point of the liquid collected?

(b) From literature, read the boiling points of chloroform and aniline and compare their boiling points with the boiling point you determined. Which liquid is separated first in this experiment?

Activity 2

By consulting chemistry books from your school library or using the internet, identify and write the differences between simple distillation, fractional distillation and steam distillation. Support your note with figures of each type of distillation. Finally present your findings to the rest of the class.

Extraction

Extraction refers to transference of compound(s) from a solid or a liquid into a different solvent. The process of extraction with solvents is generally employed either for the isolation of dissolved substances from solutions or from solid mixtures or for the removal of undesired soluble impurities from mixtures. In this case, appropriate solvents also have to be chosen.

The solvent selected will depend upon the solubility of the substance to be extracted in that solvent and upon the ease with which the solvent can be separated from the solute (extracted organic compound). Generally, diethyl ether, di-*iso*-propyl ether, benzene, chloroform, carbon tetrachloride and petroleum ether are common

solvents employed in the extraction of organic compounds. Water is sometimes used for the extraction of water soluble organic compounds (polar organic compounds). For example, the stimulant caffeine and compounds responsible for the taste and color of tea are readily extracted into hot water.

Paper Chromatography

Paper chromatography is a technique widely used for the analysis of organic mixtures. Paper chromatography usually employs the use of high grade filter paper strips as the stationery phase. A base line is marked in pencil near the bottom of the paper and a small sample of the mixture is spotted on it using a capillary tube. The paper is then placed vertically in a suitable solvent which rises up to the base line and beyond by capillary action. The components within the sample mixture dissolve in this mobile liquid and carried up on the paper. However, different compounds in the sample mixture are not carried up on the paper at equal rates. When the solvent has already reached the top of the paper, the paper is removed and quickly dried. The paper is developed to locate the positions of colorless fractions or compounds by spraying with a suitable chemical like *ninhydrin*, or by exposure to ultraviolet radiation. The components are identified by comparing the distance they travelled up on the paper with standard solutions that have been run simultaneously.

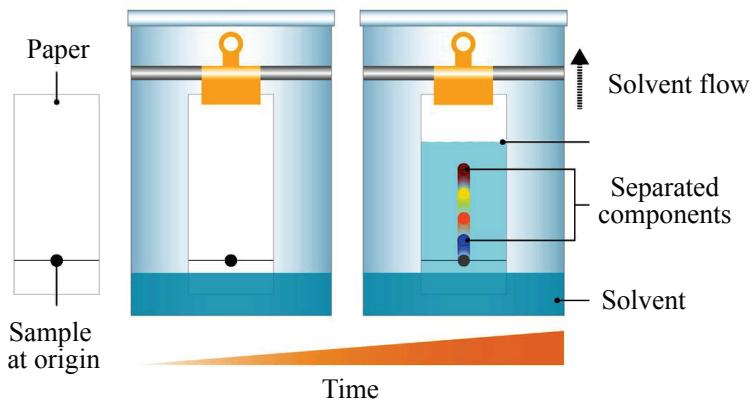


Figure 3. Separation by Paper Chromatography

Experiment 4

Separating components of a pigment by chromatography

Objectives: To separate components of a pigment by paper chromatography.

Materials required: Graduated cylinder, square glass lid, petroleum ether, acetone filter paper (chromatography paper), pigment.

Procedure

1. Prepare a piece of chromatography paper by measuring 2 cm from bottom of paper and drawing a line with pencil.
2. At the other end, attach a piece of tape long enough to drop the paper to the bottom of the graduated cylinder.
3. At center, touch the capillary pipette with pigment and allow the spot to dry.
4. Pour 5 mL of petroleum ether: Acetone solution in to a 100 mL graduated cylinder.
5. Cover the top of the cylinder with a square glass lid.
6. Place chromatography paper inside the cylinder so that the paper extends into the solvent.
7. Wait 10 minutes, then remove the paper from the cylinder, and mark the location of the solvent front with pencil after solvent is evaporated.
8. Label the location and color of the spots formed.
9. Measure the distance of the solvent and each spot travelled from the pencil line.

Observation and analysis

(a) How many different colored spots are formed after the pigment is separated.

(b) What is the color of the pigment that travelled, (i) the longest distance (ii) the shortest distance up the chromatography paper?

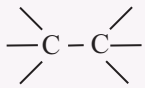
(C) Functional groups

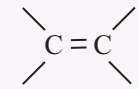
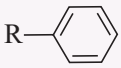
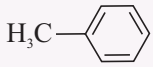
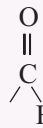
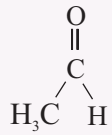
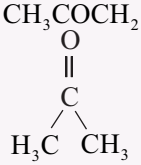
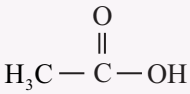
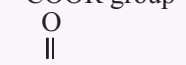
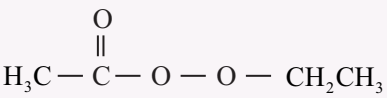
Do you know the functional groups of carboxylic acids, esters, and alcohols?

Organic compounds are also classified based on their functional groups. ***A Functional group is part of an organic molecule or compound that determines the chemical properties of that compound.*** It also determines some physical properties of the compounds. Organic compounds of the same group have the same functional group and hence exhibit similar chemical properties.

The most common organic compounds and their functional groups are given in Table 1.

Table 1 **Some classes of organic compounds, their functional groups, general structural formulas with specific examples.**

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)	$R-CH\equiv C-R$	$H-C\equiv C-H$ Ethyne
Aromatic	 (benzene ring)		 Methyl benzene
Alcohols	$-OH$	$R-OH$	CH_3CH_2-OH Ethanol
Aldehydes	$-CHO$ group 	$R-CHO$ 	CH_3-CHO  Ethanal
Ketone	$-CO-$ group 	$RCOR'$ 	CH_3COCH_2  Propanone
Carboxylic Acid	$-COOH$ group 	$R-COOH$ 	 Ethanoic acid
Ester	$-COOR$ group 	$RCOOR'$ 	 Ethyl ethanoate

(D) **Homologous series**

Group of compounds in which consecutive members of the group differ from one another by a methylene ($-CH_2-$) group.

Activity 3

Form groups of four students and discuss on the following points for five minutes.

1. What are the common features of compounds of the same homologous series?
2. Do they have the same functional group, general formula, methods of preparation and similar properties?
3. When you complete discussion, share the opinion of your group with the rest of the class.

(E) Isomerism

Isomerism is defined as the existence of two or more chemical compounds with the same molecular formula but different structures. The compounds that have the same chemical formula but different structures are called isomers.

Look at the following compounds. Count the number of carbon and hydrogen atoms in each compound. Do they have the same chemical formula? In what way do they differ?

Examples

$CH_3 - CH_2 - CH_2 - CH_2 - CH_3$ — *n*-Pentane

$$CH_3 - \underset{\displaystyle CH_3}{\underset{|}{CH}} - CH_2 - CH_3$$ — *iso*-Pentane

$$CH_3 - \underset{\displaystyle CH_3}{\underset{|}{\overset{\displaystyle CH_3}{\overset{|}{C}}}} - CH_3$$ — *neo*-Pentane

Exercises

Part I. Choose the correct answer from the given alternatives

1. Which one of the following elements is a constituent of all organic compounds?
   (a) Hydrogen
   (b) Oxygen
   (c) Carbon
   (d) Nitrogen
2. Of the following compounds which one is not an organic compound?
   (a) H_2CO_3
   (b) CH_3CH_2OH

(c) CH_3COOH
(d) C_4H_{10}

3. The name organic compound was first used to describe carbon compounds:
   (a) derived from mineral constituents of the earth
   (b) derived from petroleum and natural gas
   (c) synthesized in chemical laboratories
   (d) originated from living organisms
4. Part of an organic molecule that determines the chemical properties of that compound is called:
   (a) isomerism
   (b) functional group
   (c) homologous series
   (d) polymer
5. The separation of an organic compound from a solid or liquid mixture of compounds using an appropriate solvent is:
   (a) extraction
   (b) sublimation
   (c) distillation
   (d) crystallization
6. A group of compounds possessing the – COOH group are:
   (a) aldehydes
   (b) esters
   (c) carboxylic acids
   (d) alcohols
7. Compounds with the same molecular formula having different structural formulas are named as:
   (a) homologous series
   (b) isomers
   (c) polymers
   (d) methylene group
8. If the general structural form of a compound is $R\text{-}CH_2\text{-}CHO$, then the compound is a/an:
   (a) ketone
   (b) alcohol
   (c) ester
   (d) aldehyde

9. Which method of separation of an organic compound involves the conversion of a solid directly to vapor or gas?
   (a) crystallization
   (b) sublimation
   (c) distillation
   (d) extraction
10. Organic compounds containing carbon atoms linked to one another in such a manner to form ring structures are collectively called:
   (a) open chain compounds
   (b) straight chain compounds
   (c) branched chain compounds
   (d) cyclic compounds
11. The basis for the separation of organic compounds by distillation is the difference in their:
   (a) boiling points
   (b) densities
   (c) sublimation temperature
   (d) molecular mass
12. Which one of the following is not a common feature of compounds in the same homologues series?
   (a) they are represented by the same general formula.
   (b) they are prepared by similar methods.
   (c) their chemical properties are identical.
   (d) they have similar physical properties.

Part II. Answer the following questions

1. Explain how an organic compound is purified by crystallization.
2. When do you use sublimation as a separation method of organic compounds?

1.2 Hydrocarbons

Hydrocarbons are organic compounds composed of the elements carbon and hydrogen only. Based on the type of bonding between carbon atoms, hydrocarbons are classified as:

- saturated hydrocarbons and
- unsaturated hydrocarbons.

Saturated hydrocarbons are compounds of carbon and hydrogen containing only single bonds between carbon atoms. Examples are alkanes and cycloalkanes.

Unsaturated hydrocarbons are compounds of carbon and hydrogen containing one or more multiple (double or triple) bonds. Examples are alkenes, cycloalkenes, alkynes and aromatic hydrocarbons.

ACTIVITY 4

Discuss the following points In groups and present your opinion to the rest of the class.

1. Write the electron configuration of carbon atom ($z = 6$) and hydrogen atom ($z = 1$).
2. How many valence electrons do an atom of carbon and hydrogen possess?
3. How many atoms can form single covalent bonds with one carbon atom for this atom to have octet of electrons in its valence shell?
4. For a carbon atom to form a stable compound with hydrogen, how many hydrogen atoms can form bonds with one atom of carbon?

(A) **Alkanes or Paraffins**

Alkanes are saturated hydrocarbons that contain chains of carbon atoms linked by single bonds only. Every carbon atom in an alkane molecule forms four single covalent bonds with other atoms. The general formula of alkanes is C_nH_{2n+2}, where, n = 1,2,3…. Using this general formula, we can write the formula of any alkane containing specific number of carbon atoms, this can be done by introducing the number of carbon atom in place of "n" in the general formula. For example, the formulas of alkanes containing one, two, three, carbon atoms are CH_4, C_2H_6 and C_3H_8, respectively. These consecutive members of the alkane series differ from one another by a $-CH_2-$ group

A group of organic compounds in which the consecutive members of the group differ by a $-CH_2-$ group (methylene group) is called a *homologous series*. The individual members of the group are called *homologues*.

Physical properties of alkanes

At room temperature, the first four members, methane (CH_4), ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}), are gases whereas pentane (C_5H_{12}), to heptadecane ($C_{17}H_{36}$) are liquids and higher alkanes are solids.

Alkanes are non-polar compounds and are almost insoluble in polar solvents like water, but soluble in non-polar organic solvents like benzene, toluene, ether and carbon tetrachloride.

Alkane molecules are held together by weak intermolecular forces called *Van der Waals forces*. The strength of these forces increases with increasing surface area (molecular mass) of the alkanes.

The density, melting point and boiling point in the homologous series of alkanes increase with an increase in carbon number.

For alkanes of the same carbon number, branched chain isomers have lower boiling points than the straight chain isomer. This is because as branching increases, there is a decrease in surface area and the strength of the intermolecular forces. This results in a decrease in boiling points. For example, the boiling points of *n*-pentane, *iso*-pentane and *neo*-pentane are 36°C, 28°C and 9.5°C, repectively.

ACTIVITY 5

Discuss the following points in groups for five minutes and present the opinion of your group to the rest of the class.

1. What is the functional group of alkanes?
2. Based on the given boiling points, arrange *n*-pentane, *iso*-pentane and *neo*-pentane, in increasing order of branching.

Nomenclature of alkanes

The names of alkanes and most of the organic compounds are derived from a prefix that indicate the number of carbon atoms and a suffix indicating the type of the functional group present in the molecule.

Table 2 Prefixes 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

For example, in the name octane, the prefix oct indicates the presence of eight carbon atoms in the molecule and the suffix –ane indicates the functional group of an alkane to be carbon-carbon single bond.

ACTIVITY 6

Discuss the following points in groups and present your opinion to your classmates.

1. Write the chemical formulas of the alkanes containing one to ten carbon atoms.
2. Using the prefixes given in Table 2, name the first ten alkanes.

In the nomenclature of alkanes, common names and IUPAC names are used.

Common names of alkanes

Lower alkanes have common names. In the common names the prefixes *n*-(normal), "*iso*-" and "*neo*" are used.

The prefix ***n-*** is used when all the carbon atoms form a continuous chain.

Example

$H_3C - CH_2 - CH_2 - CH_3$ *n*-Butane

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

Examples

$$H_3C - \underset{\displaystyle CH_3}{\underset{|}{CH}} - CH_3$$ *iso*-Butane

The prefix *neo*- is used when the central carbon is bonded to four other carbon atoms.

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

IUPAC System of nomenclature of alkanes

To name more branched and complex alkanes, the International Union of Pure and Applied Chemistry (IUPAC) system is used.

Alkyl radicals are groups obtained by removing one hydrogen atom from the corresponding alkanes. Their general formula is the C_nH_{2n+1}, where, n = 1, 2, 3…. The names of these radicals are obtained from the alkanes containing the same number of carbon atoms as that of the radical by changing the suffix *-ane* to *-yl*.

Names of some alkyl radicals

Formula and name of alkane	Formula of alkyl radical	Condensed structured	Name of alkyl radical
CH_4(methane)	CH_3–	CH_3–	methyl
C_2H_6(ethane)	C_2H_5–	CH_3CH_2–	ethyl
C_3H_6(propane)	C_3H_7–	$CH_3CH_2CH_2$–	*n*-propyl
		CH_3–CH(–CH_3)–	*iso*-propyl

The following rules are applied in naming alkanes using the IUPAC system.

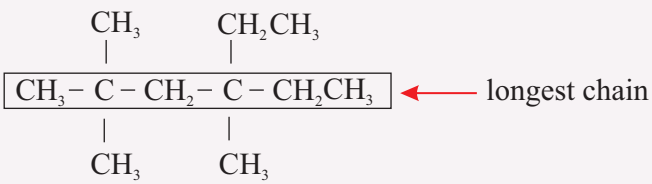
1. Select the longest continuous chain of carbon atoms in the molecule as parent structure. The longest chain gets name of straight chain alkane processing the same number of carbon atoms.
2. Assign numbers to the carbon atoms of the longest chain starting from one end to the other so that carbon atoms to which substitutes are attached to the longest chain have the smaller sum. They can be alkyl radicals, halogens, etc.
3. Indicates the position of the side chain by the number assigned to the carbon atom to which it is attached. When there are more than one identical substituent, use the prefix di-, tri-, tetra-, etc. before the name of the side chain to show two, three, four, etc. substituent.
4. Separate numbers by commas from each other and numbers from substituent names by hyphens.
5. Arrange names of substituents before the parent name in alphabetical order.

See the following examples to understand how the rules of the IUPAC system are applied to name alkanes.

Examples

Give the IUPAC name of the following compound,

Step 1-



In the longest chain or parent structure, there are six carbon atoms. So, the longest chain gets the name hexane**.**

Steps 2- To decide the correct direction of numbering (either from left to right or the reverse) add the numbers assigned to the carbon atoms to which substituents are attached. These numbers are called Locants. The smaller sum of Locants indicates the correct direction of numbering.

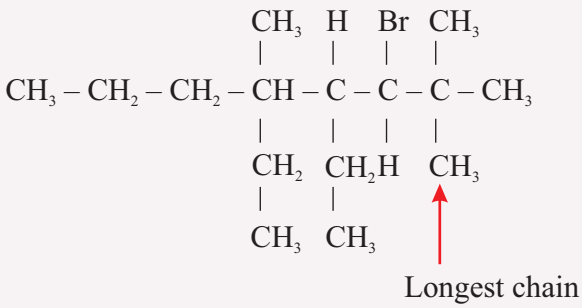
(a) **From left to right:** Two methyl (CH_3-) groups are attached at carbon –number 2, one methyl (CH_3-) group and two ethyl (CH_2-CH_3) groups are attached at carbon number-4. The sum of Locants will be 2+2+4+4=12.

(b) **From right to left:** One methyl and one ethyl groups are attached at carbon number C-3 and two methyl groups at carbon number C-5. The sum of Locants will be 3+3+5+5=16.

(c) Thus, numbering from left to right is correct. When two similar or different groups are attached to the same carbon, we write the locant twice. Thus the name of the compound becomes 4-Ethyl-2,2,4-trimethylhexane.

Example

Give IUPAC name of the following compound,



The longest chain gets the name octane. The total number of substituents is six. These are three methyl groups, two of them bonded to carbon number-2 and one at carbon number-5. There is one bromine at carbon number-3, two ethyl groups attached to carbon number-4 and carbon numbers-5.

So, when the names of the substituents are arranged in alphabetical order, the name of the compound becomes 3-Bromo-4,5-diethyl-2,2,5–trimethyloctane.

When *fluorine, chlorine, bromine and iodine* appear as substituents, their names changed to fluoro, chloro, bromo, and iodo**,** respectively.

Example

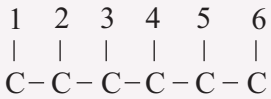
Write the structure of 2-Chloro-4-ethyl-2,3-dimethylhexane.

Solution

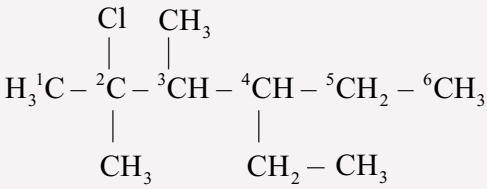
To write the structure of a hydrocarbon, first identify the parent name and decide the number of carbon atoms it contains. It is found at the end of the entire name of the compound. Arrange the carbon atoms in straight chain, number them starting from one end to the other, attach the substituents to the carbon atoms indicated by the numbers in the name. Finally attach the appropriate number of hydrogen atoms to carbon atoms where necessary. To write the structure of the compound;

Step – 1 Parent name is hexane which contains six carbon atoms

Step – 2 Arrange carbon atoms and assign numbers.



Step – 3 Attach substituents to the carbon atoms based on the numbers of the carbon atoms indicated in the name. That is, chlorine at carbon-2, ethyl group at carbon-4, one methyl group to each of carbon number-2 and carbon number-3. Then, attach three hydrogen atoms to each of carbon atoms number 1 and 6, two hydrogen atoms to carbon 5, one hydrogen atom each of carbon 3 and 4.



Isomerism and isomers are already defined in section 1. The type of isomerism that alkanes exhibit is structural isomerism called chain or skeletal isomerism. That is the isomers differ in the arrangement of the carbon chain. Those alkanes containg one to three carbon atoms have only one possible structure each. However, alkanes containing four and more than four carbon atoms have two or more different structures. For example, C_4H_{10} has two possible structures, C_5H_{12} has three possible structures, C_6H_{14} has five possible structures or isomers.

Exercises

1. Write the structure of the isomers of C_4H_{10} and name them using the IUPAC system.
2. Write three possible structures of C_5H_{12} and give them IUPAC names.

3. Write five possible structures of C_6H_{14} and name them according to the IUPAC system
4. Do you agree with the idea that the number of structural isomers of alkanes increases with increasing carbon number?

Preparation of alkanes

Alkanes are the main constituents of petroleum and natural gas. They are principally obtained from natural sources.

Alkanes can also be prepared in the laboratory by the following methods:

1. Hydrogenation of alkenes in presence of metal catalyst

General Reaction: $R - CH = CH_2 + H_2 \xrightarrow{Pt,\ Heat} R - CH_2 - CH_3$

Alkene — Alkane

Example

$$CH_3CH = CH - CH_2CH_3 + H_2 \xrightarrow{Pt,\ Heat} CH_3CH_2CH_2CH_2CH_3$$

2-Pentene — Pentane

2. 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, ($-COO^-$) from the sodium salt of the carboxylic acid. This type of reaction is called decarboxylation.

General Reaction: $R - COO^-Na^+ + 2NaOH \xrightarrow{CaO,\ Heat} R - H + Na_2CO_3$

Sodium salt of organic acid — Alkane

Example

$$CH_3COO^-Na^+ + 2NaOH \xrightarrow{CaO,\ Heat} CH_4 + Na_2CO_3$$

Sodium acetate (sodium ethanoate) — Methane

Methane CH_4

Methane is the simplest alkane. About 90% of natural gas is methane. It is also obtained during fractional distillation of crude oil. Methane is also formed in marshy

lands by the decay and decomposition of animal and plant remains. Hence, it is named marsh gas.

Experiment 5

Laboratory preparation of methane

Objective: To prepare methane and study its properties

Materials required: Sodium acetate, $CH_3COO^-Na^+$, soda lime (NaOH, CaO), test tube, delivery tube, rubber stopper or cork, gas jar, gas jar lid, Pneumatic trough, stand clamp, Bunsen burner, Beehive shelf, and balance, match box.

Procedure

1. Weigh 5 g powdered sodium acetate and 10 g of soda lime.
2. Mix the two compounds thoroughly and add the mixture into the test tube.
3. Arrange the assembly as shown in Figure 4.
4. Light the Bunsen burner and heat the test tube containing sodium acetate and soda lime.
5. Collect the gas by downward displacement of water. Collect several jars of the gas.
6. Insert a burning splint into one of the jar full of the gas and observe what happens in the jar.
7. Add a few drops of bromine water into one gas jar full of the gas and cover the gas jar with gas jar lid and observe.

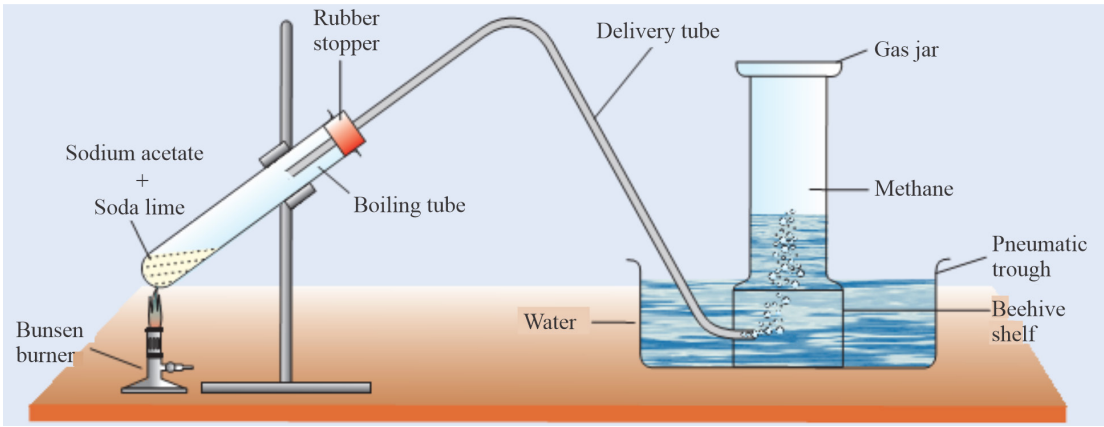


Figure 4. Laboratory Preparation of Methane

Observation and analysis

(a) Is the gas soluble in water?

(b) What is the color of the gas?

(c) Is the gas combustible? If yes write the balanced chemical equation for its combustion

(d) What change did you observe when bromine water is added to the jar filled with the gas?

(e) Write a laboratory report and submit to your teacher.

Chemical properties of alkanes

The name paraffin was suggested to alkanes by deriving from two Latin words **'parum'** meaning *little* and **'affinis'** meaning *affinity.* This is because alkane are inert towards many reagents like acids, bases, oxidizing and reducing agents. But, alkanes undergo several reactions under suitable conditions.

The reactions of alkanes are:

1. **Combustion Reaction:** Burning of alkanes in excess oxygen produces carbon dioxide and water liberating heat energy.The general equation for the combustion reaction is as follows;

$$C_nH_{2n+2} + \frac{3n+1}{2}O_2 \longrightarrow nCO_2 + (n+1)H_2O + \text{heat}$$

Where 'n' is the number of carbon atoms in the alkane molecule. For the combustion of octane, C_8H_{18}, $n = 8$. Substituting '8' in place of 'n' gives the following balanced equation

$$2C_8H_{18} + 25O_2 \longrightarrow 16CO_2 + 18H_2O + \text{heat}$$

2. **Combustion with limited supply of oxygen**

Alkanes burn in limited oxygen and produce carbon monoxide and water.

$$C_8H_{18} + \frac{17}{2}O_2 \longrightarrow 8CO + 9H_2O$$

3. **Substitution Reaction:** Reaction that involves the replacement of one atom or group of atoms by another atom or group of atoms. Halogenations of alkanes is a very good example of substitution. The reaction involves reacting alkanes with chlorine and bromine. The reaction of alkanes with chlorine or bromine proceeds in presence of heat or sun light. Such a reaction is called *photochemical reaction***.** The reactions of alkanes with chlorine and bromine follow sequence of steps. For example, the photochemical reaction of methane with chlorine proceeds in sequence of steps as follows.

(i) **Chain initiating step:** Step that involves absorption of light energy to generate reactive particles called *free radicals*. A *free radical* is electrically neutral atom or a group of atoms possessing unpaired electron.

In this step, chlorine molecule absorbs light energy and decomposes to two chlorine atoms.

$$Cl_2 \xrightarrow{\text{Light}} 2Cl\bullet$$

(ii) **Chain propagating step:** Step that consumes a free radical produced in step (i) and generates another free radical.

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

(iii) **Chain terminating step:** Step in which reactive particles (free radicals) are consumed but not generated.

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

During the chain terminating step, reactive particles produced in step (i) and step (ii) can react and produce unwanted products. Such reactions are called side reactions.

Examples

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

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

Chlorination of methane in presence of sunlight involves a series of steps. Such type of reaction is called *chain reaction*. The reaction of methane and chlorine proceeds as follows:

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

Methyl chloride

$$CH_3Cl(g) + Cl_2(g) \longrightarrow CH_3Cl_2(g) + HCl(g)$$

Methylene chloride (Dichloromethane)

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

Chloroform (Trichloromethane)

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

Carbon tetrachloride (Tetrachloromethane)

4. **Elimination Reaction**: Reaction that involves removal of atoms or smaller molecule from a compound to form unsaturated compound.

It can also involve the removal of hydrogen atoms from neighboring carbon atom at high temperature.

Examples

$$\underset{\text{Propane}}{CH_3 - CH_2 - CH_3} \xrightarrow{400\text{-}600^oC} \underset{\text{Ethene}}{CH_2 = CH_2} + \underset{\text{methane}}{CH_4}$$

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

Uses of alkanes

The major uses of alkanes is as fuels. They are also used as solvents of organic compounds.

Alkanes are also used as raw materials for the production of alkenes, alcohols, soap and detergents, plastics, etc.

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. It is greenish or a dark- brown colored viscous liquid and 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, sulfur 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. Refining of petroleum involves removal of impurities as well as separating the crude oil into different fractions.

Crude oil is separated into several components by fractional distillation based on the differences in boiling ranges of its fractions. The fractional distillation of crude oil is carried out in specially designed fractionating tower. The crude oil is heated in a furnace to about 400°C and introduced into the tower. High boiling fractions

condense first and flow out of the lower end of the tower whereas low boiling fractions rise upwards and collected as soon as they condense.

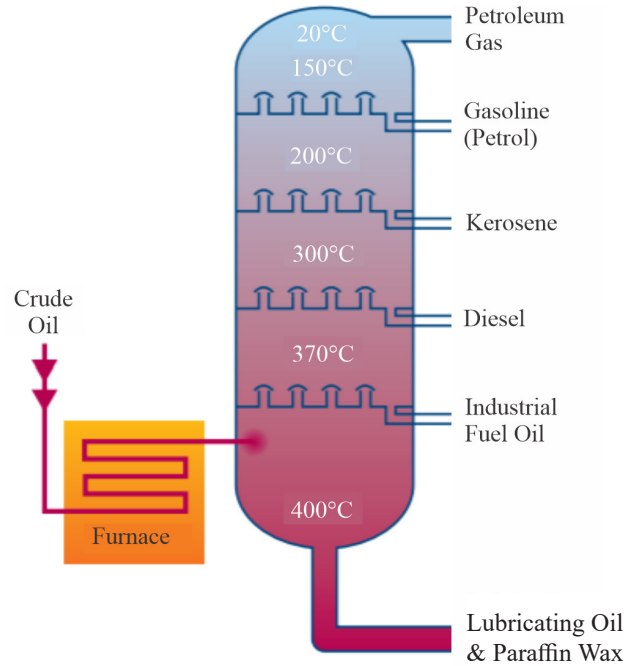


Figure 5. Refining of Crude Oil

Table 3 Common petroleum products

Fractions	Approximate composition	Boiling Point range (°C)	Uses
Gases	$C_1 - C_4$	Below 30	As fuel for stoves heating homes
Petroleum ether	$C_5 - C_7$	20 – 100	As solvent, dry cleaning
Petrol or Gasoline	$C_5 - C_{12}$	40 – 200	Fuel for internal combustion engines
Kerosene	$C_{12} - C_{16}$	175 – 275	Fuel for stoves, aeroplanes
Fuel oil, Diesel oil	$C_{15} - C_{18}$	250 – 350	Furnace fuel, Diesel engine fuel, for cracking
Lubricating oil, Grease, Petroleum jelly	$>C_{19}$	Non-volatile liquid	Lubrication
Paraffin wax, Asphalt, Bitumen, Coke	$>C_{20}$	Non-volatile solid	To make candles, polishes, roofing and road surfacing Electrode, fuel for power stations

What is the purpose of carrying out the processes called cracking and reforming during fractional distillation of crude oil?

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.

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

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

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

Reforming is a process carried out during refining of petroleum. The process mainly involves changing the structure of a hydrocarbon molecule to improve the quality of petroleum products. Fuels containing straight chain alkanes are not good fuels. On the other hand, fuels containing branched chain and cyclic hydrocarbons are good fuels.

Thus reforming is carried out to increase the quality of these fuels by changing straight chain alkanes into branched chain alkanes and cyclic hydrocarbons.

Petrochemicals

Petrochemicals are chemical substances obtained from petroleum, natural gas and mineral coal. They are starting materials for the production of a variety of commodities that are used in our modern lives. For example, plastic materials such as plates, cups, bottles, toys, etc. are all made from petrochemicals. Substances like ethylene, propylene, vinyl chloride, styrene, acetylene, benzene, etc. are petrochemicals. Petrochemicals are generally starting materials for the synthesis of different plastics, synthetic fibers, soaps and detergents, medicines, dyes, synthetic clothes, etc.

Octane rating (number)

The octane rating (number) of a fuel is a measure of its efficiency and anti-knocking properties. An automobile engine works properly when its fuel burns smoothly. If a fuel burns spontaneously (with explosion) before the piston is in the proper position, power is lost and knocking sound is heard.

***n*-Heptane (CH_3-$(CH_2)_5$-CH_3)** is a straight chain hydrocarbon that burns with a lot of engine knocking, so it is given an arbitrary octane rating of zero. *iso-octane also called 2,2,4-trimethylpentane* is a branched chain hydrocarbon that burns smoothly without knocking and is given octane rating of 100. A gasoline mixture with octane rating of 85 causes the same amount of knocking as a mixture of 85% *iso*-octane and 15% *n*-heptane. Until recently, small amounts of chemicals called *anti-knocking agents* like *tetraethyllead Pb* $(C_2H_5)_4$, were added to fuels. these chemicals inhibit knocking and increase the octane rating of a fuel. Unfortunately, tetraethyllead directly contributes to air pollution and also ruins the catalytic converters installed on new cars to meet the reduced emission requirements of pollutants.

At present, hydrocarbons with branched chain or ring structures are added to fuels to increase their octane ratings instead of anti-knocking agents.

Generally, fuels containing straight chain hydrocarbons produce a lot of knocking, have low octane rating or number and are not good fuels. On the other hand, fuels containing hydrocarbons with branched chain and ring structures produce less knocking, have high octane ratings and are good fuels.

Exercises

Part I. Choose the correct answer

1. The molecular formula of an alkane that contains eight carbon atoms is:
   (a) C_8H_{18}
   (b) C_8H_{16}
   (c) C_8H_{14}
   (d) C_8H_{10}
2. Of the following alkanes, which one is found in the liquid state at room temperature?
   (a) C_4H_{10}
   (b) CH_4
   (c) C_3H_8
   (d) C_6H_{14}

3. In the laboratory, methane is prepared by:
   (a) dehydration of ethanol
   (b) heating a mixture of sodium acetate and soda lime
   (c) the reaction of calcium carbide and water
   (d) dehydrogenation of ethene
4. The combustion of hexane in a limited supply of oxygen is given by the equation:

$$C_6H_{14} + O_2 \longrightarrow CO + H_2$$

   When this equation is balanced, the coefficient of carbon monoxide will be:
   (a) 6
   (b) 12
   (c) 13
   (d) 24
5. During the photochemical reaction of methane with chlorine, which step may result in side reactions?
   (a) chain initiating step
   (b) chain propagating step
   (c) chain terminating step
   (d) rate determining step
6. Which compound is not formed when sufficient amount of methane and excess chlorine are reacted in presence of sunlight?
   (a) CCl_4
   (b) $CHCl_3$
   (c) CH_3Cl
   (d) CH_4Cl
7. The name 'Paraffin' was suggested to alkanes because alkanes are:
   (a) inert towards many reagents
   (b) unsaturated hydrocarbons
   (c) more reactive than alkenes and alkynes
   (d) totally unreactive
8. The reaction represented by the equation:

$CH_3 - CH_2 - CH_3 \longrightarrow CH_2 = CH_2 + CH_4$ is an example of:
   (a) addition reaction
   (b) elimination reaction
   (c) substitution reaction
   (d) oxidation reaction

9. What product is formed from the reaction represented by the following equation?

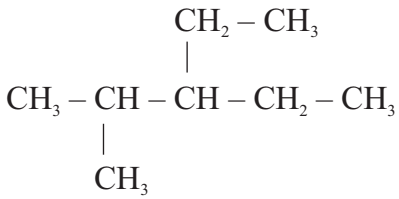
$$2CH_3CH_2Cl + 2Na \longrightarrow$$

(a) butane
(b) ethane
(c) methane
(d) propane

10. Hydrogenation of 2–Pentene in presence of platinum catalyst yields:
(a) pentyne
(b) hexane
(c) pentanol
(d) pentane

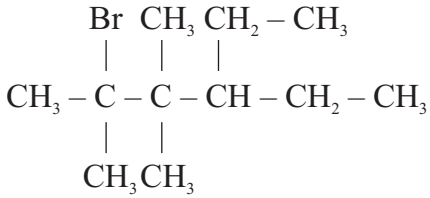
11. Which of the following reactions can be used as a general method for the preparation of alkanes?
(a) dehydrohalogenation of vicinal dihalides with a base
(b) dehydration of alcohols with alumina or sulfuric acid
(c) heating sodium salt of an organic acid with soda lime
(d) dehydrohalogenation of alkyl halides with a base

12. The IUPAC name for an organic molecule having the following structural formula is:



(a) 2, 2, 3–Trimethylpentane
(b) 2–Isopropylpentane
(c) 3–Ethyl–4–methylpentane
(d) 3–Ethyl–2–methylpentane

13. The correct IUPAC name of the following compound is:



(a) 5–Bromo–3–ethyl–4, 4, 5–trimethylhexane
(b) 2–Bromo–3, 3–dimethyl–4–ethylheptane
(c) 2–Bromo–4–ethyl–2, 3, 3–trimethylhexane
(d) 2–Bromo–4–ethyl–2, 3, 3–trimethylheptane

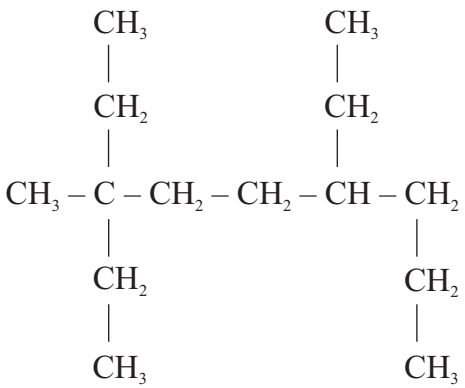
14. Four different fuels labeled A, B, C and D are given octane ratings of 80, 65, 90, and 50 respectively. Which one of these fuels is the best fuel?
(a) D
(b) C
(c) B
(d) A

15. Alkanes undergo the following reactions except:
(a) addition reaction
(b) elimination reaction
(c) substitution reaction
(d) combustion

16. Which one of the following alkanes has no isomers?
(a) pentane
(b) propane
(c) hexane
(d) butane

17. Which of the following compounds is a structural isomer of 2-Methylbutane?
(a) *n*-Propane
(b) *n*-Butane
(c) 2-Methylpropone
(d) *n*-Pentane

18. How many carbon atoms are there in the longest chain in the following structure of alkane and what name would the parent compound get?



(a) 8-Octane
(b) 9-Nonane
(c) 10-Decane
(d) 7-Heptane

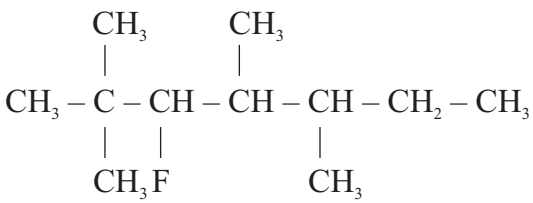
19. The major use of alkanes is as:
(a) fuel
(b) starting material
(c) solvent
(d) raw material to make detergents

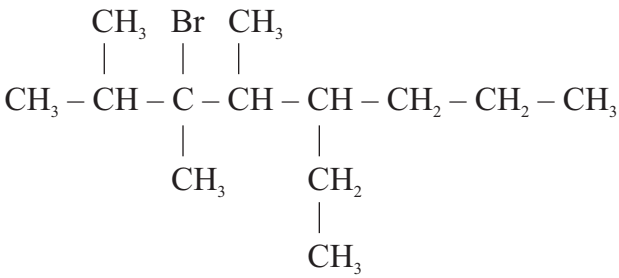
20. The reaction: $CH_4 + Cl_2 \longrightarrow CH_3Cl + HCl$, is classified as:
(a) elimination reaction
(b) addition reaction
(c) substitution reaction
(d) dehydrohalogenation

21. Crude oil is separated into a number of useful fractions by:
(a) fermentation
(b) polymerization
(c) fractional distillation
(d) destructive distillation

Part II. Answer the following questions:

1. Name the following alkanes using the IUPAC system

(a)


(b)


2. Write the structure of
   (a) 4–Ethyl–2, 2–dimethylhexane
   (b) 2, 2, 4–Trimethylpentane
3. Formerly, tetraethyllead has been added to fuels to increase their octane ratings. At present what substances are added to fuels to increase the octane ratings?
4. What is the purpose of performing the processes called cracking and reforming during refining of petroleum?
5. What are the sources of petrochemicals and what are their uses?

(B) Alkenes or olefins

Alkenes are unsaturated hydrocarbons containing a carbon-carbon double bond as their functional group is C = C, 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 4 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

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 inter-molecular 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 2 and adding the suffix '*ylene*':

Table 5 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 of naming alkenes

The IUPAC names of alkenes are obtained by using the prefixes listed in Table 2 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 used 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.
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.

Examples

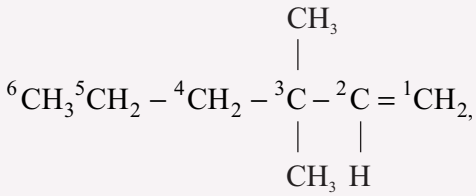
To give IUPAC name for the compound, we assign numbers to the carbon chain as shown below:

$$\overset{1}{H_3C} - \overset{2}{CH_2} - \overset{3}{CH} = \overset{4}{CH} - \overset{5}{CH_2} - \overset{6}{CH_2} - \overset{7}{CH_3},$$

There are seven carbon atoms in the chain and the double bond is between the third and fourth carbon atoms. So the compound gets the name 3-Heptene or Hept-3-ene.

Examples

What is the IUPAC name of the following alkene?



Numbering is done from right to left.

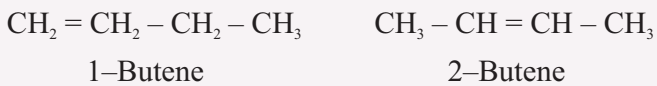
There are six carbon atoms in the longest chain; 2 methyl groups are attached to carbon 3, and the double bond at carbon number 1. So, the name of the alkene is **3, 3-Dimethyl-1-hexene** or **3, 3-Dimethylhex-1-ene**.

Isomerism in alkenes

Alkenes containing two or three carbon atoms have one possible structure each. Those alkenes containing four or more carbon atoms have isomers. Alkenes exhibit:

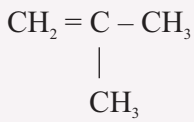
1. **Position isomerism:** Due to difference in the position of the double bond
2. **Chain isomerism:** Due to differences in the arrangement of the carbon chain.

Examples



1–Butene

2–Butene

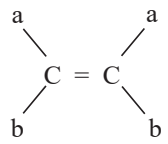


2–Methylpropene

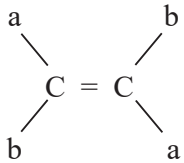
From the above structures, 1-Butene and 2-Butene are position isomers, 1-Butene and 2-Methylpropene are chain isomers

3. **Geometrical isomerism** results from the difference in the relative spatial arrangement of atoms or groups about the double bond. To differentiate geometrical isomers, we use the prefix '*cis*-' when two similar groups

are on the same side of the double bond and '*trans*-' when two similar groups are on opposite sides of the double bond. '*cis*' means 'on the same side' and '*trans*' means across. Geometrical isomers are also called *cis-trans isomers*. Geometrical isomers generally have the form:

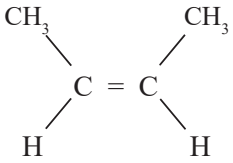


cis

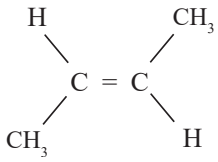


trans

The geometrical isomers of 2–Butene are the following



cis–2–butene



trans–2–butene

Preparation of alkenes

Alkenes are mostly obtained when the process of cracking is carried out during fractional distillation of petroleum. They can also be prepared by:

A. Dehydration of alcohols in presence of concentrated sulphuric acid (Tetraoxosulphate(VI)acid) or alumina and heat.

General reaction:

$$\underset{\text{Alcohol}}{R - CH_2 - CH_2OH} \xrightarrow[\text{Heat}]{H_2SO_4} \underset{\text{Alkene}}{R - CH = CH_2} + H_2O$$

$$\underset{\text{Ethanol}}{CH_3 - CH_2 - OH} \xrightarrow[\text{Heat}]{H_2SO_4} \underset{\text{Ethene}}{CH_2 = CH_2} + H_2O$$

B. Dehydrohalogenation of alkyl halides with a base of such as KOH.

General reaction:

$$\underset{\text{Alkyl halide}}{R - CH_2 - CH_2X} + KOH \longrightarrow \underset{\text{Alkene}}{R - CH = CH_2} + KX + H_2O$$

Example

$$\underset{\text{Ethyl chloride}}{CH_3 - CH_2 - Cl} + KOH \longrightarrow \underset{\text{Ethene}}{CH_2 = CH_2} + KCl + H_2O$$

Experiment 6

Laboratory preparation of ethene

Objective: To prepare ethene and study its properties.

Materials required: Ethyl alcohol, concentrated H_2SO_4, bromine water, thistle funnel, round bottom flask, rubber stopper, delivery tube, water, pneumatic trough, Bee-hive shelf, tripod stand, wire gauze, gas jar, gas jar lid, basic $KMnO_4$, clamp and stand, Bunsen burner, match box and thermometer.

Procedure

1. Measure about 20 mL of ethanol and pour it in the round bottom flask and arrange the set-up as shown in Figure 6.
2. Add concentrated H_2SO_4 through the thistle funnel and heat carefully until the temperature reaches 170°C.
3. Discard the gas collected in the first gas jar and collect three gas iar of gas by downward displacement of water.
4. Perform the following activities.
   (a) Insert a lighted splint into one of the gas jars and observe what happens.
   (b) Add two drops of bromine water into the other gas jar, and cover the jar and shake well.
   (c) Add few drops of alkaline $KMnO_4$ solution to another gas jar and see what happens.

Observation and analysis

(a) What is the color and odor of the gas?
(b) What substance is left after a burning splint is introduced into the first gas jar?
(c) What change is observed after the addition of bromine water and alkaline $KMnO_4$ to the gas jars? Write chemical equations for the change
(d) What substance is used as a dehydrating agent in this experiment?
(e) Which method of preparation of alkene is used in this experiment?

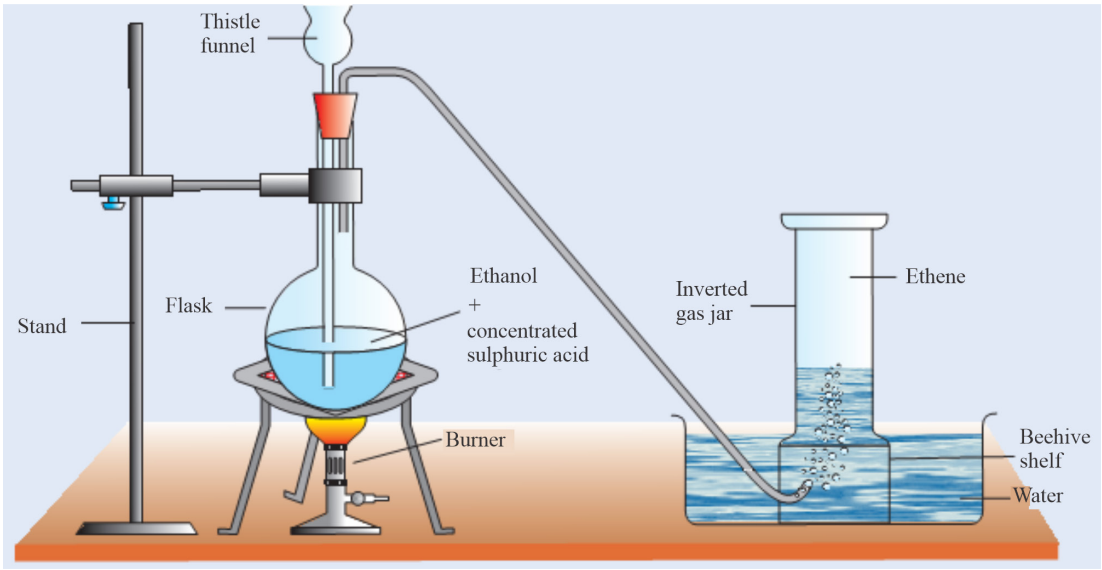


Figure 6. Laboratory preparation of ethene

Chemical properties of alkenes

Alkenes are more reactive than alkanes due to the double bond they possess. Alkenes undergo the following reactions.

A. **Combustion reactions:** Alkenes burn with a luminous flame to form carbon dioxide, water and liberate heat.

General reaction:

$$C_nH_{2n} + \frac{3n}{2}O_2 \longrightarrow nCO_2 + {}_nH_2O + \text{heat}$$

B. **Addition reaction:** Alkenes undergo addition reaction at the double bond and yield saturated compounds.

(i) **Halogenation:** Addition of a halogen molecule, X_2(Cl_2 or Br_2) to an alkene yields a dihaloalkane.

$$R - CH = CH_2 + X_2 \longrightarrow R - \underset{|}{\overset{X}{CH}} - \underset{|}{\overset{X}{CH_2}}$$

Alkene

Dihaloalkane

When bromine water (Br_2 in CCl_4) is added to an alkene, the reddish-brown color of bromine water disappears. This is due to the addition of bromine to the carbon-carbon double bond. Bromine water is used to identify unsaturated hydrocarbons. When bromine water is added to unsaturated hydrocarbons, its color disappears. The following reaction takes place when bromine water is added to ethene.

$$\underset{\text{Ethene}}{CH_2 = CH_2} + Br_2 \longrightarrow \underset{\text{1, 2 - Dibromoethane}}{\begin{matrix} CH_2 & - & CH_2 \\ | & & | \\ Br & & Br \end{matrix}}$$

(ii) **Hydrogenation:** Addition of hydrogen to alkenes in presence of metal catalyst such as nickel or platinum yields alkanes.

$$\underset{\text{Alkene}}{R - CH = CH_2} + H_2 \xrightarrow{Ni} \underset{\text{Alkane}}{R - CH_2 - CH_3}$$

$$\underset{\text{Propene}}{CH_3 - CH = CH_2} + H_2 \xrightarrow{Ni} \underset{\text{Propane}}{CH_3 - CH_2 - CH_3}$$

(iii) **Hydration:** Addition of water in the presence of an acid catalyst to alkenes yields alcohols.

$$\underset{\text{Alkene}}{R - CH = CH_2} + H_2O \xrightarrow{H^+} \underset{\text{Alcohol}}{\begin{matrix} R - CH & - & CH_3 \\ | & & \\ OH & & \end{matrix}}$$

$$\underset{\text{Propene}}{CH_3 - CH = CH_3} + H_2O \xrightarrow{H^+} \underset{\text{2-Propanol}}{\begin{matrix} CH_3 - CH & - & CH_3 \\ | & & \\ OH & & \end{matrix}}$$

(iv) **Hydrohalogenation:** Addition of a hydrogen halide, HX to alkenes yields alkyl halides.

$$R - CH = CH_2 + HX \longrightarrow R - \underset{\displaystyle X}{\underset{|}{CH}} - CH_3$$

Alkene — Alkyl halide

(v) **Oxidation of alkenes:** When cold alkaline potassium permanganate ($KMnO_4$) solution is added to alkenes, they oxidize to form compounds containing two hydroxyl (OH) groups called *diols*.

$$R - CH = CH_2 \xrightarrow{\text{Alkaline } KMnO_4} R - \underset{\displaystyle OH}{\underset{|}{CH}} - \underset{\displaystyle OH}{\underset{|}{CH_2}}$$

Alkene — Diol

$$CH_2 = CH_2 \xrightarrow{\text{Alkaline } KMnO_4} \underset{\displaystyle OH}{\underset{|}{CH_2}} - \underset{\displaystyle OH}{\underset{|}{CH_2}}$$

Ethene — 1, 2–Ethanediol

When alkaline $KMnO_4$ solution is added to alkenes, the purple color of the solution disappears. Thus alkaline $KMnO_4$ solution (also called Baeyer's reagent) is used for the identification of unsaturated hydrocarbons. The purple color of $KMnO_4$ disappears or fades and a brown precipitate is formed in the presence of unsaturated compound.

(vi) **Polymerization of Alkenes:** Polymerization is a combination of many small molecules (monomers) to form a large molecule called Polymer. This reaction is also called self-addition.

Example

$$nCH = CH_2 \longrightarrow [- \underset{\displaystyle CH_3}{\underset{|}{CH}} - CH]_{2-n}$$

Propylene — Poly propylene

Uses of alkenes

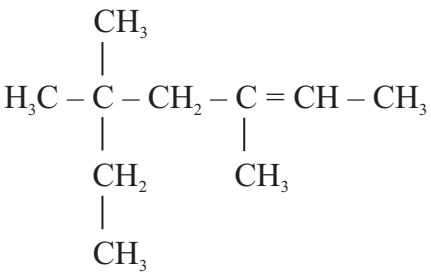
Alkenes are mostly used as raw materials in the production of plastics, alcohols and many other organic compound. Ethene (ethylene) is used to make 1,2-ethanediol

that serves as an antifreeze material and also for preservation and artificial ripening of fruits, to make polyethene plastic, ethanol, etc.

Exercises

Part I. Choose the correct answer

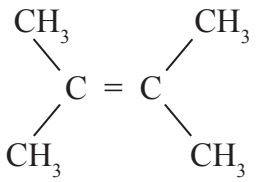
1. Hydrogenation of 2–Pentene in presence of platinum catalyst yields:
   (a) Pentyne
   (b) Hexane
   (c) Pentanol
   (d) Pentane
2. Which group of hydrocarbons posses a carbon–carbon double bond as their functional group?
   (a) alkanes
   (b) olefins
   (c) aromatics
   (d) alkynes
3. An alkene found in the liquid state at room temperature is the one with the formula:
   (a) C_2H_4
   (b) C_4H_8
   (c) $C_{10}H_{20}$
   (d) $C_{20}H_{40}$
4. What is the correct IUPAC name of the hydrocarbon represented by the following structure?



   (a) 3, 5, 5 – Trimethyl–2–heptene
   (b) 2–Ethyl–2, 4–dimethyl–5–hexane
   (c) 4, 6, 6–Trimethyl–2–octane
   (d) 3, 3, 4–Trimethyl–2–heptene

5. Which of the following pairs of alkenes do not exhibit position isomerism?
   (a) Ethene and Propene
   (b) Butene and Pentene
   (c) Hexene and Heptene
   (d) Octene and Nonene
6. Which pair of hydrocarbons has the same molecular formula?
   (a) 1–Butene and 2–Butene
   (b) 2–Methylpropene and 1–Butene
   (c) 2–Methyl–1–butene and 1–Hexene
   (d) 2, 3–Dimethyl–1–butene and 2–Hexene
7. Which one of the following is not an isomer of the alkene with formula C_6H_{12}?
   (a) 1–Hexene
   (b) 2–Methyl–1–pentene
   (c) 2,3–Dimethyl–1–butene
   (d) 2,3–Dimethyl–1–pentene
8. Heating 2–Propanol with concentrated H_2SO_4 yields:
   (a) propanone
   (b) propene
   (c) propyne
   (d) propanal
9. Consider the reaction: $CH_3CH_2 - CH_2 - CH_2Cl + KOH \longrightarrow X + KCl + H_2O$, what is the missing product 'X'?
   (a) 1–Butene
   (b) 1–Pentene
   (c) 1–Butyne
   (d) 1–Butanol
10. Hydration of ethene in presence of acid catalyst yields:
   (a) ethyne
   (b) propene
   (c) ethyl alcohol
   (d) ethane
11. The name of the compound that can be formed when 1–Butene reacts with Br_2 in CCl_4 is:
   (a) 1, 1–Dibromobutane
   (b) 1, 2–Dibromobutene
   (c) 2, 2–Dibromobutane
   (d) 1, 2–Dibromobutane

12. Ethene is prepared in the laboratory by:
    (a) dehydrohalogenation of 1,2-dibromo ethane
    (b) dehydration of ethanol with concentrated H_2SO_4
    (c) partial hydrogenation of ethyne
    (d) hydration of ethyne in presence of acid catalyst
13. Ethene or Ethylene is not used:
    (a) in the production of ethanol and polymers
    (b) in the production of ethylene glycol (antifreeze)
    (c) for the preservation and artificial ripening of fruits
    (d) as a solvent for fats and rubber
14. The most important industrial application of alkenes is:
    (a) as solvent
    (b) as fuel
    (c) in polymers production
    (d) in insecticides production
15. Which alkene is known by the name propylene?
    (a) $CH_3–CH_2–CH_3$
    (b) $CH_2=CH–CH_3$
    (c) $CH_2=CH–CH_2–CH_3$
    (d) $CH_3–CH_2–CH_2–CH=CH_2$
16. What is the IUPAC name of the following compound?



    (a) 2, 3–Dimethyl–2–butene
    (b) 2, 3, 3–Trimethyl–2–propane
    (c) 2, 3, 3–Trimethyl–2–propane
    (d) 2–Hexene
17. A reaction that involves the combination of many small molecules to form a large molecule is known as:
    (a) esterification
    (b) saponification
    (c) polymerization
    (d) decarboxylation

18. Alkenes decolorize the purple color of alkaline potassium permanganate solution. This is due to:
    (a) the oxidation of alkenes to diols
    (b) polymerization of alkenes
    (c) the conversion of alkenes to alkanes
    (d) the conversion of alkenes to alkynes
19. The formula of the hydrocarbon used for the preservation and artificial ripening of fruits is:
    (a) CH_4
    (b) C_2H_4
    (c) C_6H_6
    (d) C_2H_6
20. Isomers of an alkene that differ only in the spatial arrangement of atoms or groups about the double bond are:
    (a) position isomers
    (b) chain isomers
    (c) geometrical isomers
    (d) functional isomers
21. Which one of the following is a member of the olefins homologous series?
    (a) C_3H_8
    (b) C_4H_6
    (c) C_7H_8
    (d) C_6H_{12}

Part II. Attempt the following questions

1. Name the following compound:

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

2. Write the structure of 2, 3, 5–Trimethyl–2–hexene.
3. Complete the following reactions and name the products:
    (a) $Ch_3 - CH = CH - CH_3 + H_2 \xrightarrow{Pt}$
    (b) $Ch_3 - CH_2 - CH = CH - CH_2 - CH_3 + Br_2 \longrightarrow$

C. Alkynes

Alkynes are unsaturated hydrocarbons containing a carbon to carbon triple bond as their functional group. Alkynes are represented by the general formula C_nH_{2n-2}, where $n \geq 2$. Alkynes are also called acetylene series

Table 6 Homologous series of alkynes

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	$CH \equiv C - CH_3$	Proopyne	-101.5	-23
C_4H_6	$CH \equiv C - CH_2$	1-Butyne	-122	9
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
C_9H_{16}	$CH \equiv C - (CH_2)_6 - CH_3$	1-Nonyne	-65	151
$C_{10}H_{18}$	$CH \equiv C - (CH_2)_7 - CH_3$	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.

Nomenclature of alkynes

- **Common names:** Lower members of the alkyne series are named as derivatives of acetylene. The two carbon atoms linked by a triple bond gets the name acetylene and the names of the alkyl radicals attached to these carbon atoms are prefixed to the name acetylene. When the same alkyl groups are attached to the carbon atoms linked by triple bonds the prefix "*di*" is used.

Examples

$CH \equiv CH$	$CH_3 - C \equiv C - CH_3$	$CH_3 - CH_2 - C \equiv C - CH_3$
Acetylene	Dimethyl acetylene	Ethyl methyl acetylene

IUPAC system: In the IUPAC system of naming alkynes, the suffix **'-*yne*'** replaces **'-*ane*'** from the name of the corresponding alkanes to indicate the presence of a triple bond. During nomenclature of branched chain alkynes, the longest chain containing the triple bond is chosen as a parent structure. The chain is numbered from the end closer to the triple bond.

Examples

$^{1}CH \equiv {}^{2}C - {}^{3}CH_2 - {}^{4}CH_2 - {}^{5}CH_2 - {}^{6}CH_3$

1-Hexyne, Hex-1-yne

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

2, 2 - Dimethyl-3-hexyne or

2, 2 - Dimethylhex-3-yne

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

5-Bromo-5-ethyl-4, 4-dimethyl-2-heptyne or

5-Bromo-5-ethyl-4, 4-dimethylhept-2-yne

Isomerism in alkynes

Alkynes exhibit both chain isomerism and position isomerism

Examples

(a) $CH \equiv C - CH_2 - CH_2 - CH_2 - CH_3$

1 – Hexyne

(b) $CH_3 - C \equiv C - CH_2 - CH_2 - CH_3$

2 – Hexyne

(c)
$$CH_3 - C \equiv C - \underset{\displaystyle CH_3}{\underset{|}{CH}} - CH_3$$

4–Methyl–2–pentyne

Alkynes given by the structures (a) and (b) are position isomers, structures (b) and (c) are chain isomers.

Preparation of alkynes

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

General reaction:

$$\underset{\displaystyle X \quad X}{\underset{| \quad |}{R - C = CH}} + 2NaOH \longrightarrow R - C \equiv CH + 2NaX + 2CH_2O$$

Vicinal dihalides (X = Cl, Br, I) Alkyne

Examples

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

Ethyne

1, 2 – Dibromoethane

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

General reaction:

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

Sodium acetylide — alkyl halide — Alkyne

Examples

$$CH \equiv C^{-}Na^{+} + CH_3CH_2Br \longrightarrow CH \equiv C - CH_2CH_3$$

Sodium carbide Ethyl bromide 1-Butyne

Experiment 7

Laboratory preparation of ethyne (acetylene)

Objective: To prepare ethyne from calcium carbide and water

Materials required: CaC_2, H_2O, bromine water, round bottom flask separating funnel delivery tube, trough Behive shelf, gas jar, gas jar lid, Pneumatic trough, stand and clamp, sand or gravels.

Procedure

1. Put a layer of sand or gravels to cover the bottom of the round bottom flask and then place calcium carbide on the sand or gravels.
2. Arrange the setup as shown in Figure 7 and add water drop by drop from the separating funnel onto the calcium carbide.
3. Watch what happens, touch the flask with the tip of your finger.
4. Collect several jars of the gas over water and perform the following tasks.
   (a) Insert a burning splint into one of the gas jar filled with ethyne and observe what happens.
   (b) Add few drops of bromine water into the other gas jar filled with ethyne, cover the jar with a lid, wait for some time and note the changes.

Observation and analysis

(a) What do you feel when you touch the flask by the tip of your finger?
Is the reaction between calcium carbide and water endothermic or exothermic?
(b) What is the color of the gas produced?
(c) How do you compare the color of the flame produced with that of methane and ethene?
(d) What happened to the color of bromine water when added to the jar filled with the gas?

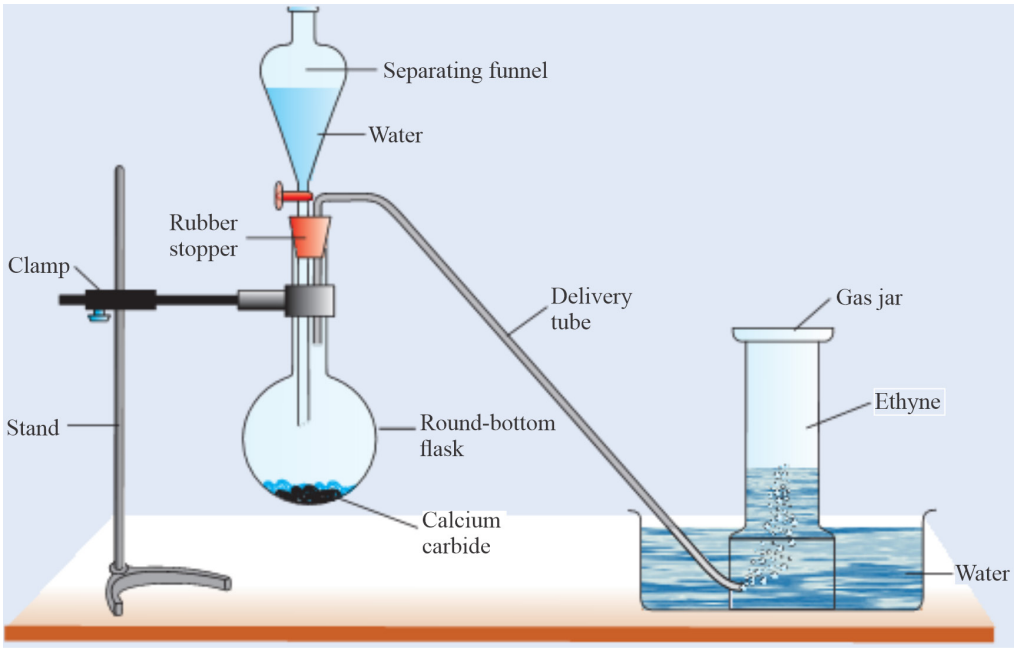


Figure 7. Laboratory Preparation of Ethyne

Chemical properties of alkynes

Alkynes are more reactive than alkanes and alkenes. They undergo the following reactions

1. **Combustion reaction:** Alkynes burn in oxygen with a smoky luminous flame to form carbon dioxide and water according to the following general equation.

$$C_nH_{2n-2} + \frac{3n-1}{2}O_2 \longrightarrow nCO_2 + (n-1)H_2O$$

Where 'n' is the number of carbon atoms.

For the combustion of hexyne, n = 6, substituting 6 in place of n gives the following equation.

$$C_6H_{10} + \frac{17}{2}O_2 \longrightarrow 6CO_2 + 5\,H_2O$$

Multiplying the entire equation by 2 gives

$$2C_6H_{10} + 17O_2 \longrightarrow 12CO_2 + 10H_2O$$

2. **Addition reaction:** Alkynes undergo addition reaction at the carbon–carbon triple bond.

Hydrogenation of alkynes: Addition of hydrogen to alkynes gives alkenes or alkanes.

(a) Partial hydrogenation of alkynes in the presence of Lindlar's catalyst (powdered palladium deactivated with lead acetate) gives alkenes

General reaction:

$$C_nH_{2n-2} + H_2 \xrightarrow{\text{Lindlar's catalyst}} C_nH_{2n}$$

Alkyne Alkene

Examples

$$CH_3 - C \equiv CH + H_2 \xrightarrow{\text{Lindlar's catalyst}} CH_3 - CH = CH_2$$

Propyne Propene

(b) Hydrogenation of alkynes in presence nickel or platinum catalyst yields alkanes.

General reaction:

$$C_nH_{2n-2} + 2H_2 \xrightarrow{Pt} C_nH_{2n+2}$$

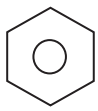
Alkyne Alkane

Examples

$$CH_3 - C \equiv C - CH_3 + 2H_2 \xrightarrow{Pt} CH_3 - CH_2 - CH_2 - CH_3$$

2-Butyne Butane

3. **Trimerization:** Ethyne on prolonged heating at 600–700°C gives benzene.

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

Ethyne Benzene

Uses of ethyne (acetylene)

Ethyne is used as a fuel in oxyacetylene torch which produces about 3000°C, which is used for cutting and welding metals. Ethyne is also used as starting material to prepare acrylonitrile and vinyl chloride. Acrylonitrile is used to manufacture poly acrylonitrile which is a raw material for textile fiber. Vinyl chloride is used to manufacture polyvinyl chloride This polymer is used to make floor tiles, electrical insulators water pipes, etc.

D. 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. Each angle represents a carbon atom to which one hydrogen atom is attached. He also suggested a resonance hybrid structure. He represented benzene by the resonance structures in which the two structures shown make equal contribution for the resonance hybrid or actual structure.

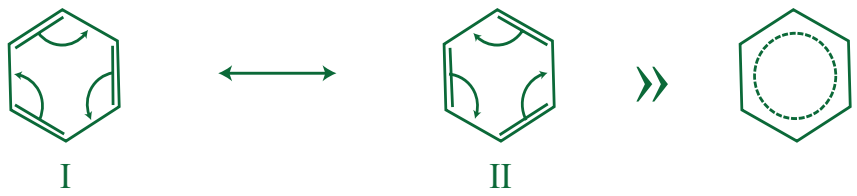


Figure 8.

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. The six electrons in the hexagonal ring are delocalized.

From structures I and II above one may think that benzene has three double bonds and has the same chemistry as that of alkenes. But, this is not true. Benzene is 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, colorless, 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 5.4°C and boils at 80.4°C. It is a carcinogenic (cancer causing) substance.

Chemical properties of benzene

Benzene and other aromatic hydrocarbons are more stable than alkenes and alkynes due to the stability of the aromatic hexagonal ring. 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.

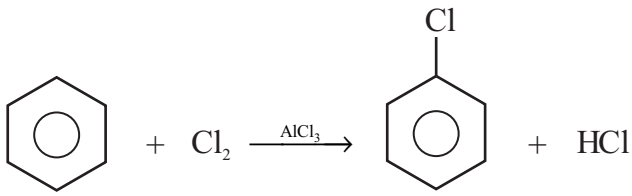
$$2C_6H_6 + 15O_2 \longrightarrow 12CO_2 + 6H_2O + \text{Heat}$$

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 substituted products.

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

Or



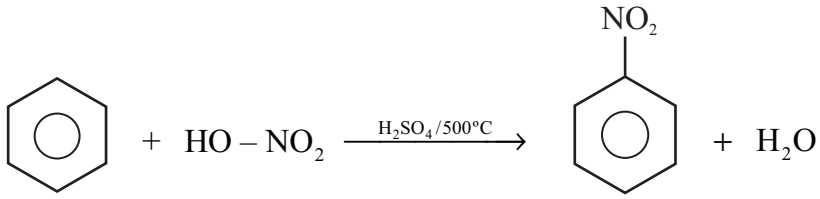
Benzene Chlorobenzene

(b) **Nitration:** Concentrated trioxonitrate(V) acid, HNO_3 mixed with some concentrated tetraoxosulfate(VI) acid, H_2SO_4 reacts with benzene at moderate temperatures to form nitrobenzene.

$$C_6H_6 + HNO_3 \xrightarrow{H_2SO_4/500°C} C_6H_5NO_2 + H_2O$$

Trioxonitrate (V) acid Nitrobenzene

Or

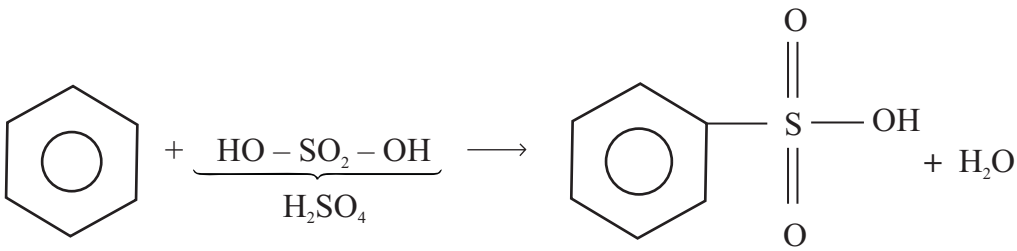


Trioxonitrate (V) acid Nitrobenzene

(c) **Sulfonation:** Benzene reacts with concentrated tetraoxosulfate (VI) acid, H_2SO_4, at room temperature to form benzenesulfonic acid.

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

Tetraoxosulphate (VI) acid

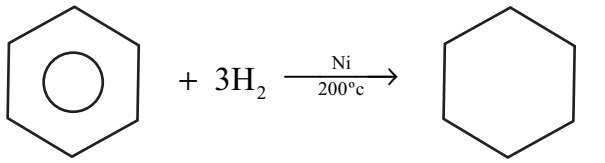


Benezene Tetraoxosulphate (VI) acid BenezeneSulphonic acid

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

Or



Benzene Cyclohexane

Uses of benzene

Benzene is used as a fuel, as solvent for fats, gums, rubber etc. and in the manufacture of dyes, drugs and explosives.

Experiment 8

Laboratory test for benzene

Objective: To investigate the effect of benzene on bromine water and acidified $KMnO_4$

Material required: Two test tubes, test tube rack, benzene, bromine water, acidified $KMnO_4$ solution, measuring cylinder and dropper.

Procedure

1. Measure 5 mL of benzene, pour in one test tube and 5 mL of benzene in the second test tube.
2. Add a few drops of bromine water into the first test tube and shake well. Observe if there is any change.
3. Add few drops of acidified $KMnO_4$ solution in the second test tube and shake the mixture

Obseravation and analysis

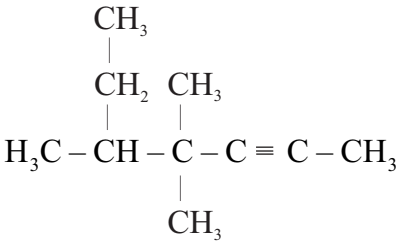
(a) Does benzene decolorize bromine water in the same way as ethene and ethyne do?
(b) Is there a change in the color of acidified $KMnO_4$ in the second test tube?
(c) What is your conclusion based on your observation in the experiment?

Exercises

Part I. Choose the correct answer

1. The correct IUPAC name of diethyl acetylene is:
   (a) 2–Pentyne
   (b) 3–Heptyne
   (c) 3–Hexyne
   (d) 3–Hexene

2. What is the IUPAC name of the following compound?



(a) 4, 4–Dimethyl–5–ethyl–2–hexyne
(b) 3, 4– Dimethyl–4–ethylpentane
(c) 2–Ethyl–3, 3–dimethyl–4–hexyne
(d) 4, 4, 5–Trimethyl–2–heptyne

3. Ethyne is prepared in the laboratory by:
   (a) alkylation of sodium acetylide with primary alkyl halide
   (b) the reaction of calcium carbide and water
   (c) dehydrohalogenation of 1, 2–dibromo propane with KOH
   (d) oxidation of ethene with alkaline $KMnO_4$
4. Which hydrocarbon is produced by the following reaction?

$$HC \equiv C^-Na^+ + CH_3Br \longrightarrow X + NaBr$$

   (a) Propyne
   (b) Ethene
   (c) Propene
   (d) Propane
5. Hexyne burns in excess oxygen according to the following equation

$$C_6H_{10} + O_2 \longrightarrow CO_2 + H_2O$$

   The coefficients of oxygen and carbon dioxide respectively when the equation is balanced will be:
   (a) 17, 12
   (b) 9, 6
   (c) 12, 17
   (d) 17, 10
6. Which one of the following gaseous hydrocarbons largely serves as a fuel to produce a flame used for cutting and welding metals?
   (a) Butane
   (b) Ethyne

(c) Bethane
(d) Propene

7. The reaction:

$$\begin{array}{l} CH_2 - CH_2 \\ | \quad\quad | \\ Br \quad\quad Br \end{array} + 2NaOH \xrightarrow{Heat} HC \equiv CH + 2NaBr + 2H_2O$$

is classified as:
(a) dehalogenation
(b) dehydrogenation
(c) elimination
(d) substitution

8. Acetylene (Ethyne) decolorizes the reddish brown color of Br_2 in CCl_4 solution when passed through it. This is due to the formation of:
(a) 1,2–Dibromoethane
(b) 1,1,2,2–Tetrabromoethene
(c) 1,1,2,2–Tetrabromoethyne
(d) 1,1,2,2–Tetrabromoethane

9. When a mixture of benzene vapour and hydrogen gas is passed over powdered nickel catalyst at 200°C, the product formed is:
(a) *n*-Hexane
(b) Cyclohexene
(c) Cyclohexane
(d) Nitrobenzene

10. The reaction of benzene with chlorine in the presence of $AlCl_3$ catalyst is an example of:
(a) addition reaction
(b) substitution reaction
(c) elimination reaction
(d) polymerization reaction

11. Which one of the following is not true about the reaction of benzene with concentrated nitric acid mixed with some concentrated sulphuric acid at moderate temperature?
(a) The reaction product is nitrobenzene
(b) The reaction involves the replacement of hydrogen atom from benzene ring with a nitro ($-NO_2$) group

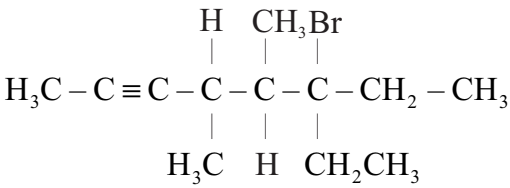
(c) The reaction is known as nitration
(d) The reaction involves addition of the nitro ($-NO_2$) group to benzene ring

12. Which of the following statements is true about benzene?
(a) Most of its reactions are addition reactions
(b) Generally it is less reactive than unsaturated aliphatic hydrocarbons
(c) it is not naturally occurring compounds
(d) it burns with a clean blue flame

13. How do you test whether a given hydrocarbon is unsaturated or not?
(a) by conducting solubility test in water.
(b) by checking its combustibility.
(c) by observing the color change.
(d) by treating it with bromine water.

14. Suppose that you were given two unknown solutions of hydrocarbons in separate test tubes. What must you do to identify the unsaturated hydrocarbon?
(a) Adding chlorine gas to both of the test tubes in the presence of sunlight
(b) Adding fluorine gas to both of the test tubes in the absence of sunlight
(c) Adding basic potassium permanganated solution to both of the test tubes
(d) Adding drops of water to both of the test tubes

15. The IUPAC name of the following compound is:



(a) 3–Bromo–3–ethyl–4, 5–dimetyloctane
(b) 6–Bromo–6–ethyl–4, 5–dimetyloctane
(c) 6–Bromo–6–ethyl–4, 5–dimethyl–2–octyne
(d) 3–Bromo–6–ethyl–4–hydro–4, 5–dimethyloctane

16. Among the following compounds, which one has the lowest boiling point?
(a) 2, 2–Dimethylpropane
(b) 2–Methylbutane
(c) Pentane
(d) Hexane

17. Which of the following statements is not true about benzene?
(a) It is carcinogenic substance.
(b) It is widely used as a solvent for fats, gums, rubber, etc.

(c) It is used to manufacture dyes and explosives
(d) It is a polar compound and miscible with polar solvents.

1.3 Hydrocarbon derivatives

(A) Alcohols or Alkanols

So far you have studied organic compounds containing carbon and hydrogen atoms only (hydrocarbons). If other elements or groups substitute one or more hydrogen atoms from a hydrocarbon, hydrocarbon derivatives are formed. In this section, we will study hydrocarbon derivatives containing oxygen besides carbon and hydrogen and hydrocarbon derivatives containing halogens (alkyl halides).

Oxygen derivatives of hydrocarbons can be classified as:

- alcohols (alkanols),
- aldehydes (alkanals),
- ketones (alkanones),
- ethers (alkoxy alkanes),
- carboxylic acids (alkanoic acids) and
- esters (alkyl alkanoates).

Activity 7

Form groups of four students and discuss on the following points for some minutes and present your opinion to your classmates.

1. What are the sources of alcohols?
2. Do you agree with the idea that bread baked after fermentation of wheat or maize flour contains little percentage of alcohol?
3. Beer and wine are alcoholic beverages prepared by fermentation. Which alcohol is present in these alcoholic beverages?

Alcohols can be obtained by fermentation of starch and cellulose. Alcohols can also be made by hydration of substances like alkenes in chemical laboratories. Glycerol is an alcohol that is obtained by hydrolysis of animal fat or vegetable oil.

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.

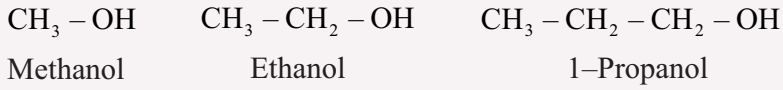
Alcohols are hydroxyl derivatives of hydrocarbons that can be obtained by replacing one or more hydrogen atom(s) of a hydrocarbon with the hydroxyl (–OH) group. The hydroxyl group is the functional group of alcohols.

Classification of alcohols

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

Monohydric alcohols are alcohols containing only one hydroxyl group.

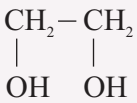
Examples



Methanol Ethanol 1–Propanol

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

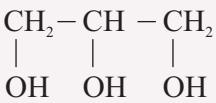
Examples



Ethane–1, 2–diol (Ethylene glycol)

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

Examples



Propane–1, 2, 3–triol or Glycerol or glycerine

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

Nomenclature of alcohols

Lower members of the alcohol series have common names. The common names are obtained by prefixing the name of the alkyl radical to which the hydroxyl group is attached to the word alcohol. Table 7 shows common names of some alcohols.

Table 7 Common names of some alcohols

Structure of Alkyl Radical	Name of alkyl radical	Structure of Alcohol	Name of Alcohol
CH_3-	Methyl	CH_3-OH	Methyl alcohol
$CH_3 – CH_2$ -	Ethyl	$CH_3 – CH_2$-OH	Ethyl alcohol
$CH_3 – CH_2 – CH_2$-	*n*-Propyl	$CH_3 – CH_2–CH_2$-OH	*n*-Propyl alcohol

An alcohol can be considered to be derived from an alkane 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. In the IUPAC system alcohols are also called **alkanols.**

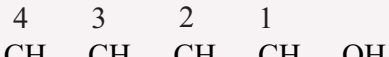
Table 8 IUPAC names, condensed structure and physical constants of the first six monohydric alcohols

Structure of monohydric alchol	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

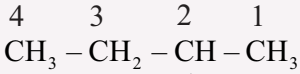
Can you derive a general formula for monohydric alcohols with general structure of R – OH? (Hint: R- is an alkyl radical)

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.

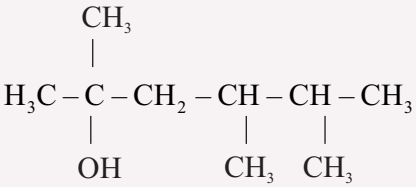
Examples



1 – Butanol



2 – Butanol

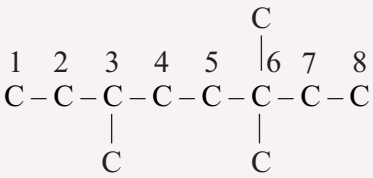


The longest chain contains six carbon atoms. Carbon atoms of this chain are numbered from left to right. Hydroxyl group is attached to the 2nd carbon, and three methyl groups to 2nd , 4th and 5th carbon atoms. So the alcohol gets the name 2,4,5–Trimethyl–2–hexanol.

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.

Examples



Carbon atoms denoted by number 1, 8 are primary, those denoted by number 2, 4, 5 and 7 are secondary, carbon number 3 is tertiary, and the one denoted by number 6 is quaternary carbon atom

Based on the type carbon atom to which the hydroxyl group is attached monohydric alcohols are classified as primary alcohols, secondary alcohols and tertiary alcohols.

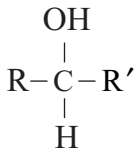
Primary alcohols are those alcohols which have the hydroxyl group connected to a primary carbon. They can also be defined as a molecule containing a "–CH_2OH" group.

General Structure

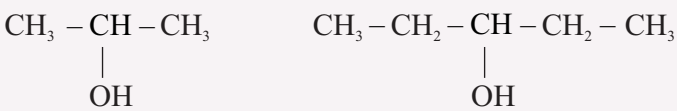
$R - CH_2 - OH$ (Primary alcohol)

Examples

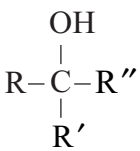
Secondary alcohols are those in which the carbon atom bonded to the hydroxyl group is attached to two alkyl groups or contains an –OH group bonded to a secondary carbon atom.

General structure:  where R and R' may be similar or different hydrocarbon groups

Examples

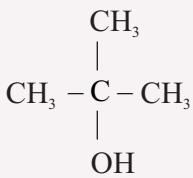


Tertiary alcohols are those in which the carbon atom bonded to the hydroxyl group is attached to three hydrocarbon (alkyl) groups or contain –OH group attached to a tertiary carbon atom.

General Structure: 

where R, R' and R" may be same or different hydrocarbon groups.

Examples



2–Methyl–2–propanol

Can you explain why quaternary alcohols do not exist?

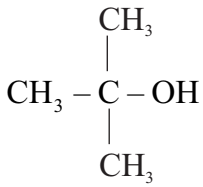
Physical properties of alcohols

The lower alcohols are liquids at ordinary temperatures. They become oily as we go higher up in the series and from $C_{12}H_{25}OH$ upwards they are waxy solids.

The hydrogen in an alcohol is polar. As a result, there is significant hydrogen bonding in alcohols.

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  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.

Preparation of alcohols

Alcohols can be prepared in a large amount using different methods. For example, methanol (CH_3OH) can be prepared by destructive distillation of dry saw dust. Large amount of ethanol (CH_3CH_2OH) is manufactured by fermentation of starch and sugar. Here we will see some common laboratory methods of alcohol preparation. In the laboratory, alcohols can be prepared by the following methods

(a) **Acid catalyzed hydration of alkenes** (by the addition of water to alkenes in presence of acid catalyst).

General reaction

$$R - CH = CH_2 + H_2O \xrightarrow{H^+} R - \underset{\displaystyle OH}{\underset{|}{CH}} - CH_3$$

Alkene Alcohol

Examples

$$CH_2\,CH_2 + H_2O \xrightarrow{H^+} CH_3 - CH_2 - OH$$

Ethene Ethanol

(b) **Hydrolysis of esters.** Heating esters with potassium hydroxide yields alcohol and salt

General reaction:

$$RCOOR' + KOH \xrightarrow{Heat} RCOO^-K^+ + R'OH$$

Ester Salt Alcohol

Examples

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

Ester Potassium acetate Ethanol

Ethanol, Ethyl alcohol (CH_3CH_2OH)

Ethanol is the second member of the homologous series of monohydric alcohols. It is the constituents of all alcoholic beverages. Beer, wine, gin and whisky contain ethanol.

There are a number of methods for preparing ethanol using different materials. Industrially, ethanol can be prepared by fermentation of carbohydrates such as sugar (sucrose) or starch.

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.

$$C_{12}H_{22}O_{11} + H_2O \xrightarrow{\text{Invertase}} C_6H_{12}O_6 + C_6H_{12}O_6$$

Sucrose — Glucose — Fructose

$$C_6H_{12}O_6 \xrightarrow{\text{Zymase}} 2CH_3CH_2OH + 2CO_2$$

Glucose — Ethanol — Carbon (iv) oxide

Fermentation of starch to ethanol and carbon dioxide takes place in a series of steps by the actions of different enzymes as shown below.

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

Strach — Maltose — Glucose

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

Carbon (IV) oxide

Experiment 9

Preparation of ethanol by fermentation

Objective: To prepare ethanol from sugar.

Materials required: Conical flask, measuring cylinder, glass rod, distillation flask, balance, condenser, spatula, thermometer, watch glass, Bunsen burner, beaker, rubber stopper, delivery tube, sugar, ammonium phosphate or ammonium sulphate, yeast, calcium hydroxide solution.

Procedure

1. Measure 50 mL of distilled water and pour it into a conical flask. Add 15 g of sugar to it and stir. Add about 1.0 g of yeast and a small amount of ammonium phosphate or ammonium sulfate to the solution. Arrange the set-up as shown below and the flask stand for three days at a warm place.

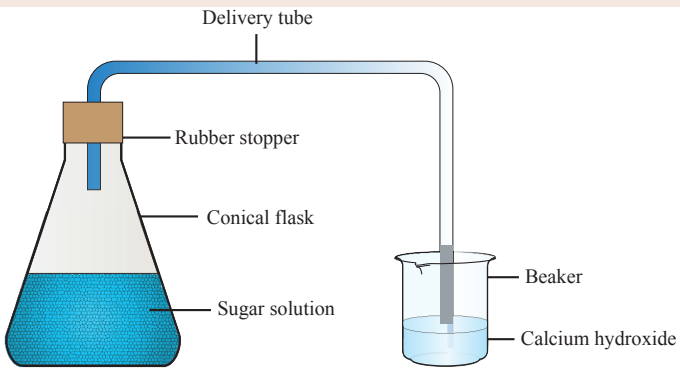


Figure 9. Fermentation of sugar

Observation and analysis

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

(b) What is the importance of adding ammonium phosphate or ammonium sulfate to the sugar solution?

(c) What happened to the calcium hydroxide solution at the end of the first or second day? What 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 in a warm place?

2. After three days, filter the solution, pour about 20 mL of the filtrate in a distillation flask, arrange the set up as shown in the following figure, heat the distillation flask with a Bunsen flame, and collect the distillate in a receiver.

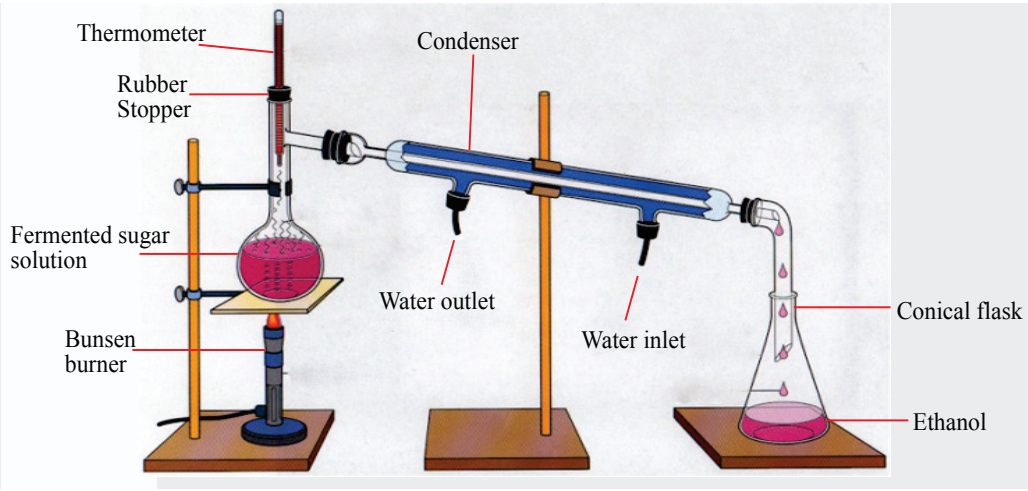


Figure 10. Separation of ethanol by distillation

Points to observe

(a) What is the color and odor 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?

Physical properties and uses of ethanol

Ethanol is a colorless 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.

Chemical properties of alcohols

Alcohols contain a hydrocarbon group and a functional group (–OH). 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 liberate H_2 gas.

General reaction:

$$2R-CH_2-O-H + 2Na \longrightarrow 2R-CH_2-O^-Na^+ + H_2\uparrow$$

Alcohol — Sodium Alkoxide

Examples

$$2CH_3-CH_2-O-H + 2Na \longrightarrow 2CH_3-CH_2-O^-Na^+ + H_2\uparrow$$

Ethanol — Sodium Ethoxide

Experiment 10

Reactions of alcohols with active metals

Objective: To observe the reactions of alcohols with sodium and calcium

Materials required: Ethanol, methanol, sodium, calcium, four test tubes, test tube holder, test tube rack, measuring cylinder, Bunsen burner, match box, scissors or knife

Procedure

Take two test tubes. Measure 3 mL of methanol and pour it in the first test tube. Measure the same amount of ethanol and pour it in the second test tube. Cut a grain size of sodium (two pieces) and drop one piece each to the test tubes containing methanol and ethanol. Bring a burning splint closer to the mouth of each test tube and observe. (Don't insert the burning splint into the test tubes)

Observation and analysis

1. What do you observe in both the test tubes?
2. Is there an evolution of a gas?
3. What do you observe when you bring a burning splint closer to the mouths of the test tubes?
4. What is your conclusion about the identity of the gas?
5. Write chemical equations for the reactions that occurred in both tes tubes and name the products.

(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:

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

Primary alcohol — Aldehyde

Example

$$CH_3\,CH_2OH \xrightarrow{Cu,\,360°C} CH_3 - CHO$$

Ethanol — Ethanal (Acetaldehyde)

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

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

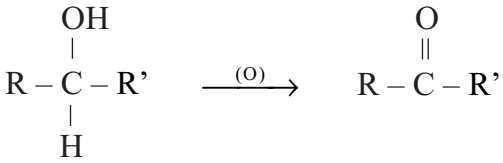
Primary alcohol — Aldehyde — Carboxylic acid

$$CH_3\,CH_2OH \xrightarrow{H^+/K_2Cr_2O_7} CH_3\,CHO \xrightarrow{H^+/K_2Cr_2O_7} CH_3\,COOH$$

Ethanol — Ethanal — Ethanoic acid

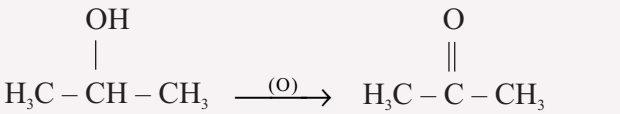
(i) Oxidation of secondary alcohols yields ketones.

General reaction:



Secondary Alcohol Ketone

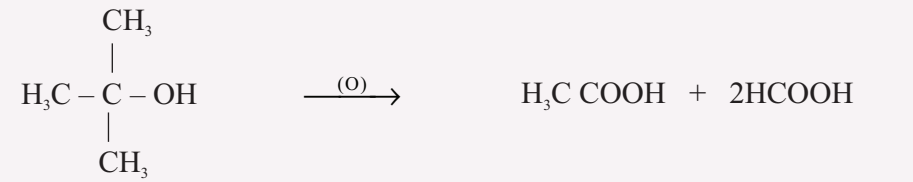
Examples



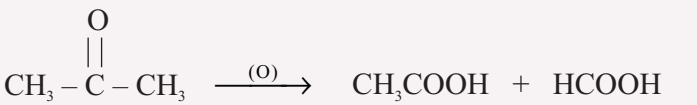
2-Propanol Propanone (Acetone)

(ii) **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



2-Methyl-2-propanol (3^0alcohol) Ethanoic acid Methanoic acid



Propanone (ketone) Ethanoic acid Formic acid

Experiment 11

Oxidation of primary alcohols

Objectives: To observe oxidation of ethanol

Materials required: Boiling tube or bigger test tube, potassium dichromate solution, ethanol, concentrated H_2SO_4, test tube holder, dropper, match box, Bunsen burner and measuring cylinder.

Procedure

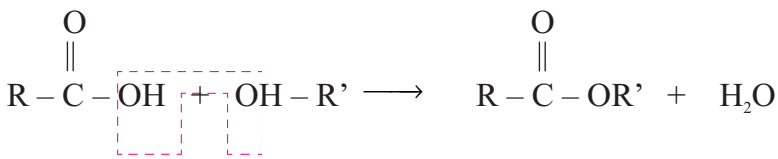
1. Measure 10 mL of potassium dichromate solution and acidify it by adding some drops of concentrated H_2SO_4
2. Add 2 mL of ethanol to the acidified potassium dichromate solution and pour the reaction mixture into a boiling tube.
3. Heat the boiling tube gently, insert red and blue litmus paper into the mouth of the boiling tube and observe.

Observation and analysis

(a) Is there any color change when you warm the reaction mixture in the boiling tube?
(b) What does this color change of potassium dichromate solution indicate?
(c) Do you feel any disagreeable smell upon heating the boiling tube?
(d) What happened to the color of blue or red litmus paper when you introduce into the mouth of the tube?
(e) If there is color change in any one of the litmus papers, what substance is produced in this reaction?
(f) What has happened to the ethanol initially used in the experiment? Write a chemical equation for the reaction that occurred in the experiment

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

General reaction:



Example

$$CH_3CH_2OH + HOOCCH_3 \longrightarrow CH_3COOCH_2CH_3 + H_2O$$

Ethanol — Ethanoic acid — Ethyl ethanoate (Ester)

Experiment 12

Reaction of alcohols and carboxylic acids

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

Materials required: Ethanol, ethanoic acid, concentrated H_2SO_4, test tubes, 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 sulfuric 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.

Observation and analysis

(a) What smell did you recognize? What do you think is the origin of this smell?

(b) Write a balanced chemical equation to show what has happened on heating the mixture of ethanol and ethanioic acid?

(c) What is the purpose of adding few drops of concentrated sulphuric acid to the mixture of the alcohol and acid?

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

General reaction

$$\underset{\text{Alcohol}}{R - CH_2 - CH_2OH} \longrightarrow \underset{\text{Alkene}}{R - CH = CH_2} + H_2O$$

Examples

$$\underset{\text{Ethanol}}{CH_3 - CH_2OH} \xrightarrow{\text{Conc. } H_2SO_4} \underset{\text{Ethene}}{CH_2 = CH_2} + H_2O$$

Reactions of alcohols with hydrogen halides produce alkyl halides:

$$\underset{\text{Alcohol}}{R - CH_2 - OH} + HX \longrightarrow \underset{\text{Alkyl halide}}{R - CH_2 - X} + H_2O \qquad (X = Cl, Br, I)$$

Examples

$$\underset{\text{Ethanol}}{CH_3 - CH_2 - OH} + HCl \longrightarrow \underset{\text{Ethyl chloride (1 – Chloroethane)}}{CH_3 - CH_2Cl} + H_2O$$

ACTIVITY 8

Perform the following activity

Take 1 mL of ethanol and pour it on a watch glass strike a match and bring the flame closer to the alcohol and observe. Hold a flat bottom flask filled with cold water above the flame.

(a) What is the color of the flame produced?
(b) What do you conclude about combustibility of alcohols?
(c) Is there any liquid formed at the bottom or sides of the flask? If yes test it with cobalt chloride paper
(d) Does the color of cobalt chloride paper change? If yes what is the liquid formed?
(e) Write a balanced chemical equation for the combustion of ethanol in air or oxygen.

Exercises

Part I. Choose the correct answer.

1. Which one of the following is a tertiary alcohol?
   (a) 2–Butanol
   (b) 2–Methyl–1–butanol
   (c) 2–Methyl–2–butanol
   (d) 2–Pentanol
2. Which statement about alcohols is not correct?
   (a) Alcohols have higher melting and boiling points than hydrocarbons of comparable molecular size.
   (b) The boiling point of straight chain alcohol is higher than that of its more branched isomer.
   (c) The boiling points of dihydric and trihydric alcohols are higher than monohydric alcohols of comparable molecular size.
   (d) Monohydric alcohol are generally more soluble in water than dihydric and trihydric alcohols of comparable molecular size.
3. Warming 1–chloropropane propane with sodium hydroxide yields:
   (a) Propanal
   (b) 1–Propanol
   (c) Propane
   (d) Propanone
4. Heating ethyl propanoate (ester) with potassium hydroxide gives:
   (a) ethanol and potassium propanoate
   (b) ethanol and propanoic acid
   (c) propanol and potassium ethanoate
   (d) ethanol and potassium ethanoate
5. Which one of the following is not a property of ethanol?
   (a) It is colorless liquid with pleasant smell
   (b) It is miscible with water in all proportions

(c) It is extremely poisonous
(d) It is a hypnotic substance

6. Ethanol is not used:
   (a) as alcoholic beverage
   (b) as a solvent for paints, dyes and perfumes
   (c) as a fuel for cars
   (d) in dry cleaning
7. The general structural formula for the compound obtained by the oxidation of primary alcohols in the presence of mild oxidizing agents is:
   (a) RCOOH
   (b) RCOR'
   (c) RCHO
   (d) RCOOR'
8. The general structural formula of the compounds that can be obtained by the oxidation of secondary alcohols with acidified potassium permanganate is:
   (a) RCHO
   (b) R–COOH
   (c) RCOR'
   (d) RCOOR'
9. The compounds formed when primary alcohols are oxidized using acidified potassium dichromate solution are:
   (a) ketones
   (b) carboxylic acids
   (c) esters
   (d) aldehydes
10. Given the following reaction equation:

$$CH_3CH_2CH_2CH_2OH \xrightarrow[\text{Heat}]{H^+/KMnO_4} X$$

The product 'X' is most likely:
   (a) butanone
   (b) butanal
   (c) butanoic acid
   (d) butanone
11. Given an alcohol with a condensed structural formula:

$$CH_3 - \underset{\displaystyle CH_3}{\underset{|}{CH}} - CH_2OH$$

Which of the following descriptions is true?

(a) It is a primary alcohol
(b) It is called 2–Propanol
(c) It is a tertiary alcohol
(d) It is a secondary alcohol

12. Which of the following alcohols is generally resistant to oxidation with acidified potassium permanganate solution at ordinary condition?

(a) 2–Methyl–2–propanol
(b) 2–Methyl–1–propanol
(c) 2–Butanol
(d) 1–Butanol

13. Which one of the following substances would be formed when C_2H_5OH and CH_3COOH are chemically combined?

(a) $C_2H_5COOHCH_3$
(b) $CH_3OC_2H_5$
(c) $CH_3COC_2H_5$
(d) $CH_3COOC_2H_5$

14. Among the following isomeric alcohols, which one would have the highest boiling point?

(a) $CH_3 - CH_2 - CH_2 - CH_2 - OH$

(b)
$$\begin{array}{l} \quad CH_3 \\ \quad | \\ CH_3 - C - OH \\ \quad | \\ \quad CH_3 \end{array}$$

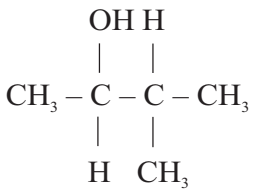
(c)
$$\begin{array}{l} \quad CH_3 \\ \quad | \\ CH_3 - CH - CH_2 - OH \end{array}$$

(d)
$$\begin{array}{l} CH_3 - CH_2 - CH - OH \\ \qquad\qquad\quad | \\ \qquad\qquad CH_3 \end{array}$$

15. Which gas is released when ethanol reacts with sodium metal?

(a) Carbon dioxide
(b) Carbon monoxide
(c) Water vapor
(d) Hydrogen

16. The process that involves slow decomposition of sugars and starch into ethanol and carbon dioxide by the action of enzymes is:
    (a) esterification
    (b) saponification
    (c) cracking
    (d) fermentation
17. The functional group of alcohols is:
    (a) carboxyl group
    (b) carbonyl group
    (c) hydroxyl group
    (d) carbon to carbon double bond
18. What products are formed by the reaction of alcohols and hydrogen halides?
    (a) esters
    (b) alkyl halides
    (c) aldehydes
    (d) carboxylic acids
19. Of the following general equations, which one represents a reaction that gives an alcohol?
    (a) $R–CH_2Br + NaOH \longrightarrow$
    (b) $R–CH = CH + H_2 \longrightarrow$
    (c) $R–CH_2OH + Na \longrightarrow$
    (d) $R–COOH + HOR \longrightarrow$
20. Why are the melting and boiling points of alcohols much higher than those of alkanes having similar molecular mass? This is because, alcohols:
    (a) contain less number of hydrogen atoms than alkanes.
    (b) are organic whereas alkanes are inorganic.
    (c) are liquids whereas alkanes are gases.
    (d) are polar whereas alkanes are non polar.
21. What is the IUPAC name of the following organic molecule?



    (a) 2, 2–Dimethyl–2–butanol
    (b) 3–Methyl–2–butanol

(c) 3, 3–Dimethyl–2–butanol
(d) 2–Methyl–3–butanol

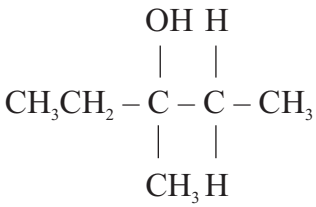
22. Industrially ethanol can be prepared by:
(a) fermentation of carbohydrates such as sugar.
(b) dehydrohalogenation of ethyl halide with KOH.
(c) the reaction between $CH_3COO^-Na^+$ and soda lime.
(d) the reaction between calcium carbide and water.

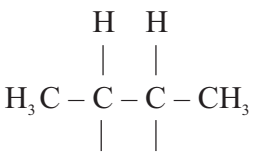
23. Hydration of alkenes in presence of acid catalyst yields:
(a) alkyl halides
(b) esters
(c) alkynes
(d) alcohols

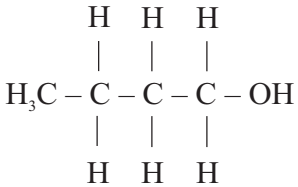
Part II. Attempt the following questions

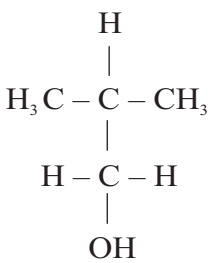
1. Classify the following alcohols as primary, secondary and tertiary

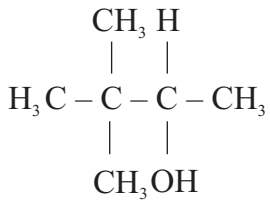
(a) CH_3CH_2OH

(b)


(c)


(d)


(e)


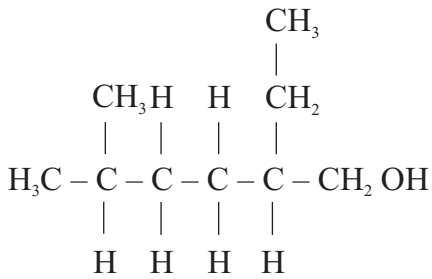
(f)


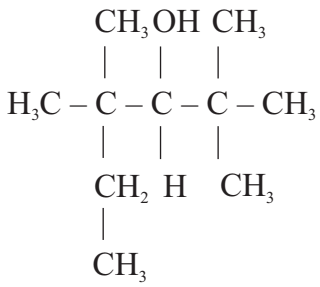
2. Complete the following chemical reactions:

   (a) $CH_3I + NaOH \longrightarrow$

   (b) $CH_3CH_2COOCH_2CH_3 + KOH \longrightarrow$

3. Write IUPAC name for each of the following alchols:

(a)


(b)


(A) **Aldehydes or Alkanals**

The term aldehyde is an abbreviation of **alcohol dehydrogenation**, meaning alcohol deprived of hydrogen. They are two hydrogen atoms less than primary alcohols containing the same number of carbon atoms.

Aldehydes are represented by the general structural formula $R-\overset{\overset{O}{\|}}{C}-H$ or RCHO, where R is an alkyl group. In the case of methanal R = H. in the IUPAC system of naming aldehydes, use the suffix *-al* to replace the terminal *-e* in the corresponding alkane name in the IUPAC system aldehydes are also named as alkanals by replacing

the last letter "*e*" from the name alkane with "*al*". The suffix "*-al*" indicates the functional group –CHO. The names and condensed structures of the first six aldehydes are given in Table 9.

Table 9 Formulas, names, condensed structures of the first six 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

Aldehydes are among the compounds called carbonyl compounds. This is because they contain a carbonyl group (a carbon atom linked to oxygen atom by a double bond). Aldehydes are naturally occurring compounds. For example, vanilla beans and lemon contain aldehydes. They are also prepared in chemical laboratories by the oxidation of primary alcohols using mild oxidizing agents. For example, the simplest aldehyde, HCHO, called methanal (common name formaldehyde) is prepared by heating methanol in presence of copper catalyst according to the following equation.

$$\underset{\text{Methanol}}{CH_3OH} \xrightarrow{Cu,360°C} \underset{\text{Methanal or Formaldehyde}}{HCHO}$$

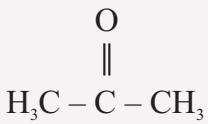
Formaldehyde or methanal is colorless pungent smelling gas at room temperature. It is soluble in water. Aqueous solution of methanal that contains 40% of methanal by volume is called *formalin*. It is used in the preservation of biological specimens. Methanal is also used as raw material to make plastic. Some aldehydes are constituents of flavors such as vanilla, jasmine, etc.

(B) Ketones or Alkanones

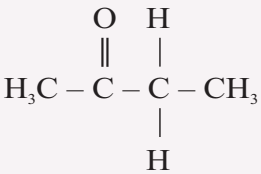
Ketones exist in some natural substances, some of which include clove oil, etc. Ketones are carbonyl compounds. They contain a carbonyl group (C═O). In ketones, the carbon atom of the carbonyl group is bonded to two similar or different alkyl groups.

The general structural formula of ketones is: R – C – R' or RCOR' where R and R' may be same or different. Lower ketones have common name and IUPAC names. Common names of ketones are obtained by prefixing the names of the alkyl groups bonded to the carbon atom of the carbonyl group to the word ketone. If the alkyl groups attached are the same we use the prefix '*di*" before the name of the alkyl groups.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. Thus, the IUPAC name of ketones is alkanones. 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.

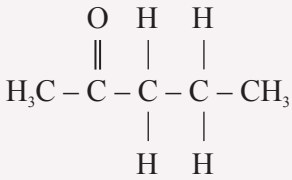
Examples



Propanone



Butanone

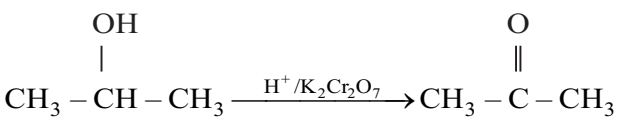


2-Pentanone or Pent-2-one

This ketone is named 3-Hexanone

Although, ketones exist in nature, they are also prepared in chemical laboratories.

The laboratory preparation of ketones involves oxidation of secondary alcohols using acidified potassium heptaoxochromate (VI), $K_2Cr_2O_7$. For example, the simplest ketone called Propanone (dimethyl ketone or acetone) is prepared by the oxidation of 2-Propanol.



2-Propanol Propanone (Acetone)

Propanone or acetone is a colorless, volatile liquid widely used as a solvent. For example: acetone is used as nail polish remover.

(C) **Ethers or alkoxy alkanes**

Ethers are another group of oxygen derivatives of hydrocarbons. They are compounds containing two hydrocarbon groups bonded to the same oxygen atom.

The general structural formula of ethers is ROR' where R and R' may be similar or different alkyl groups.

The common names of ethers are obtained by prefixing names of the two alkyl groups bonded to oxygen atom to the word ether. In the IUPAC system ethers are called *alkoxy alkanes*. In this system, ethers are named as alkoxy derivatives of alkanes, the larger radical being taken as parent structure and getting the name of an alkane containing the same number of carbon atoms.

Examples

CH_3-O-CH_3	$CH_3-O-CH_2-CH_3$	$CH_3-CH_2-O-CH_2-CH_3$
Dimethyl ether	Ethyl methyl ether	Diethyl ether (common)
Methoxy methane	Methoxy ethane	Ethoxy ethane(IUPAC)

Ethers are prepared by dehydration of alcohols. For example, diethyl ether is prepared by heating ethanol, CH_3CH_2OH in the presence of concentrated H_2SO_4 at 140°C. The equation for the reaction is as follows.

$$2CH_3CH_2OH \xrightarrow{H_2SO_4,140°C} CH_3CH_2 - O - CH_2CH_3 + H_2O$$

Ethanol — Diethyl ether

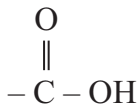
What difference do you see in the preparation of alkenes and preparation of ethers by dehydration of alcohols?

Like alcohols ethers are also flammable substance. They are only slightly soluble in water.

Ethers are generally used as solvents for many organic compounds. Diethyl ether is used as anesthetic.

(D) **Alkanoic Acids (Carboxylic or organic acids)**

Carboxylic acids form one group of oxygen derivative of hydrocarbons. Carboxylic acids are organic compounds that contain at least one carboxyl group as functional group in their structure. A carboxyl group is a functional group consisting of a carbonyl (C = O) and a hydroxyl (-OH) groups and is written as — COOH.

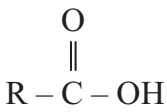


Carboxyl group

Carboxylic acids are classified depending on the number of carboxyl groups they contain as:

- monocarboxylic acids,
- dicarboxylic acids and
- tricarboxylic acids.

Monocarboxylic acids: Organic acids that contain only one carboxyl group. The general structural formula of saturated monocarboxylic acid is RCOOH.



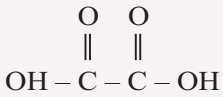
where R is either hydrogen (in case of the simplest carboxylic acid) or an alkyl group for aliphatic carboxylic acids.

Examples

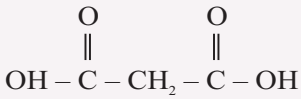
HCOOH	CH_3COOH
Methanoic (Formic) acid	Ethanoic (Acetic) acid

Dicarboxylic acids: Organic acids containing two carboxyl groups in their molecular structures

Examples

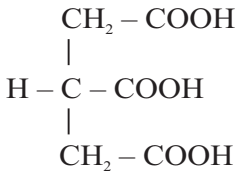


Ethanedioic acid



Propanedioic acid

Tricarboxylic acids: Contain three carboxyl groups in their structure. Typical example of tricarboxylic acid is citric acid.



Citric acid

Nomenclature of saturated monocarboxylic acids

(A) Common names of monocarboxylic acids

Monocarboxylic acids that contain an even number of carbon atoms ranging from 4 to 22 may be obtained by hydrolysis of animal and vegetable fats and oils. They are referred to as fatty acids, and they have common names derived from various sources. Formic acid derives its name from the Latin word for ants, because it is one of the toxic ingredients of the secretion injected by the stinging ant. Butanoic acid (butyric acid) derives its name from butter, in which it is found when the butter becomes rancid. Table 10 shows structures, sources of the common names of some carboxylic acids

Table 10 Structures, sources of common names, and common names of some mono-carboxylic acids.

Structure of Acid	Source of common name	Common name
HCOOH	Ant (Latin, Formica)	Formic acid
CH_3COOH	Vinegar (Latin, Acetum)	Acetic acid
CH_3CH_2COOH	Milk (Greek, propion)	Propionic acid
$CH_3CH_2CH_2COOH$	Butter (Latin, Butyrum)	*n*-Butyric acid
$CH_3CH_2CH_2CH_2COOH$	Root of Valerian plant	*n*-Valeric acid
$CH_3CH_2CH_2CH_2CH_2COOH$	Goat (Latin, Caper)	*n*-Caproic acid

(B) IUPAC system

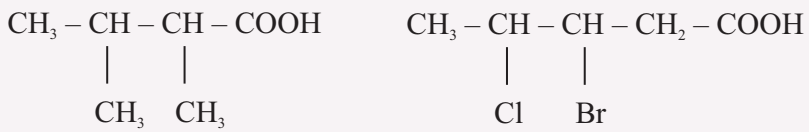
According to IPUAC system, saturated straight chain monocarboxylic acids are named as *alkanoic acids.* The IUPAC names of alkanoic acids are obtained by replacing the last letter **"***e***'** from the name of an alkane with **"-***oic acid***".** Table 11 shows IUPAC names of some common carboxylic acids.

Table 11 IUPAC names of some monocarboxylic acids.

Structure	IUPAC Name
HCOOH	Methanoic acid
CH_3COOH	Ethanoic acid
CH_3CH_2COOH	Propanoic acid
$CH_3(CH_2)COOH$	Butanoic acid
CH_3COOH	Pentanoic acid
CH_3COOH	Hexanoic acid

In IUPAC system of naming branched chain or substituted saturated monocarboxylic acids, the longest chain containing the carboxyl group is chosen as the parent structure. The numbering of the chain starts from the carbon atom of the carboxyl group and it is always assigned number one position. The name of the longest chain will be the name the carboxylic acid that contains the same number of carbon atoms as this chain. As usual, the position of side chains are indicated by the number assigned to the carbon atoms to which they are attached.

Examples



2, 3 – Dimethylbutanoic acid

3 – Bromo – 4 – chloropentanoic acid

Physical properties of saturated aliphatic monocarboxylic acids

- The lower aliphatic acids containing up to 9 carbon atoms are liquids, whereas the higher members are colorless waxy solids.

- The odours of the lower aliphatic acids progress from sharp, irritating odour of methanoic acid and ethanoic acids to the distinctly unpleasant odour of the butanoic, pentanoic and hexanoic acids. The higher acids have little odour because of their low volatility.
- Carboxylic acids have higher boiling points than alcohols of the similar size. For example, ethanoic acid (CH_3COOH) boils at 118°C while the alcohol of comparable molecular mass, propan-1-ol ($CH_3CH_2CH_2OH$) boils at 97.2°C.
- Carboxylic acids up to four carbon atoms mix well with water in any proportion. The solubility in water decreases with the increasing molecular mass and higher acids are almost insoluble.

Chemical properties of monocarboxylic acids

Carboxylic acids are weak acids. The acidic character decreases with increasing carbon number. Methanoic (Formic) acid is the strongest monocarboxylic acid. Carboxylic acids undergo the following reactions.

(A) **Ionization in water**

Carboxylic acids ionize only slightly in aqueous solution to form carboxylate ion and hydrogen ion.

$$R-\overset{\overset{O}{\|}}{C}-OH + H_2O \rightleftharpoons R-\overset{\overset{O}{\|}}{C}-O^- + H_3O^+$$

Carboxylate ion — Hydronium ion

Examples

$$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$$

Acetic (Ethanoic) acid — Acetate (Ethanoate) ion

(B) **Reaction with metals**

Carboxylic acids react with active metals such as Na, K, Mg, Ca etc. to form salts and hydrogen gas.

$$2RCOOH + Ca \longrightarrow Ca(RCOO^-)_2 + H_2$$

Carboxylic acid Salt

The salts of carboxylic acids are named by writing the name of the metal first, followed by the name of the acid replacing the ending -ic acid by -ate

Example

$$2CH_3COOH + 2Na \longrightarrow 2CH_3COO^-Na^+ + H_2$$

Acetic (Ethanoic) acid Sodium acetate (ethanoate)

Experiment 13

Reaction of carboxylic acids with active metals

Objective: To observe the reaction of ethanoic acid with magnesium and zinc metals.

Materials required: Magnesium ribbon, zinc powder, ethanoic acid, test tubes, measuring cylinder, wooden splint, match box, spatula.

Procedure

1. Measure 2 mL of ethanoic acid, pour it in a test tube and drop little magnesium ribbon into it. Bring a burning splint closer to the mouth of the test tube and observe.
2. Repeat the same procedure using ethanoic acid and zinc powder.

Observation and analysis

1. Do you observe any reaction taking place in the test tubes?
2. What do you observe when you bring the burning splint closer to the mouths of the test tubes?
3. What is your conclusion about the identity of the gas?

(C) **Reaction with Bases**

Carboxylic acids react with strong bases like sodium hydroxide or potassium hydroxide to form the corresponding salts and water.

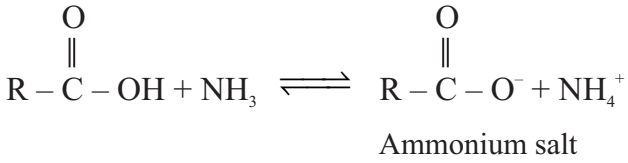
$$RCOOH + NaOH \longrightarrow RCOO^-Na^+ + H_2O$$

Examples

$$HCOOH + NaOH \longrightarrow HCOO^-Na^+ + H_2O$$

Formic (Methanoic) acid Sodium formate (methanoate)

Carboxylic acids also react with ammonia to form ammonium salt of carboxylix acid.



Experiment 14

Reaction of carboxylic acids with bases

Objective: To observe the reactions of ethanoic acid with sodium hydroxide and ammonia.

Materials required: 2 M NaOH solution, 2 M ethanoic acid solution, test tube, Bunsen burner, evaporating dish, tripod stand, wire gauze, measuring cylinder.

Procedure

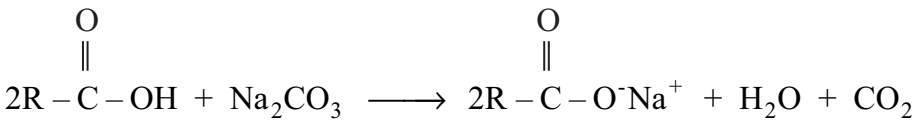
1. Measure 2 mL of 2 M NaOH and pour it in a test tube. Measure the same amount of 2 M solution of ethanoic acid.
2. Mix the two solutions, wait for some seconds. Pour the solution in an evaporating dish, place the dish on the tripod stand and heat gently until evaporation is complete.
3. Mix the same volumes and concentrations of NaOH and ethanoic acid solutions, suggested in step 1, wait for few seconds, pour the solution into a watch glass and evaporate it to dryness.

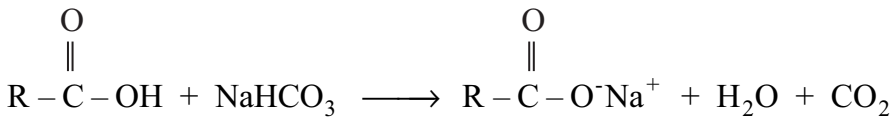
Observation and analysis

(a) What do you observe in the dish after evaporation is complete?
(b) What is the substance formed?
(c) What is the name of the substance formed in this reaction?
(d) What do you observe in the watch glass after the solution is evaporated to dryness?
(e) What is the name of the substance formed?

(D) Reaction with carbonates and hydrogen carbonates

Carboxylic acids react with carbonates or bicarbonates to form salt, water and carbon dioxide gas.





Examples

$$2CH_3-\overset{\overset{O}{\|}}{C}-OH + Na_2CO_3 \longrightarrow 2CH_3-\overset{\overset{O}{\|}}{C}-O^-Na^+ + H_2O + CO_2$$

Experiment 15

Reaction of carboxylic with carbonates and hydrogen carbonates

Objective: To see the effect of ethanoic acid on sodium carbonate.

Materials required: Ethanoic acid, sodium carbonate (Sodium Trioxocarbonate (IV)), sodium hydrogen carbonate, lime water or calcium hydroxide solution, measuring cylinder, four test tubes, delivery tube, rubber stopper with one hole, and test tube rack.

Procedure

1. Insert the delivery tube through the hole of the rubber stopper.
2. Measure 2 mL of ethanoic acid and pour it into one test tube and 5 mL of lime water into another test tube.
3. Add some sodium carbonate into the test tube containing ethanoic acid and close it immediately with the stopper through which delivery tube is inserted.
4. Hold the two test tubes in inclined position inserting the other end of the delivery tube in the test tube containing lime water.
5. Repeat the same procedure using sodium hydrogen carbonate in place of sodium carbonate.

Observation and analysis

(a) Is there formation of bubbles when you add Sodium carbonate or sodium hydrogen carbonate to ethanoic acid?

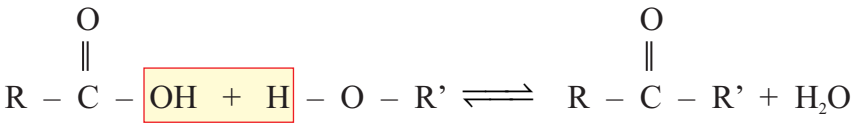
(b) What does this indicate?

(c) What change do you observe when the end of the delivery tube is inserted into the test tube containing lime water?

(d) What do you conclude about the identity of the gas liberated by the reaction of ethanoic acid and sodium carbonate or bicarbonate?

(E) Ester formation

When carboxylic acids react with alcohols, the –OH group of the acid is replaced by the alkoxy (RO-) group of the alcohol. In this reaction, carboxylic acids are heated with alcohols in the presence of concentrated sulfuric acid. The reaction is called Esterification.



Carboxylic acid Alcohol Ester

Do the following activity in your school chemistry laboratory.

Mix 2 mL of ethanoic acid and 2 mL of ethanol in a test tube. Add about 5 drops of concentrated sulphuric acid. Hold the test tube containing the mixture with a test tube holder and warm the mixture on a Bunsen flame. Do you sense any smell?

Uses of carboxylic acids

Ethanoic acid is used in the manufacture of aspirin, plastics like polyvinyl ethanoate. It is also used in the dyeing industry, in coagulating rubber from latex, in meat and fish processing.

Vinegar, a dilute solution of ethanoic acid is used as food flavoring substance. Salts of ethanoic acid are used in medicine.

For example: basic lead ethanoate is applied in fractures and burns.

Long chain carboxylic acids like octadecanoic acid (stearic acid, $C_{17}H_{35}COOH$) and hexadecanoic acid (palmitic acid. $C_{15}H_{31}COOH$) are used in the manufacture of soaps and shampoos.

(F) Esters or alkyl alkanoates

Esters are another group of oxygen derivatives of hydrocarbons. They are among the most widely occurring compounds in nature. Many esters are pleasant-smelling substances and are responsible for the flavor and fragrance of many fruits, for example, apples, pears, banana, pineapple, strawberry, etc. Oils, fats and waxes of plants or animal origin are all esters. Many esters are found in flowers too and form the part of essential oils obtained from flowers.

Esters are represented by the general formula 

Or simply RCOOR' Where R = hydrogen atom or an alkyl group and R' = alkyl group.

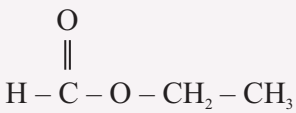
Nomenclature of Esters

Esters are named by the common system as well as by IUPAC system. In both cases, the name consists of two parts. The first part is named on the basis of the portion coming from alcohol and the second part of the name is based on the portion from acid.

Common names of esters are obtained first by naming the alkyl group that takes the place of hydrogen from the alcohol (R') followed by the common name of the acid changing the ending *–ic acid* with *–ate*.

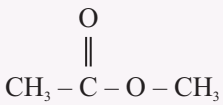
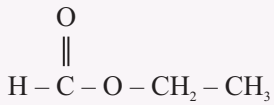
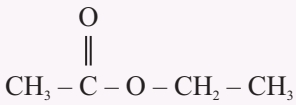
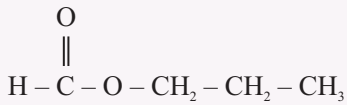
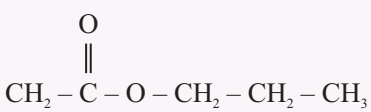
IUPAC names of esters are obtained first by naming the alkyl group that takes the place of hydrogen from the alcohol (R') followed by the IUPAC name of the acid changing the ending *–ic acid* with *–ate*.

Examples



Common names, IUPAC names and structures of some esters are given in table 12.

Table 12 Common names, IUPAC names and structures of some Esters

Structural formula	Common Name	IUPAC Name
	Methyl acetate	Methyl ethanoate
	Ethyl formate	Ethyl methanoate
	Ethyl acetate	Ethyl ethanoate
	Propyl formate	Propyl methanoate
	Propyl acetate	Propyl ethanoate

Uses of Esters

Esters have numerous uses as solvents, medicines, clothing (e.g. polyesters), fragrances, etc. Esters are used as solvents for oils and fats, nail polishes, varnishes, paints, gums and resins. Because of their pleasant fruity smells, esters are used in making artificial flavors and perfumes.

The fruit, pineapple contains the esters methyl butanoate and ethyl butanoate. Write the structures of this esters

(G) **Alkyl halides (monohaloalkanes)**

Alky halides are halogen derivatives of hydrocarbons. Monohaloalkanes are formed when one hydrogen atom of the alkane is replaced by a halogen atom. Alkyl halides are represented by the structure:

$R - CH_2 - X$ where R = H or alkyl group and X = Cl, Br or I

The following compounds are few examples of alkyl halides.

$CH_3\,CH_2\,Cl$ — Ethyl chloride

$CH_3 - \underset{\displaystyle Br}{\underset{|}{CH}} - CH_3$ — 2–Bromopropane

Alkyl halides are prepared by hydrohalogenation (addition of hydrogen halide) to alkenes and alcohols according to the following general reactions.

General reaction

$$R - CH = CH_2 + HX \longrightarrow R - \underset{\displaystyle X}{\underset{|}{CH}} - CH_3$$

Alkene (X = Cl, Br, I) — Alkyl halide

$$R - CH_2 - CH_2OH + HX \longrightarrow R - CH_2 - CH_2X + H_2O$$

Examples

$$CH_2 = CH_2 + HCl \longrightarrow CH_2 = CH_2Cl$$

Ethene — Ethyl chloride

$$CH_3 - CH_2OH + HCl \longrightarrow CH_3 - CH_2Cl + H_2O$$

Ethanol — Ethyl chloride

Exercises

Part I. Choose the correct answer from the suggested alternatives

1. Compounds whose IUPAC names end with the suffix' – al' are:
   (a) alcohol
   (b) ketones
   (c) carboxylic acids
   (d) aldehydes
2. Which compound is formed in the following oxidation reaction?

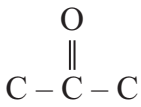
$$CH_3CH_2CH_2\underset{\underset{OH}{|}}{CH} - CH_3 \xrightarrow{H^+/K_2Cr_2O_7}$$

   (a) 2–Pentane
   (b) 2–Pentanone
   (c) Pentanoic acid
   (d) 2–Pentanol
3. Oxidation of primary alcohols with acidified potassium dichromate results in the formation of:
   (a) carboxylic acids
   (b) esters
   (c) ketones
   (d) ethers
4. Given the following reaction equation:

$$CH_3CH_2CH_2CH_2OH \xrightarrow{H^+/KMnO_4} X$$

   The product 'X' is most likely:
   (a) Butanone
   (b) Butanal
   (c) Butanoic acid
   (d) Butanone

5. The name of the ester formed by the reaction of propanoic acid and ethanol is:
   (a) Propyl ethanoate
   (b) Ethyl propanoate
   (c) Ethyl ethanoate
   (d) Methyl butanoate
6. Given formula of a functional group:



   An organic compound that has this functional group is classified as:
   (a) a ketone
   (b) an ester
   (c) an aldehyde
   (d) an acid
7. Which one of the following molecule is an aldehyde?
   (a) $CH_3CH_2CH_2\ CH_2OH$
   (b) $CH_3\ CH_2OCH_2CH_3$
   (c) $CH_3\ CH_2COCH_3$
   (d) $CH_3\ CH_2CH_2CHO$
8. Of the following compounds, which one is an ester?
   (a) $CH_3CH_2CHOHCH_3$
   (b) $CH_3CH_2COCH_2CH_3$
   (c) $CH_3CH_2COOCH_2CH_3$
   (d) $CH_3CH_2CH_2CH_2COOH$
9. The suffixes used in their IUPAC names to indicate the functional groups of ketones and esters respectively are:
   (a) '*one*' and '*-ate*'
   (b) '*-al*' and '*-oic* acid'
   (c) '*-al*' and '*ol*'
   (d) '*-ate*' and '*-oic* acid'
10. Which aldehyde is a constituent of formalin?
   (a) Propanal
   (b) Ethanal
   (c) Methanal
   (d) Propanone

11. The number of carbon atoms that the simplest ketone may contain is:
    (a) 5
    (b) 3
    (c) 1
    (d) 4
12. Which compound can have the same chemical formula as pentanoic acid?
    (a) Diethyl ether
    (b) Ethyl acetate
    (c) Methyl ethanoate
    (d) Ethyl propanoate
13. Of the following general structures, which one represents ethers?
    (a) RCOR'
    (b) RCOOH
    (c) RCOOR'
    (d) ROR'
14. The compound given by the structure, $CH_3CH_2OCH_2CH_3$ is named as:
    (a) dimethyl ketone
    (b) diethyl ether
    (c) ethyl methyl ketone
    (d) ethyl ethanoate
15. Which carboxylic acid is a constituent of the secretion injected by the stinging ant or bee?
    (a) Butyric acid
    (b) Acetic acid
    (c) Methanoic acid
    (d) Ethanoic acid
16. Ethylbutanoate is one of the esters that gives pineapple its odor and taste. The structure of this ester is:
    (a) $CH_3CH_2CH_2COOCH_2CH_3$
    (b) $CH_3CH_2CH_2COOCH_3$
    (c) $CH_3CH_2COOCH_2CH_3$
    (d) $CH_3CH_2COOCH_3$
17. Which one of the following organic compounds liberates carbon dioxide gas when a crystal of sodium carbonate is added to it?
    (a) CH_3OCH_3
    (b) CH_3COOH
    (c) CH_3CHO
    (d) $HCOOCH_3$

18. Organic compounds that react with alcohols in the presence of acid catalyst to form esters are:
    (a) ethers
    (b) aldehydes
    (c) carboxylic acids
    (d) ketones
19. Vinegar is used to flavor foods prepared from vegetables such as salad. It is a dilute solution of:
    (a) Methanoic acid
    (b) Butanoic acid
    (c) Formic acid
    (d) Ethanoic acid
20. The compounds like CH_3Cl and CH_3CH_2Br are classified as:
    (a) alkyl halides
    (b) alkanals
    (c) alkyl radicals
    (d) alkanones
21. Citric acid which is a constituent of citrus fruit juices is an example of:
    (a) trihydric alcohol
    (b) dihydric alcohol
    (c) dicarboxylic acid
    (d) tricarboxylic acid
22. What is the IUPAC name of caproic acid?
    (a) Valeric acid
    (b) Hexanoic acid
    (c) Propanoic acid
    (d) Butanoic acid
23. Which one of the following organic compounds does not contain carbonyl group as its functional group or part of its functional group?
    (a) a carboxylic acid
    (b) an aldehyde
    (c) an ether
    (d) a ketone
24. Which of the following compounds reacts with sodium bicarbonate?
    (a) CH_3CH_2OH
    (b) $HCOOH$
    (c) CH_3COOCH_3
    (d) $CH_3CH_2CH_3$

Part II. Attempt the following questions

1. Name a ketone that is used as nail polish remover.
2. What is the use of diethyl ether?
3. Identify the following compounds as an aldehyde, a ketone, an ester, an ether or a carboxylic acid:
   (a) $HCOOCH_2CH_2CH_3$
   (b) $CH_3CH_2CH_2CH_2CHO$
   (c) $CH_3CH_2CH_2COCH_2CH_3$
   (d) $CH_3CH_2CH_2OCH_2CH_3$
   (e) $CH_3CH_2CH_2CH_2COOH$
   (f) $CH_3CH_2CH_2COOCH_2CH_2CH_3$

1.4 Synthetic and Natural Polymers

Polymers are very large molecules containing hundreds or thousands of atoms. People have been using polymers since prehistoric time, and chemists have been synthesizing them for the past century. Natural polymers are the basis of all life processes, and our technological society is largely dependent on synthetic polymers.

This section discusses some of the preparation and properties of important synthetic organic polymers in addition to naturally occurring polymers.

Polymers are macro (large) molecules formed by the combination of smaller molecules or units called monomers. Hence, monomers are the building blocks of polymers. The reaction that involves the combination of many small units to form a large molecule is called polymerization.

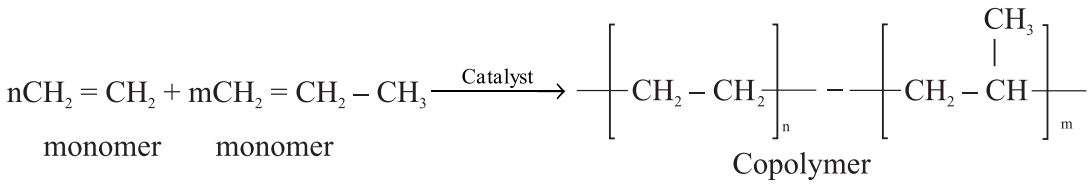
When two monomers join the resulting compound is called a dimer, when three monomers join, the compound formed is called trimer, etc when many monomers combine (50-50,000) the large molecule formed is called a polymer.

A polymer might be made from identical monomers or different types of monomers. Homopolymers are made from only one type of monomer. For example, polyethylene is synthesized by the polymerization of one type monomer, ethene (ethylene).

$$n CH_2 = CH_2 \xrightarrow{\text{Catalyst}} -[CH_2 = CH_2]_n-$$

Ethene (ethylene) (monomer) — Polyethylene (homopolymer)

Copolymers are prepared by polymerizing two kinds of monomer units. For instance, ethene ($H_2C=CH_2$) and propene ($H_2C=CH–CH_3$) can be copolymerized to produce a polymer that has two kinds of repeating units:



Polymerization can be brought about in two ways.

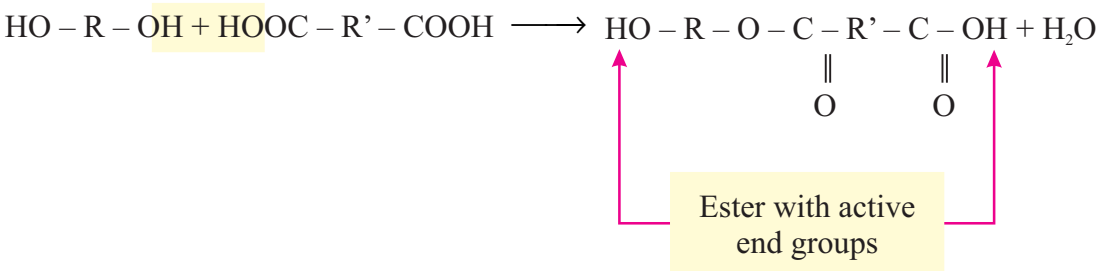
- Addition polymerization
- Condensation polymerization

(a) **Addition polymerization:** For addition polymerization the monomer units are unsaturated compounds. The monomers simply join with one another to form a compound that has long chain structure and high molecular mass. The formation of homopolymer and copolymer in the above two equations represent addition polymerization.

(b) **Condensation polymerization:** This type of polymerization involves the combination of monomer molecules with the elimination of simple molecules like water. When two or more substances combine by the expulsion of small molecule like water, the reaction is called condensation reaction**.**

In order to produce a condensation polymer, the monomers involved must have two or more functional groups.

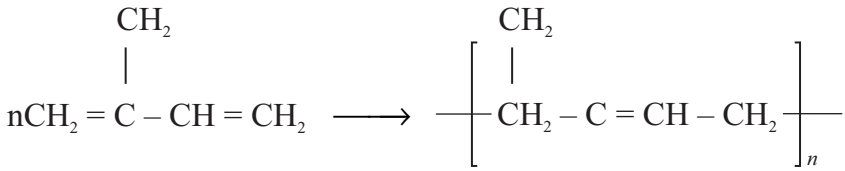
Consider what happens when an alcohol with two –OH groups, HO–R –OH, reacts with a dicarboxylic acid, HOOC–R–COOH. In this case the ester formed still has a reactive group at both ends of the molecule



The COOH group at one end of the ester molecule can react with another alcohol molecule. This process can continue, leading eventually to a long-chain polymer containing large number of ester groups.

On the basis of their source, polymers are classified as synthetic and natural.

Natural polymers, as their name indicates, are found in nature. For example, natural rubber is obtained from latex of a rubber tree. It is an addition polymer formed from the monomer, Isoprene or 2–Methyl–1, 3–butadiene. The equation for the polymerization is as follows



Isoprene Natural rubber

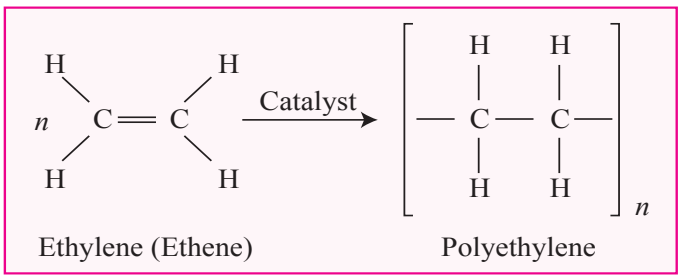
Some examples of natural condensation polymers are proteins, carbohydrates such as starch, cellulose and nucleic acids.

Synthetic polymers are man–made polymers. Most synthetic polymers are organic compounds. These synthetic polymers can be addition polymers or condensation polymers.

(A) **Synthetic addition polymers**

(i) **Polyethene or polyethylene**

Polyethylene is a polymer made by the addition polymerization of ethylene.

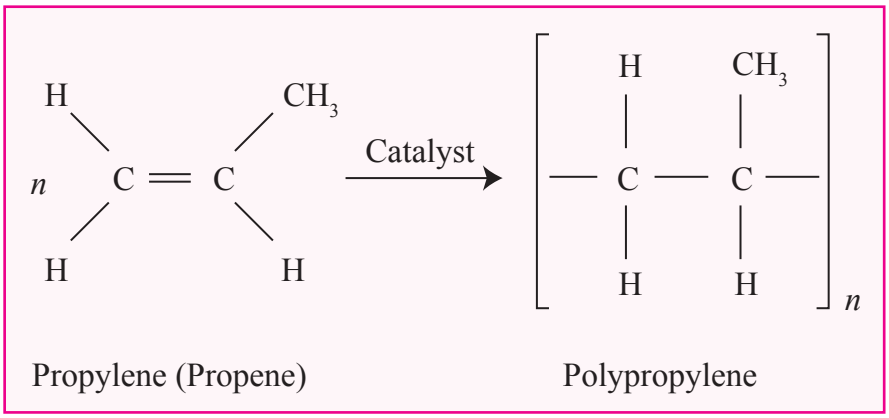


Ethylene (Ethene) Polyethylene

The primary uses of polyethylene are in making squeeze bottles, plastic wrapping, garment bags, trash bags and electrical insulation.

(ii) **Polypropylene**

The monomer of polypropylene is propylene (propene). It is produced by the addition polymerization of propylene.



Polypropylene is stronger than polyethylene. It is used for making food containers, ropes, fishing nets, carpets, and bottles.

(iii) **Polyvinyl chloride (PVC)**

Polyvinyl chloride is an addition polymer of vinyl chloride, $CH_2 = CHCl$.

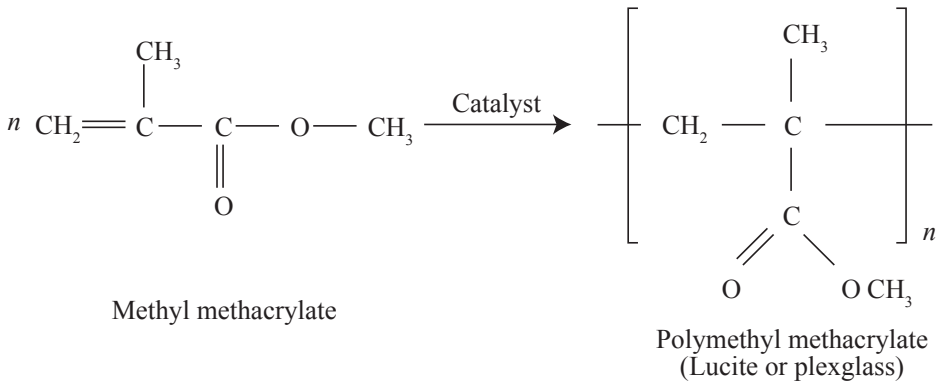
$$n\ CH_2 = CHCl \longrightarrow -[\,CH_2 - CHCl\,-]_n$$

Vinyl chloride Polyvinyl chloride

Polyvinyl chloride is commonly used for making pipes, leather-like materials, shoes, rain coats, aprons, wallpaper, floor tile, etc.

(iv) **Polymethyl methacrylate (PMMA, Perspex)**

Polymethyl methacrylate, PMMA, is prepared by the polymerization of methyl methacrylate.



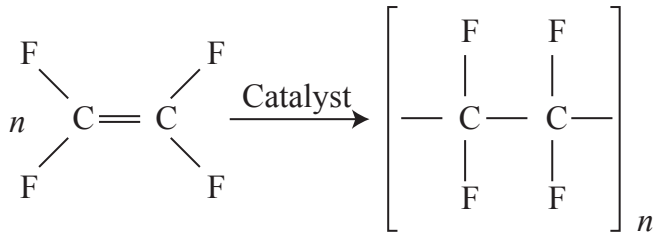
Methyl methacrylate

Polymethyl methacrylate
(Lucite or plexglass)

PMMA is a lightweight glass-like polymer used as a glass substitute. For example, in airplane windows and streetlights.

(v) Polytetrafluoroethylene, PTFE, Teflon

Teflon is prepared by the addition polymerization of tetrafluoroethylene.



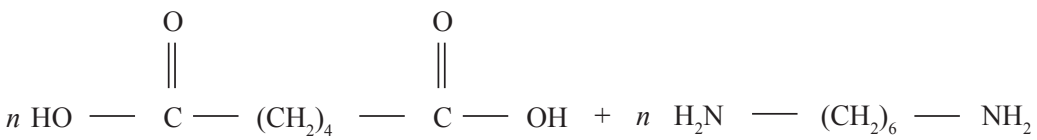
Tetrafluoroethylene Polytetrafluoroethylene (Teflon)

Teflon has good resistance to chemical attack, and it can be used at any temperature between –73°C and 260°C with no effect on its properties. Teflon is used for coating cooking utensils and for making electrical insulation.

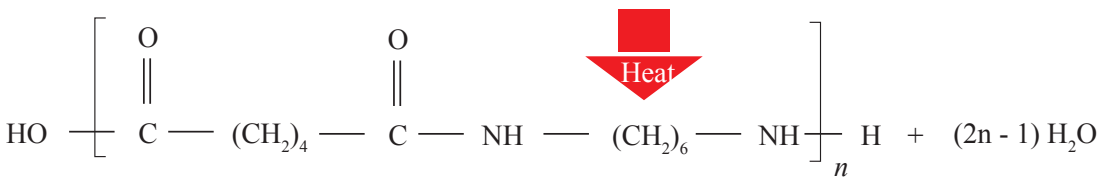
(B) Synthetic condensation polymers

(i) Nylon

Nylons are polyamides. One of the most common polyamides is nylon 66. It is a copolymer and is prepared by the condensation of 1,6-diaminohexane (hexamethylene diamine) and 1,6-hexanedioic acid (adipic acid).



Adipic acid Hexamethylene diamine

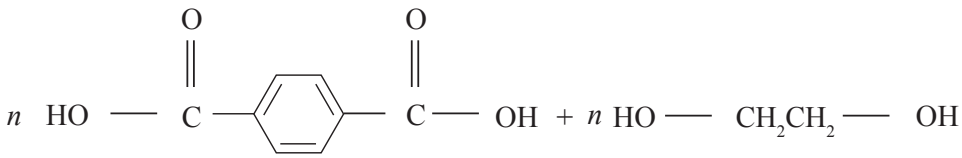


Nylon 66 (the numbers indicate there are six carbon atoms each in hexamethylene diamine and adipic acid)

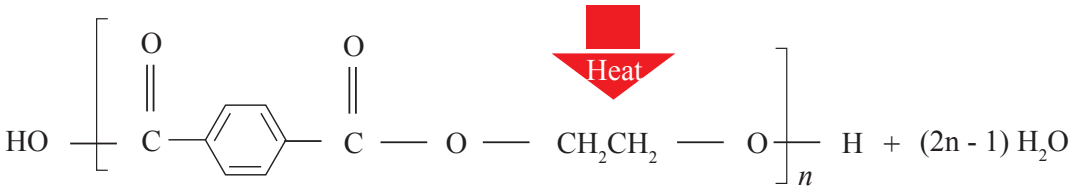
Nylon 66 is used to make parachutes, ropes, clothes, stockings, hair combs, and rugs. They are also used to reinforce automobiles tires.

(ii) Polyester (Polyethylene terephthalate or Dacron)

Dacron is a copolymer and is formed when equimolar amounts of 1, 4-benzene dicarboxylic acid (terephthalic acid) and 1, 2-ethanediol (ethylene glycol) react.



Terephthalic acid — Ethylene glycol



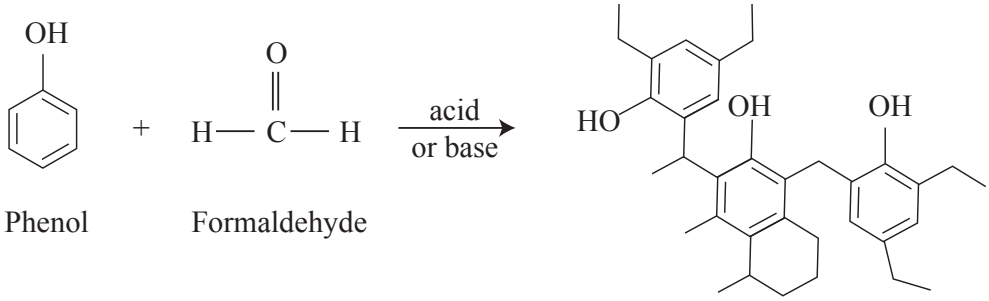
Polyethylene terephthalate (PET)

Dacron is a strong and impact resistant polymer. It is colorless and has high transparency. It is mainly used for synthetic fibers. Mixing it with various amounts of cotton gives fabrics that are durable, easily dyed and crease-resistant. It is also used for making bottles and packaging materials.

(iii) Bakelite

The monomers of Bakelite are phenol and formaldehyde. The reaction takes place in the presence of an acid or a base as a catalyst.

The chemical representation of the reaction:



Phenol — Formaldehyde — Bakelite

Bakelite has been used for making rotary-dial telephones, whistles, billiard balls, dominoes, chess, checkers, porcelain etc.

Plastics and Resins

Resin is a viscous hydrocarbon secretion of many plants mainly coniferous trees.

The main difference between Resins and Plastics is that resins are the gluey substances that mostly have a natural origin because of their direct production from the plant oozes whereas plastics are basically considered to have a nature of synthetic polymers. Both the resin and plastic have an organic nature, which means that they are mainly composed of long hydrocarbon chains. Both of them have polymer characteristics because of the presence of repetitive units. Nevertheless, resins are considered as more of a natural form. Plastics, on the other hand, usually have synthetic or semi-synthetic nature.

The basic differences between resins and plastics are given below.

- Organic compounds which mostly have a natural origin and are produced directly from the plant oozes are called resins, whereas, the substances which basically have a nature of synthetic polymers are called plastics.
- Resins have their origin in the plants, and on the other hand, plastics have their origin in the petrochemicals.
- A resin is an organic compound that is hard to remelt. Conversely, a plastic is an organic compound that can be remelted.
- Resins are referred to as less durable, on the flip side, plastic is referred to as more durable.
- Resins are considered as gluey substances and are viscous in nature; on the other side, plastics are considered as dense and hard substances.
- Resins are the organic compounds that are thought to be full of many impurities, while, plastics are referred to as more stable, and they contain fewer impurities in them.
- Resins are considered as substances that are less stable, whereas plastics are considered as substances that are more stable.
- Solid resin is referred to like a bit more versatile regarding its formation. Conversely, there is no role of versatility in solid plastic.
- Resins are considered as substances that are easier to repair; on the other hand, plastics are considered as substances that are not easy to repair.

- Resins are substances that are considered as more original, on the flip side, plastics are substances that give an unnatural impression.
- A resin is merely referred to as a form of the unprocessed plastic; on the other side, plastic is considered as the final product which can be used further.

ACTIVITY 9

Collect different plastic bags and plastic bottles or any other plastic materials from your locality. Take some part of the plastic material from each sample, hold the sample with wooden material or a tong and heat on a Bunsen flame or candle flame.

1. Are all plastic materials soften or melt on heating?
2. Is there any plastic material that remains unaffected when heated?
3. What do you conclude about the properties of plastic in relation to heat?

Thermoplastic and thermosetting polymers

Based on their response to heat, polymers can be divided into two groups: thermoplastics and thermosetting plastics.

Thermoplastics soften on heating and can be moulded into different shapes. They become hard on cooling. The process of heating and cooling can be repeated many times without causing any change in their properties. For example, polyethylene, polypropylene, polyvinyl chloride, teflon, polymethyl methacrylate, nylon and polyester (dacron) are thermoplastics.

Thermosetting polymers are plastics that can not be affected by heat. They are heat resistant. For example, Bakelite is a thermosetting plastic. Thermoplastics consist of linear or slightly branched molecules which do not chemically bond with each other when heated. Instead, the polymer molecules are held together by weak Van der Waals forces. In contrast, thermosetting plastics consist of chain molecules that can chemically bond, or cross-link, with each other when heated. Thermoplastic materials can be recycled, whereas thermosetting cannot.

Table 13 Difference between thermoplastics and thermosetting plastics

Thermoplastics	Thermosetting plastics
On heating, they soften readily and can be reshaped and reused several times.	On heating, they do not soften and cannot be remolded again.
They are generally long chain linear polymers.	They have three dimensional cross- linked polymer structure.
They are generally weak, soft and less brittle.	Thermosetting plastics are hard, strong, and brittle.
They can be recycled.	They cannot be recycled.

Exercises

Parti I. Choose the correct answer from the given alternatives

1. Small units that combine many times with one another to form a large molecule are called:
   (a) copolymers
   (b) monomers
   (c) polymers
   (d) dimers
2. The process that involves the combination of many small molecules to form a large molecule is:
   (a) isomerism
   (b) halogenations
   (c) polymerization
   (d) addition reaction
3. Which one of the following is a synthetic condensation polymer?
   (a) Dacron
   (b) Proteins
   (c) Starch
   (d) Cellulose
4. The monomer of natural rubber is:
   (a) ethylene
   (b) propylene
   (c) tetrafluoroethylene
   (d) 2–methyl–1, 3–butadiene
5. The polymer used as a substitute for glass in airplane windows is:
   (a) Polyethene
   (b) Teflon
   (c) Perspex
   (d) PTFE
6. Which statement about Nylon-66 is not correct?
   (a) It is a condensation polymer.
   (b) It is a polyamide.
   (c) It made by polymerizing hexamethylene diamine and hexanedioic acid.
   (d) It is a natural addition polymer.
7. The polymer made by polymerizing the monomer, $CF_2 = CF_2$ is:
   (a) PMMA
   (b) Teflon

(c) Polypropylene
(d) Polyvinyl chloride

8. Which one of the following is a thermosetting plastic?
   (a) Bakelite
   (b) Polypropylene
   (c) Dacron
   (d) Polyethylene
9. The monomer (s) of polyester or Dacron is/are:
   (a) hexamethylene diamine and hexane dioic acid
   (b) ethene and propylene
   (c) ethylene glycol and terephthalic acid
   (d) phenol and formaldehyde
10. Which one of the following is not a copolymer?
   (a) Dacron
   (b) Bakelite
   (c) Nylon-66
   (d) Polymethyl methacrylate

Part II. Attempt the following questions

1. Classify the following as natural and synthetic polymers.
   (a) Polyethylene
   (b) Starch
   (c) Polypropylene
   (d) Dacron
   (e) Perspex
   (f) Teflon
   (g) Bakelite
   (h) Cellulose
2. Classify the following as addition or condensation polymers.
   (a) Polyethylene
   (b) Starch
   (c) Polypropylene
   (d) Dacron
   (e) Perspex
   (f) Teflon
   (g) Bakelite
   (h) Cellulose

3. Explain the differences between addition and condensation polymerization.
4. What criterion should the monomers fulfill to involve in addition and condensation polymerization?
5. Explain the differences between thermoplastic and thermosetting polymers.

1.5 Introductory Biochemistry

The chemistry of living things is impressive in two ways. First, these living things are composed of more than half water. Second, what is not water is mainly composed of organic molecules which all contain carbon. All these things are alive, and they are kept alive by reactions between organic molecules. The study of chemical substances and chemical processes is crucial to understand how living things survive.

The field of science concerned with the study of chemical substances found in and chemical processes taking place in living organisms is called biochemistry.

Most of the compounds found in living organisms are macromolecules and they do many jobs in the body.

Most of the macromolecules essential to life belong to four main classes. These are:

- proteins,
- carbohydrates,
- lipids and
- nucleic acids.

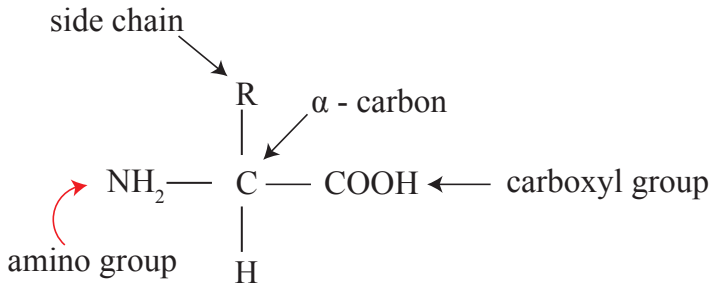
In this section, we will emphasize on proteins and carbohydrates. Among lipids we will discuss about fats and oils. The macromolecules, proteins, carbohydrates, fats and oils are considered as types of food.

(A) **Proteins**

Proteins contain the elements carbon, hydrogen, oxygen, nitrogen, and usually some sulfur.

Proteins are made by the condensation polymerization of the twenty naturally occurring amino acids. An amino acid is a compound that contains both an amino ($–NH_2$) group and a carboxyl (–COOH) group. The amino acids found in proteins are always α-amino acids (the amino group is attached to the carbon atom adjacent to the carboxyl group).

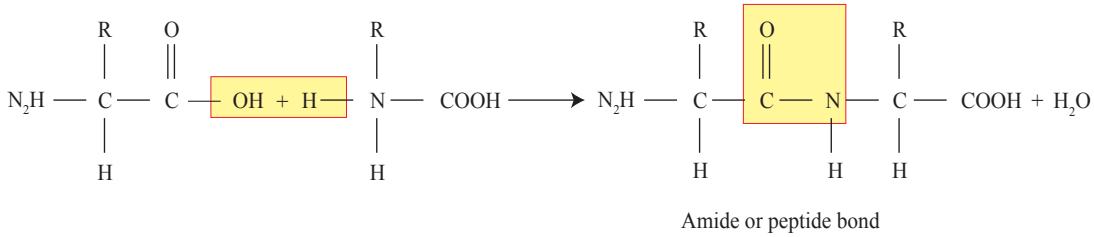
The structural formula for an α-amino acid is:



Amino acids contain a carboxyl group and amino group. Thus they are bifunctional (difunctional) group molecules.

The combination of amino acids to form proteins takes place through the formation of peptide (amide) bond. A peptide (amide) is a bond formed between the carboxyl group of one amino acid and the amino group of another amino acid.

If two amino acids are allowed to react, the carboxyl group of one amino acid reacts with the amino group of the other amino acid. The products are a molecule containing the two amino acids linked by an amide bond or a peptide bond and water.



A compound containing two amino acids joined by a peptide bond is called a dipeptide. Either end of the dipeptide can undergo a condensation reaction with another amino acid to form a tripeptide, tetrapeptide and so on.

A polypeptide is a sequence of amino acids, containing up to 50 amino acid units, in which the amino acids are joined together through amide (peptide) bonds. Proteins are polypeptides that contain more than 50 amino acid units.

Proteins are made up of long, unbranched chain of amino acids, but the final protein is quite a complex structure. This is because peptide chains fold up to form various structures. Each peptide chain may also link up with other chains to form the final protein, for instance, insulin, a hormone that helps the body to regulate the level of sugar in the blood, is made up of two linked chains. Hemoglobin, which caries

oxygen in the blood, is a large protein consisting of four long chains with complicated three dimensional structures.

ACTIVITY 10

Discuss the following point in groups and present your opinion to the rest of the class.

1. What do you understand by the term hydrolysis?
2. What products are expected to form when proteins are hydrolyzed in the presence of acid catalyst or enzymes?

A complex animal structure has several thousands different proteins, each with a special structure and function. Table 14 shows some functions of proteins

Table 14 Some functions of proteins

Types of protein	Example	Function
Enzymes	amylase	Promotes the breakdown of starch to the simplest sugar glucose.
Structural protein	keratin, collagen	Promotes the formation of hair, wood, nails, horns, tendons and cartilage.
Contractile protein	actin, myosin	Contracting fibers in muscle.
Hormones	insulin, glucagon	Regulate use of blood sugar.
Storage protein	ferritin	Store iron in spleen.
	hemoglobin	Carries oxygen in the blood.
Transport protein	serum albumin	Carry fatty acids in blood.
Immunological protein	antibodies	Defend the body from foreign invaders.

Experiment 16

Test for Proteins

Objective: To identify the presence of protein in egg albumin or milk

Materials Required: Copper sulfate solution, sodium hydroxide, Ninhydrin reagent, distilled water, test tubes, test tube holder, dropper, water bath.

(a) **Biuret Test**

1. Take some amount of egg albumin or milk in a clean test tube.
2. Add 2 mL of sodium hydroxide solution to it.
3. To that add 5 to 6 drops of copper sulfate solution to it.

4. If there is the appearance of bluish violet color indicates the presence of protein.

b. **Ninhydrin Test**

1. Take some egg albumin or milk in a clean test tube.
2. Add 1-2 mL of ninhydrin solution to it.
3. Boil the mixture and observe the change.
4. If there is the appearance of blue coloration then the presence of protein is confirmed.

(B) Carbohydrates

Carbohydrates are compounds that contain carbon, hydrogen and oxygen. Green plants produce carbohydrates by photosynthesis. In this process, carbon dioxide from air and water from the soil are the reactants and sunlight absorbed by chlorophyll is the energy source. The synthesis of carbohydrates by green plants is represented by the following equation.

$$CO_2 + H_2O + \text{Solar energy} \xrightarrow[\text{Plant enzymes}]{\text{Chlorophyll}} \text{Carbohydrate} + O_2$$

Earlier, carbohydrates that were purified and analysed had molecular formula that corresponds to $C_n H_{2n} O_n$ or $C_n(H_2O)_n$. As a result, they were considered to be "hydrates of carbon" or carbohydrates. However, examination of the structures of carbohydrates shows that this view is inaccurate. Even though this definition is no more used, the name carbohydrate is still used.

At present, carbohydrates are defined as polyhydroxy aldehydes, polyhydroxy ketones or compounds that yield such substances upon hydrolysis. For example, glucose is a polyhydroxy aldehyde, and fructose is a polyhydroxy ketone.

Carbohydrates are classified on the basis of their acid-catalyzed hydrolysis products as monosaccharide, disaccharides and polysaccharides.

Monosaccharides

Monosaccharides, or simple sugars, are carbohydrates that cannot be hydrolyzed into smaller compounds. Monosaccharides are also often called sugars. The word sugar is associated with"sweetness" and most monosaccharides have a sweet taste.

The most common monosaccharides are glucose, galactose, and fructose. They are represented by the formula $C_6H_{12}O_6$. These monosaccharides are water soluble, white and crystalline solids.

Glucose is the most abundant monosaccharide in nature. It is called blood sugar because blood contains dissolved glucose. Cells use this glucose as a primary

energy source. In the human body, galactose is synthesized from glucose in the mammary glands for use in lactose (milk sugar). Fructose is the sweetest-tasting of all sugars and is found in many fruits. It is also present in honey, in equal amounts with glucose.

Is it possible to say that glucose, galactose and fructose are isomers? Refer to chemistry or biology books and identify what their differences are.

Disaccharides

They are dimers made up of two monosaccharide molecules. The monosaccharides may be either the same or different. The common examples of disaccharides are sucrose, lactose and maltose. They are represented by the molecular formula $C_{12}H_{22}O_{11}$.

Sucrose: It is extracted from sugar cane or sugar beat. Thus it is also called cane sugar or beat sugar. It is common table sugar used at home. It is the sweetest among the disaccharides. Sucrose hydrolyzes into glucose and fructose by the enzyme sucrase according to the following equation.

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

Maltose: It is called malt sugar. It is produced whenever a polysaccharide starch breaks down. This happens when seed germinates in plants and during starch digestion in human beings. Maltose is made of two glucose units. It hydrolyses into two glucose units by the enzyme maltase according to the following equation.

$$\underset{\text{Maltose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{\text{Maltase}} \underset{\text{Glucose}}{2C_6H_{12}O_6}$$

Lactose: It is also called milk sugar. It is the most common carbohydrate in mammalian milk. Lactose is made up of glucose and galactose. Very young children have the enzyme lactase that helps them digest lactose. In the presence of this enzyme, lactose hydrolyzes to glucose and galactose.

$$\underset{\text{Lactose}}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{\text{Lactase}} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Galactose}}{C_6H_{12}O_6}$$

Experiment 17

Test for reducing and non-reducing sugars

Materials required: Glucose solution, sucrose solution, Benedict's solution, test tubes, test tube holder, test tube rack, Bunsen flame, beaker and water.

Procedure

1. In a clean test tube add 1 mL of sample glucose solution.
2. Add 2 mL of Benedict's reagents over the sample.
3. Place the test tube over a boiling water bath and heat for 3–5 minutes or directly heat over a flame.
4. Observe for color change.
5. Repeat the same procedure with solution of sucrose. Formation of brick-red color confirms that the carbohydrate in the sample is reducing sugar. If the color of the solution remains blue, the carbohydrate sample contains non-reducing sugar.

Polysaccharides

Polysaccharides are polymers. They consist of a large number of monosaccharide units bonded together. The three important polysaccharides, all made up of glucose units, are cellulose, starch and glycogen. They are represented by the formula, $(C_6H_{10}O_5)_n$ where '*n*' is a large number.

Cellulose: Cellulose is the most abundant polysaccharide and the most common organic compound on earth. It is the structural component of the cell walls of plants. Cellulose, the main building material made from glucose in plants is the structural polysaccharide. Cellulose is not a source of nutrition for humans because humans lack the enzyme cellulase which can break bonds that link glucose units and produce free glucose from cellulose.

However, animals such as horses, cows and sheep contain bacteria in their intestine that produce cellulase and produce free glucose from cellulose.

Starch: It is the polysaccharide that is used to store energy in plants. Starch consists of two kinds of glucose polymers. A plant hydrolyses its starch into glucose. The plant uses some of this glucose for energy, and some as a building material to produce more cells.

Glycogen: It is a glucose storage polysaccharide in humans and animals. It is called animal starch. Liver cells and muscle cells are the storage sites for glycogen in humans. When excess glucose is present in the blood, the liver and muscle tissues convert the excess glucose to glycogen, which is then stored in these tissues. If the level of glucose in blood decreases, some stored glycogen is hydrolyzed back to glucose.

Experiment 18

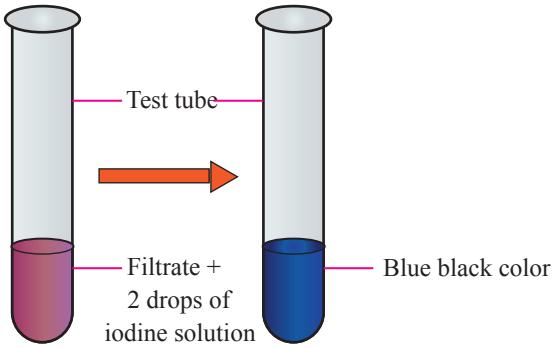
Test for starch

Objective: To test the presence of starch in a given food sample.

Materials required: Test tubes, test-tube stand, test-tube holder, spirit lamp, dropper, filter paper, iodine solution, distilled water, and foodstuff (potato, rice, wheat or maize grains).

Procedure

1. Take a few small, freshly cut pieces of potato or a few grains of rice or wheat or maize in a clean test tube.



Test for the presence of starch in food stuff

2. Pour 10 mL distilled water into the test tube.
3. Now, boil the contents of the test tube for about 5 minutes.
4. Allow the test tube to cool.
5. Filter the contents of the test tube through a filter paper.
6. Take 2 mL filtrate in clean test tube and add 2-3 drops of iodine solution. The formation of dark blue-black color shows the presence of starch.

(C) Fats and Oils

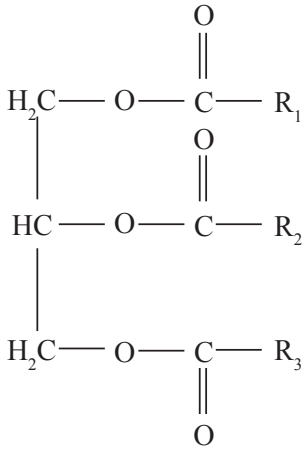
Fats and oils belong to a class of biomolecules called **lipids**. They are triesters of glycerol and long chain fatty acid which are collectivity known as **triglycerides** or **triacylglycerols.** The distinction between a fat and an oil depends on their physical states. Fats are solids whereas Oils are liquids.

Sources of fats and oils

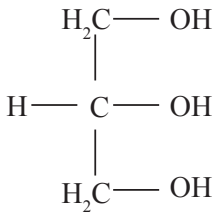
Fats and oils are widely found in nature especially in living things. Animal fats and oils are derived both from terrestrial (land) and marine (water) animals. Vegetable fats and oils are found in greatest abundance in fruits and seeds of plants.

Structure of fats and oils

Fats and oils share a common molecular structure. Variation in the structure of fats and oils occur in the fatty acid portion of the triglyceride (or triacylglycerol). Fats and oils are represented by the following general structural formula:



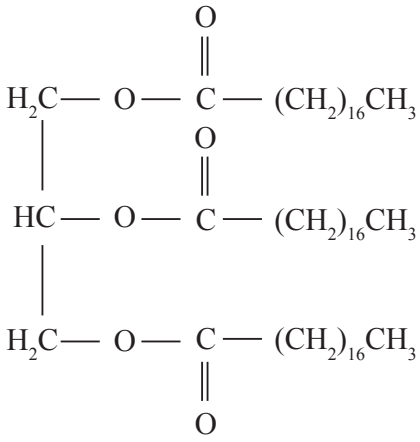
A triglyceride (triacylglycerol)



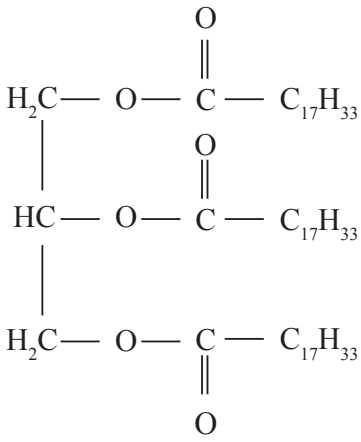
Glycerol

where R_1, R_2 and R_3 may be the same or different hydrocarbon groups. Fats are esters of glycerol and saturated fatty acids and oils are liquid esters of primarily derived from unsaturated fatty acids (fatty acids containing one or more double bond in the hydrocarbon chain) and glycerol. The acid part of fats and oils almost always contain an even number of carbon atoms.

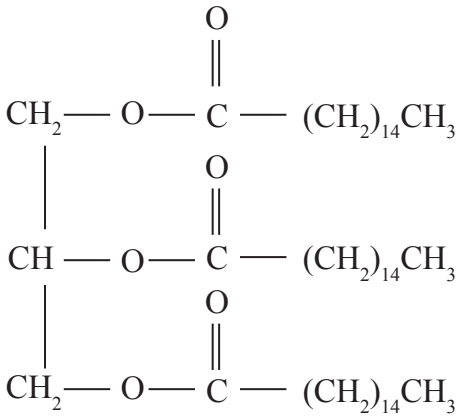
The structures of some common triglycerides are shown below:



Glyceryl tristearate (stearin) fat



Glyceryl trioleate (olein) oil



Palm oil

Physical properties of fats and oils

The common physical properties of fats and oils are that; they are greasy to the touch, and have lubricating properties. They are not readily volatile. Fats are solids at room temperature. On the other hand, oils are mainly obtained from plants, e.g., corn oil, peanut oil, cotton seed oil, olive oil and soya bean oil which are liquids at room temperature. All oils and fats are lighter than water and immiscible with it. They are soluble in organic solvents e.g. benzene, ether and chloroform etc.

Chemical properties of fats and oils

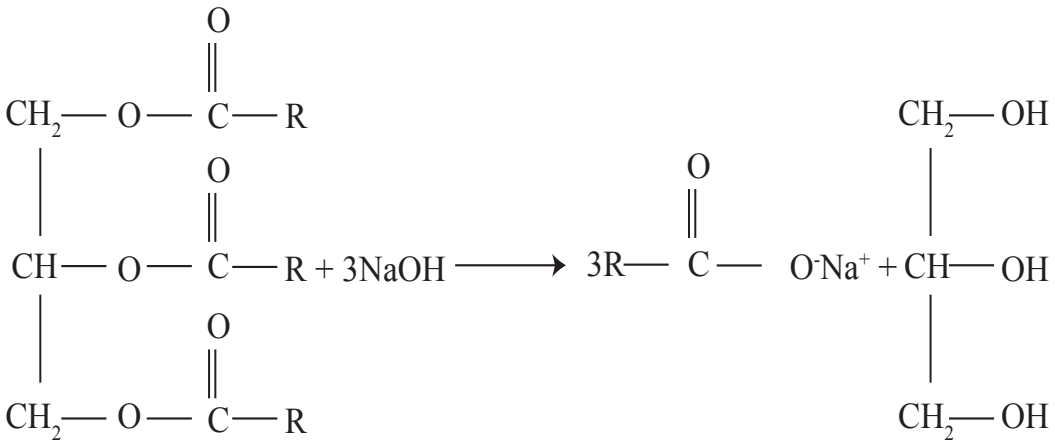
Fats are stable compounds than oils. Oils can undergo oxidation easily than do fats. When stored for any considerable length of time, especially when the temperature is high and the air has free access to them, both fats and oils deteriorate and spoil. Among the various fats, spoilage takes the form of rancidity. Fats and oils develop an unpleasant odor due to rancidity. It is caused mainly due to the hydrolysis of ester linkage and oxidation across the double bonds. In this respect, different fats differ markedly. Some spoil very much more rapidly than others. The fat acquires a peculiarly disagreeable odor and flavor.

Oils can be converted to solid fats by the process called hardening. This process involves hydrogenation (addition of hydrogen) of oils at high pressure in the presence of nickel or palladium catalyst. This reaction is used to make margarine.

Animal fats and vegetable oils hydrolyze when heated with aqueous NaOH or KOH. Alkaline hydrolysis of animal fats and vegetable oils is called Saponification. The

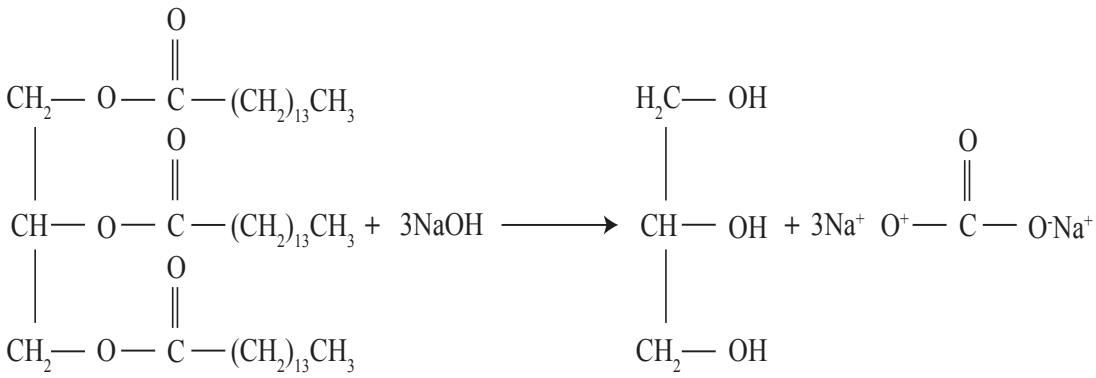
products of saponification are soap and glycerol. Soaps are either sodium salts or potassium salts of higher and long chain carboxylic acids

A general reaction for saponification of fat or oil can be written as follows:



Triglyceride Soap Glycerol

We can write the equation for Saponification of animal fat as follows:



Glyceryl tristearin, a fat Glycerol Sodim Stearate a Soap

The soap formed in this reaction is called sodium stearate or sodium octadecanoate which is sodium salt of stearic acid or octadecanoic acid.

Experiment 19

Laboratory 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 5 mL vegetable oil or 5 g animal fat and place it in a 400 mL beaker; add 15 mL of ethanol and 15 mL of 20% NaOH solution. Stir the mixture vigorously with a glass rod and gently heat over a flame for 30 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 50 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 twice.

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?

Exercises

Part I. Choose the correct answer

1. Of the following organic substances, which one of them is not a polymer?
   (a) nucleic acids
   (b) carbohydrates
   (c) lipids
   (d) proteins
2. A peptide bond in proteins is formed by the interaction of:
   (a) -COOH group of one amino acid with -OH group of another amino acid.
   (b) A carbon to carbon double bond of on amino acid with the double bond of one amino acid.
   (c) -COOH group of one amino acid with nitrogen atom of another amino acid.
   (d) -COOH group of one amino acid with $-NH_2$ group of another amino acid.
3. Which one of the following statements is correct about proteins?
   (a) They are addition polymers of amino acids.
   (b) They are polypeptides containing greater than 50 amino acid units.

(c) Proteins are compounds that give ammonia and carboxylic acids on hydrolysis.
(d) They are polyamides that contain less than 50 amino acid units.

4. The term triglycerides refers to:
   (a) fats and oils
   (b) polysaccharides
   (c) proteins
   (d) disaccharides
5. Compounds defined as polyhydroxy aldehydes or polyhydroxy ketones are:
   (a) proteins
   (b) carbohydrates
   (c) fats and oils
   (d) polysaccharides
6. Which one of the following statements is not true about starch and cellulose?
   (a) both starch and cellulose are copolymers.
   (b) starch and cellulose are condensation polymers.
   (c) glucose is the monomer unit of both starch and cellulose.
   (d) starch and cellulose are made only from one kind of monomer.
7. Which disaccharide is found in mammalian milk?
   (a) sucrose
   (b) maltose
   (c) lactose
   (d) galactose
8. Which of the following statement is false about carbohydrates?
   (a) They are prepared by green plants during photosynthesis.
   (b) They are polyhydroxyl ketones or aldehydes or substances that yield such substances upon hydrolysis.
   (c) They are compounds containing carbon, hydrogen and oxygen
   (d) All carbohydrates are polymers.
9. Alkaline hydrolysis of animal fat and vegetable oil yields:
   (a) salt and carboxylic acid
   (b) alcohol and carboxylic acid
   (c) soap and glycerol
   (d) soap and water
10. Which one of the following statement is incorrect about polysaccharides?
   (a) Cellulose, starch and glycogen are hompolymers.
   (b) Cellulose is a polymer that serves as energy store of plants.

(c) Animals store excess glucose in the form of starch.
(d) Glycogen is a glucose storage polysaccharide in humans and animals.

11. The most abundant polysaccharide on earth is:
    (a) cellulose
    (b) starch
    (c) glycogen
    (d) sucrose
12. Which carbohydrate is named 'blood sugar?
    (a) fructose
    (b) galactose
    (c) sucrose
    (d) glucose
13. The sweetest-tasting substance among sugars is:
    (a) glucose
    (b) sucrose
    (c) fructose
    (d) maltose

Part II. Answer the following questions

1. Why do we say disaccharides are dimers?
2. Are polysaccharides condensation or addition polymers?
3. Are polysaccharides homopolymers or copolymers?
4. Why do we define fats and oils as triester of glycerol?
5. What name is given to the link formed by the reaction of amino group and carboxyl group?
6. What are the constituent elements of proteins?
7. Which carbohydrates produce many monosaccharide units on hydrolysis?

Key Terms

- Acyclic organic compound
- Addition polymerization
- Addition reaction
- Alkanals/aldehydes
- Alkanes
- Alkanoic (carboxylic) acid
- Alkanols/alcohols
- Alkanones/ketones
- Alkenes
- Alkyl halide
- Alkyl radical
- Alkynes
- Amino acids
- Benzene

- Chromatography
- Condensation polymerization
- Copolymer
- Cyclic organic compound
- Dimer
- Elimination reaction
- Esterification
- Esters
- Ethers
- Fats and oils
- Functional group
- Geometrical isomers
- Glycols
- Homologous series
- Homopolymer
- Isomerism
- Monomer
- Monosaccharide
- Natural polymer
- Octane rating
- Organic chemistry
- Organic compound
- Petrochemicals
- Petroleum
- Plastics
- Polypeptide
- Polymer
- Polymerization reaction
- Polysaccharide
- Positive isomers
- Protein
- Resins
- Saponification
- Saturated hydrocarbon
- Substitution reaction
- Synthetic polymer
- Thermoplastics polymers
- Thermosetting polymers
- Triglyceride

SUMMARY

- Organic chemistry is the study of carbon compounds with the exception of oxides of carbon, carbonates and hydrogen carbonates, carbides of metals, cyanides, etc.
- Organic compounds are volatile and combustible, non-polar and insoluble in water, have complex structures, and exhibit isomerism.
- Acyclic organic compounds are those compounds in which the carbon atoms are joined to one another in such a manner to form open chain structure. They are also called open chain organic compounds or aliphatic organic compounds.
- Cyclic organic compounds are those compounds in which the carbon atoms are linked to each other in a manner to form closed chain or ring structure.
- Methods of separation and purification of organic compounds include sublimation, crystallization, distillation, extraction, and chromatography.

- Functional group is part of an organic molecule that determines the chemical properties of that compound.
- Homologous series is a group of compounds in which consecutive members of the group differ from one another by a methylene (- CH_2 -) group.
- Isomerism is the existence of two or more chemical compounds with the same molecular formula but different structures.
- Compounds that have the same chemical formula but different structures are called isomers.
- Saturated hydrocarbons are compounds of carbon and hydrogen containing only single bonds between carbon atoms.
- Unsaturated hydrocarbons are compounds of carbon and hydrogen containing one or more multiple (double or triple) bonds.
- Alkanes are saturated hydrocarbons that contain chains of carbon atoms linked by single bonds only. The general formula of alkanes is C_nH_{2n+2} , where, n=1,2,3…
- Alkanes exhibit is structural isomerism called chain or skeletal isomerism.
- Substitution reaction is a reaction that involves the replacement of one atom or group of atoms by another atom or group of atoms.
- Elimination reaction is a reaction that involves removal of atoms or smaller molecule from a compound.
- Petroleum is a complex mixture of hydrocarbons and mainly contains alkanes, cycloalkanes and aromatic hydrocarbons.
- 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).
- Reforming is a process carried out during refining of petroleum and mainly involves changing the structure of a hydrocarbon molecule to improve the quality of petroleum products.
- Petrochemicals are chemical substances obtained from petroleum, natural gas and mineral coal.
- The octane rating (number) of a fuel is a measure its efficiency and anti-knocking properties.
- Alkenes or olefins are unsaturated hydrocarbons containing a carbon-carbon double bond as their functional group. They form a homologous series represented by the general formula C_nH_{2n}, where n = 2, 3, 4….
- Alkenes exhibit chain isomerism, position isomerism and geometrical isomerism.
- Geometrical isomerism results from the difference in the relative spatial arrangement of atoms or groups about the double bond.

- Polymerization is a combination of many small molecules (monomers) to form a large molecule called polymer.
- Alkynes are unsaturated hydrocarbons containing a carbon to carbon triple bond as their functional group. They are represented by the general formula C_nH_{2n-2}, where n is > 2.
- Benzene is the simplest aromatic hydrocarbon with molecular formula C_6H_6.
- Benzene undergoes combustion reaction, substitution reaction, and addition reaction.
- 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.
- Alcohols are generally classified as monohydric, dihydric, trihydric, and polyhydric alcohols depending on the number of hydroxyl (–OH) groups they contain in their molecular structure.
- Based on the type carbon atom to which the hydroxyl group is attached monohydric alcohols are classified as primary alcohols, secondary alcohols and tertiary alcohols.
- Alcohols are prepared by acid catalyzed hydration of alkenes and base hydrolysis of esters.
- Aldehydes are represented by the general structural formula $R-\overset{\overset{O}{\|}}{C}-H$ or RCHO, where R is an alkyl group. In the case of methanal R = H.
- Aldehydes can be prepared by the oxidation of primary alcohols.
- The general structural formula of ketones is: $R-\overset{\overset{O}{\|}}{C}-R'$ or RCOR'.
- Both aldehydes and ketones are carbonyl compounds.
- Ethers or alkoxyalkanes are compounds containing two hydrocarbon groups bonded to the same oxygen atom. Their general structural formula is ROR' where R and R' may be similar or different alkyl groups.
- Carboxylic acids (Alkanoic acids or organic acids) are organic compounds that contain at least one carboxyl group (-COOH) as functional group in their structure.
- Carboxylic acids are classified depending on the number of carboxyl groups they contain as monocarboxylic acids, dicarboxlic acids and tricarboxylic acids.
- Carboxylic acids are weak acids. They undergo ionization in water, reaction with metals, bases, carbonates and hydrogen carbonates and reaction with esters.

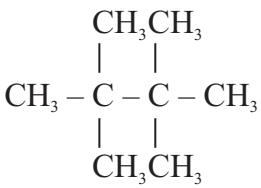
- Esters (Alkyl alkanoates) are among the most widely occurring compounds in nature. Many esters are pleasant-smelling substances and are responsible for the flavor and fragrance of many fruits and flowers.
- Esters are represented by the structural formula RCOOR' where R and R' are alkyl radicals.
- Esterification is the reaction of alcohols and carboxylic acid.
- Polymers are macro (large) molecules formed by the combination of smaller molecules or units called monomers.
- Homopolymers are made from only one type of monomer.
- Copolymers are prepared by polymerizing two kinds of monomer chapter.
- Polymerization can be brought about either by addition polymerization or condensation polymerization.
- Polymers can be classified as natural polymers (like natural rubber, starch and cellulose, etc) and synthetic polymers (like nylon, polyester, polyvinyl chloride, etc).
- Resins are the gluey substances that mostly have a natural origin because of their direct production from the plant oozes.
- Based on their response to heat, polymers can be divided into two groups: thermoplastics and thermosetting plastics.
- Thermoplastics soften on heating and can be moulded into different shapes. They become hard on cooling.
- Thermosetting plastics can be moulded into different shapes by heating and they become hard when cooled. However, once solidified and set they cannot be softened or remoulded by heating.
- The field of science concerned with the study of chemical substances found in and chemical processes taking place in living organisms is called biochemistry.
- Proteins contain the elements carbon, hydrogen, oxygen, nitrogen, and usually some sulfur.
- Proteins are polypeptides that contain more than 50 amino acid units.
- Carbohydrates are compounds that contain carbon, hydrogen and oxygen.
- Fats and oils are triesters of glycerol and long chain fatty acid which are collectively known as triglycerides or triacylglycerols.
- At room temperature, fats are solids and oils are liquids.
- Fats are composed of saturated fatty acids while oils are composed of unsaturated fatty acids.
- Alkaline hydrolysis of animal fats and vegetable oils is called Saponification.
- Heating animal fat and vegetable oil with a base yields soap and glycerol.

Exercises

Part I. Choose the correct answer from the suggested alternatives

1. The process for the isolation of dissolved organic substances from solution or from solid mixtures using an appropriate solvent is:
   (a) sublimation
   (b) extraction
   (c) distillation
   (d) chromatography
2. The scientist who prepared the first organic compound in the laboratory is:
   (a) John Dalton
   (b) Friedrich A. Kekule
   (c) Henry Moseley
   (d) Friedrich Wohler
3. Of the following compounds, which one is a cyclic organic compound?
   (a) Benzene
   (b) *n*-Butane
   (c) 2-Pentene
   (d) Propane
4. Each of the following describes the compound, $CH_3CH_2CH_2CH_3$, except:
   (a) aliphatic compound
   (b) open chain compound
   (c) alicyclic organic compound
   (d) acyclic organic compound
5. Naphthalene is a solid organic compound that changes directly from solid to gas on heating. Which separation technique can be used to separate it from a mixture of naphthalene and common salt?
   (a) distillation
   (b) crystallization
   (c) paper chromatography
   (d) sublimation
6. The reaction of methane, CH_4, with chlorine to form methyl chloride, CH_3Cl, takes place in presence of sunlight. Which of the following doesn't describe this reaction?
   (a) substitution reaction
   (b) chlorination
   (c) elimination reaction
   (d) photochemical reaction

7. Of the following compounds, which one is not a homolog of paraffin series?
   (a) C_5H_8
   (b) C_7H_{16}
   (c) $C_{10}H_{22}$
   (d) C_6H_{14}
8. If each of the following hydrocarbons has open chain structure, which one would contain a triple bond?
   (a) C_5H_{12}
   (b) C_6H_{10}
   (c) C_9H_{18}
   (d) C_8H_{18}
9. The boiling point of a branched chain alkane is lower than its isomeric straight chain alkane. This is because as branching increases:
   (a) The bond between carbon atoms become stronger.
   (b) The surface area of the branched isomer increases.
   (c) The force of attraction between molecules becomes stronger.
   (d) The strength of intermolecular forces decreases.
10. Which of the following equation represents an addition reaction?
   (a) $C_4H_{10} + Cl_2 \longrightarrow C_4H_9Cl + HCl$
   (b) $C_4H_8 + HCl \longrightarrow C_4H_9Cl$
   (c) $C_3H_8 \longrightarrow C_2H_4 + CH_4$
   (d) $C_{14}H_{30} \longrightarrow C_8H_{18} + C_6H_{12}$
11. The IUPAC name of the hydrocarbon given by the following structure will end with the parent name:



   (a) Octane
   (b) Pentane
   (c) Butane
   (d) Butene

12. Which one of the following is an alcohol?
    (a) $CH_3CH_2CH_2OH$
    (b) CH_3COCH_3
    (c) $CH_3CH_2CH_2O$
    (d) CH_3CH_2COOH
13. What is the molecular formula of 4,4–dimethyl–2–pentyne?
    (a) C_7H_{14}
    (b) C_6H_{12}
    (c) C_7H_{12}
    (d) C_7H_{16}
14. Which alkane is the main constituent of the gaseous fuel obtained by an aerobic fermentation of organic matter?
    (a) Butane
    (b) Methane
    (c) Ethane
    (d) Propane
15. Which of the following pairs of alkenes do not exhibit position or chain isomerism?
    (a) Ethene and propene
    (b) Butene and pentene
    (c) Hexene and heptene
    (d) Octene and nonene
16. The correct IUPAC name of diethyl acetylene is:
    (a) 2–Pentyne
    (b) 3–Heptyne
    (c) 3–Hexene
    (d) 3–Hexyne
17. The reaction of benzene with chlorine in the presence of $AlCl_3$ catalyst is an example of:
    (a) addition reaction
    (b) substitution reaction
    (c) elimination reaction
    (d) polymerization reaction
18. Warming 1–Chloropropane with sodium hydroxide yields:
    (a) Propanal
    (b) Propane

(c) 1–Propanol
(d) Propanone

19. The general structural formula for the compounds formed by the oxidation of secondary alcohols in the presence of an oxidizing agents is:
(a) ROR'
(a) RCOOR'
(b) RCHO
(c) RCOR'

20. Given the following reaction equation:

$$CH_3CH_2CH_2OH \xrightarrow{H^+/KMnO_4} X, \text{ the product 'X' is}$$

(a) Proanoic acid
(b) Propanal
(c) Propanone.
(d) Dimethyl ketone

21. The correct IUPAC name for the compound, $CH_3 – O – CH_2 - CH_2 – CH_3$ is:
(a) Ethoxy propane
(b) Methoxy propane
(c) Propoxy methane
(d) 2-Butanone

22. Among the following isomeric alcohols, which one would have the highest boiling point?

(a) $CH_3 – CH_2 – CH_2 – CH_2 – OH$

(b) $CH_3 – \underset{\displaystyle CH_3}{\underset{|}{CH}} – CH_2 – OH$

(c) $CH_3 – \underset{\displaystyle CH_3}{\underset{|}{\overset{\displaystyle CH_3}{\overset{|}{C}}}} – OH$

(d) $CH_3 – CH_2 – \underset{\displaystyle CH_3}{\underset{|}{\overset{\displaystyle CH_3}{\overset{|}{C}}}} – OH$

23. The alcohol obtained during saponification reaction is an example of:
    (a) tertiary alcohol
    (b) dihydric alcohol
    (c) trihydric alcohol
    (d) secondary alcohol
24. Which statement about hydrogenation of 2–Butyne in the presence of Lindlar's catalyst is not true?
    (a) The reaction product is butane.
    (b) The reaction is addition reaction.
    (c) The reaction takes place at the carbon atoms linked by a triple bond.
    (d) The reaction product is 2–Butene.
25. Which alcohol is produced during hydrolysis of animal fat or vegetable oil with a base like NaOH?
    (a) Ethylene glycol
    (b) 1,2-Ethandiol
    (c) Glycerol
    (d) 1,2-Propandiol
26. The aldehyde commonly used to preserve biological specimens is:
    (a) Propanal
    (b) Ethanol
    (c) Butanal
    (d) Methanal
27. The gas that liberates when ethanol reacts with sodium metal is:
    (a) hydrogen
    (b) methane
    (c) carbon dioxide
    (d) water vapor
28. What products are formed when ethanoic acid reacts with sodium carbonate?
    (a) sodium ethanoate and carbon dioxide
    (b) sodium ethanoate, carbon dioxide and water
    (c) sodium ethanoate and water
    (d) sodium ethanoate, carbon dioxide and methane
29. Of the following acids, which one is a tricarboxylic acid?
    (a) citric acid
    (b) propanoic acid
    (c) ethanedioic acid
    (d) propanedioc acid

30. Glycerin is an example of:
    (a) tertiary alcohol
    (b) trihydric alcohol
    (c) dihydric alcohol
    (d) secondary alcohol.
31. Which acid is the strongest of all carboxylic acids?
    (a) butyric acid
    (b) propanoic acid
    (c) caproic acid
    (d) methanoic acid

Part II. Attempt the following Questions

1. Write the general equation for:
    (a) The oxidation of primary alcohols that yields aldehydes.
    (b) The oxidation of primary alcohols to yield carboxylic acid.
    (c) The oxidation of secondary alcohols that yields ketones.
    (d) Esterification reaction.
    (e) Hydrolysis of animal fat or vegetable oil with NaOH to form soap and glycerol.
    (f) The formation of alkyl halides by hydrohalogenation of alkenes and alcohols.
2. Why do we say fats and oils are triesters?
3. What is meant by primary, secondary, tertiary, and quaternary carbon atoms?
4. Explain why the boiling points of alcohols are higher than hydrocarbons of comparable molecular size.
5. What makes benzene to be less reactive than alkenes?
6. Write the structural formula of each of the following compounds:
    (a) 3-Pentanone
    (b) *n*-Propylbutanoate
    (c) Ethoxy butane
    (d) 3-Ethyl-3,4-dimethyl hexanoic acid
    (e) 2,3-Dimethyl-2-hexanol
    (f) 2, 3-Dimethyl-2-pentene
    (g) 3,5-Dimethy-2-hexyne
7. Write examples of natural a) addition polymers b) condensation polymers.
8. Write examples of synthetic a) addition polymers b) condensation polymers.

9. Name a synthetic condensation polymer which is a polypeptde.
10. Explain the difference between homopolymer and copolymer.
11. Explain the differences between thermosetting and thermoplastic polymers.
12. Is it possible to say that all polypeptides are proteins? Why?
13. Which functional groups should interact to form a peptide link?
14. Are starch and cellulose homopolymers or copolymers? Explain why?

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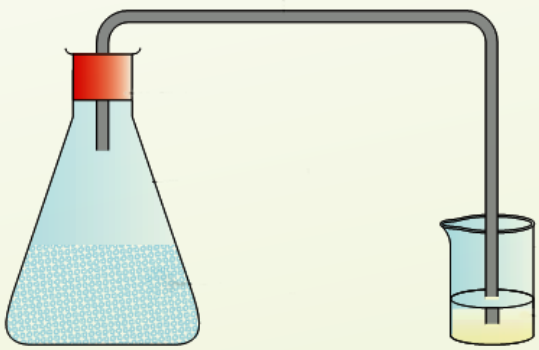
CHAPTER 2

INDUSTRY AND THE ENVIRONMENT

Chapter Contents



Chapter Outcome

After completing this chapter, you will be able to:

- discuss the development of chemical industry in Liberia as well as its effects on the environment and biotechnology concept.

2.1 Historical Development of Industry

Objectives

After completing this topic, you will be able to:

- discuss the historical development of industry.
- explain the general characteristic of industries as well as the classification of chemical industry.

The modern industry has seen great advances since its earliest interaction at the beginning of the industrial revolution in the 18th century. For centuries, most of the goods including weapons, tools, food, clothing and housing, were manufactured by hand or by using work animals. This changed in the end of the 18th century with the introduction of manufacturing processes. The progress from the 1st stage of industrialization was then rapid uphill climb leading up to the upcoming industrial era of the modern times. Here we discuss the overview of this industrial evolution.

First stage of industrialization: The late 18th century introduced mechanical production facilities to the world. Water and steam powered machines were developed to help workers in the mass production of goods. The first weaving loom was introduced in 1784. With the increase in production efficiency and scale, small businesses grew from serving a limited number of customers to large organizations with owners, manager and employees serving a larger number. Industry can also be deemed as the beginning of the industry culture which focused equally on quality, efficiency and scale.

Second stage of industrialization: The beginning of 20th century marked the start of the second industrial revolution. The main contributor to this revolution was the development of machines running on electrical energy. Electrical energy was already being used as a primary source of power. Electrical machines were more efficient to operate and maintain, both in terms of cost and effort unlike the water and steam based machines which were comparatively inefficient and resource hungry. The first assembly line was also built during this era, further streamlining the process of mass production. Mass production of goods using assembly line became a standard practice.

This era also saw the evolution of the industry culture introduced in the first stage into management program to enhance the efficiency of manufacturing facilities. Various production management techniques such as division of labor, just-in-time manufacturing and lean manufacturing principles refined the underlying processes

leading to improved quality and output. The study of approached to optimize worker, workplace techniques and optimal allocation of resources was introduced in this era of industrialization.

Third stage of industrialization: The next industrial revolution resulting in the third stage was brought about and spurred by the advances in the electronics industry in the last few decades of the 20th century. The invention and manufacturing of a variety of electronic devices including transistor and integrated circuits automated the machines substantially which resulted in reduced effort, increased speed, greater accuracy and even complete replacement of the human agent in some cases. Programmable Logic Controller (PLC), which was first built in 1960s, was one of the landmark invention that signified automation using electronics. The integration of electronics hardware into the manufacturing systems also created a requirement of software systems to enable these electronic devices, consequentially fueling the software development market as well. Apart from controlling the hardware, the software systems also enabled many management processes such as enterprise resource planning, inventory management, shipping logistics, product flow scheduling and tracking throughout the factory. The entire industry was further automated using electronics and IT. The automation processes and software systems have continuously evolved with the advances in the electronics and IT industry since then. The pressure to further reduce costs forced many manufacturers to move to low-cost countries. The dispersion of geographical location of manufacturing led to the formation of the concept of Supply Chain Management.

Fourth stage of industrialization: The boom in the Internet and telecommunication industry in the 1990's revolutionized the way we connected and exchanged information. It also resulted in paradigm changes in the manufacturing industry and traditional production operations merging the boundaries of the physical and the virtual world. Cyber Physical Systems (CPSs) have further blurred this boundary resulting in numerous rapid technological disruptions in the industry. CPSs allow the machines to communicate more intelligently with each other with almost no physical or geographical barriers.

The fourth stage of industrialization using Cyber Physical Systems to share, analyze and guide intelligent actions for various processes in the industry to make the machines smarter. These smart machines can continuously monitor, detect and predict faults to suggest preventive measures and remedial action. This allows better preparedness and lower downtime for industries. The same dynamic approach can be translated to other aspects in the industry such as logistics, production scheduling

and optimization of throughout times, quality control, capacity utilization and efficiency boosting. CPSs also allow an industry to be completely virtually visualized, monitored and managed from a remote location and thus adding a new dimension to the manufacturing process. It puts machines, people, processes and infrastructure into a single networked loop making the overall management highly efficient.

As the technology-cost curve becomes steeper everyday, more and more rapid technology disruptions will emerge at even lower costs and revolutionize the industrial ecosystem. The fourth stage is still at a nascent stage and the industries are still in the transition state of adoption of the new systems. Industries must adopt the new systems as fast as possible to stay relevant and profitable.

Characteristics of chemical industry

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, and
- 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.

Classification of the chemical industry

Chemical industries are classified as:

1. Basic chemicals industry
2. Specialty chemicals industry
3. Consumer chemicals industry

Basic chemicals, produced in large quantities, are mainly sold within the chemical industry and to other industries before becoming products for the general consumer.

For example, ethanoic acid is sold on to make esters, much of which in turn is sold to make paints and at that point sold to the consumer. Huge quantities of ethene are transported as a gas by pipe line around Europe and sold to companies making polyethene and other polymers. These are then sold on to manufacturers of plastic components before being bought by the actual consumer. Basic chemicals include *petrochemicals, polymers* and *basic inorganic substances.*

Specialty chemicals this category covers a wide variety of chemicals for crop protection, paints and inks, colorants (dyes and pigments). It also includes chemicals used by industries as diverse as textiles, paper, and engineering. Speciality chemicals deliver better and more stable profit. New products are being created to meet both customer needs and new environmental regulations. An every day example is household paints which have evolved from being organic solvent-based to being water-based.

Consumer chemicals are sold directly to the public. They include, for example, fragrant, cosmetics, detergents, soaps and other toiletries.

Exercises

1. By consulting government officials or journals related to chemical industries, describe the development of chemical industries in Liberia.
2. Explain the characteristics of the chemical industries in Liberia.
3. Classify the chemical industries in Liberia.

2.2 Raw Materials of the Chemical Industries in Liberia

After completing this topic you will be able to:

- describe the raw materials of the chemical industries in Liberia.

The key factor to be considered in deciding the site of a chemical industry is:

- Favorable climatic conditions
- The availability of space to store raw materials
- Its nearness to other industrial establishments
- Its nearness to the source of raw material

Activity 1

1. List down the chemical industries found in Liberia.
2. Name the raw materials used in the manufacturing activity of each chemical industry

Field trip

Your school will arrange a field trip for you to visit a leading chemical industry in Liberia. During your visit to this chemical industry:

1. Get information by asking workers in the industry what the industry is manufacturing.
2. Identify what raw materials the industry uses for its manufacturing activity.
3. What the impact of the industry on the environment is, if any, and
4. What processes the industry applies to reduce environmental pollution.

Write a report in groups about your visit to the chemical industry and present your findings to the rest of the class.

2.3 Heavy and Fine Chemicals

After completing this topic, you will be able to: discuss the difference between heavy and fine chemicals.

We can categorize the products of the chemical industry in two ways: *fine chemicals* and *heavy chemicals.* Fine chemicals are more complex, used for specialty products like medicine, fragrances, and food additives. Heavy chemicals, however, have been standardized. Chemical manufacturing plants can produce them in large quantities.

What truly makes heavy chemicals and fine chemicals different from one another?

Heavy Chemicals

These are chemicals that plants can produce in large quantities because there's no need to tweak their composition. The amount may be in tons a day. They can fulfill general purpose needs. Some of these chemicals include salt, chlorine, ammonia, caustic soda, soda ash, acids (such as trioxonitrate (V) acid, tetraoxophosphate (V) acid, and tetraoxosulfate (VI) acid), titanium dioxide, and hydrogen peroxide. You may also see them referred to as "commodity chemicals," because they exist within the global market and prove easy to acquire. Heavy chemical plants aim to keep the markets saturated enough with these commodity chemicals to keep prices low.

Fine Chemicals

Fine chemicals, on the other hand, are typically specially requested and only produced in limited quantities. One of the biggest differences between heavy chemicals versus fine chemicals is that fine chemicals are developed with batch manufacturing while bulk chemicals are produced through a continuous process. Because fine chemicals are meant for very specific purposes, they require complex

processes, such as chemical synthesis, biotechnology, extraction, and hydrolysis. The specialty chemicals must also be used in combination with other chemicals to reach their full potential. This makes them the building blocks of products in your daily life, such as pharmaceuticals, biocides, fragrances, and pigments. Fine chemicals are mainly used in the chemical industry. They are the starting chemicals.

To sum up the differences, bulk chemicals are widely available because they are much cheaper and easier to use. Fine chemicals, on the other hand, must be specially requested and altered to fit the specific needs of the client. They must also be combined with other chemicals to create the final product.

Exercises

1. Name the chemical industries found in Liberia and identify what products they manufacture.
2. Classify the products of each chemical industry as fine chemicals and heavy chemicals.
   Share your opinion to your classmates.

2.4 Effects of Industries on the Environment in Liberia

After completing this topic, you will be able to discuss the effects of industries on the environment in Liberia.

Liberia is richly endowed with natural resources. Unfortunately, uncontrolled exploitation of these resources has failed to improve the lives of most Liberians and the natural environment is near to the point of collapse. Mining concessions that once supported thriving communities are now ghost towns with enormous craters, mine tailings and sludge deposited in nearby rivers. Industrial operations have polluted the environment without regard for the health and safety of local people. In Liberia, the forest is exceptionally diverse, with large populations of many species that are nearly extinct outside the country. Sadly, multinational and Liberian timber companies threaten these ancient and pristine forests.

Activity 2

You are already familiar with the chemical industries found in Liberia from section 2. Referring to journals, magazines and any other available materials, prepare a written document on the effects of chemical industries on the environment in Liberia. The document should include the:

1. Type of pollutant the industry releases to the environment.
2. Effect of the pollutant on the environment, people, and animals.

3. Solutions you recommend to overcome these pollution problems.

Finally, present contents of the document you prepared to your classmates.

Exercises

1. Consult experts working on environmental protection.
2. Write an essay on one of the environmental challenges facing Liberia based on the information you gathered from the experts.
3. In your essay, include your opinion how the nation can overcome the challenge. Present your essay to your classmates.

2.5 Air, Water and Soil Pollution

After completing this topic, you will be able to:

- discuss the various types of environmental pollution,
- distinguish between biodegradable and non-biodegradable pollutants.

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 (soil) pollution.

Air Pollution

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:

- sulfur(IV) oxide,
- nitrogen(II) oxide,
- carbon(II) oxide,
- ozone,

- hydrocarbons,
- particulates,
- chlorofluorocarbons (CFCs), and
- lead compounds.

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 (II) oxide: 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 hemoglobin.

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.

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 to lead contamination. High levels of lead cause damage to the brain, kidneys and liver.

2.6 Greenhouse Effect/Acid Rain and Depletion of Ozone Layer

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 tones 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, methane and water vapor absorb infrared radiation, re-radiated from the earth, behaving like the glass in a green house.

Greenhouse gases in the atmosphere absorb heat energy and prevent it from escaping into space. This keeps the Earth warmer than it would be without these

gases. Greenhouse gases are not a bad thing by themselves, but too much of them in the atmosphere leads to an increase in the greenhouse effect and global warming.

Since CO_2, methane and water vapor absorb heat and 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 coast lines and lowland areas, which can submerge these areas.

Sulfur(IV) oxide (SO_2): This enters the atmospheric air from the combustion of coal and petroleum, and during extraction of metals from their sulfide 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(IV) oxide, 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(IV) oxide in the presence of ultraviolet light.

$$2NO\,(g) + O_2\,(g) \longrightarrow 2NO_2\,(g)$$

SO_2, SO_3 and NO_2 react with rainwater and form trioxosulfate(IV) acid (H_2SO_3), tetraoxosulfate(VI) acid (H_2SO_4) and trioxonitrate (V) 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.

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:

$$CF_2Cl_2 \xrightarrow{UV} CF_2Cl\cdot + \cdot Cl$$

The free chlorine, Cl, reacts with ozone to form chlorine monoxide and oxygen.

$$\cdot Cl + O_3 \longrightarrow ClO\cdot + O_2$$

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, which causes skin cancer in human beings.

Methods of reducing air pollution

- Removal of sulfur dioxide from gaseous fuels (Fuel-Gas desulfurizatioin) or using low-sulfur fuels.
- Using furnaces and internal combustion engines operating at low temperatures to avoid the combing of N_2 and O_2 and reduce the amount of the oxides of nitrogen produced and released into the atmosphere.
- Using catalytic converters fitted to car exhausts to convert unburnt hydrocarbons into CO_2 and water, carbon monoxide to carbon dioxide and the oxides of nitrogen to N_2 and O_2.
- Increasing the air-to-fuel ratio complete combustion of fuels.
- Using spray of water to wash out particles from the waste gases.
- Passing waste gases through filters.
- Banning the use of CFCs as aerosol propellant gases and replacing them with less harmful alternatives.
- Reducing the use of lead paints and using lead-free fuels.
- Reducing CO_2 emission to the atmosphere from the combustion of fossils fuels like petroleum and mineral coal, and using alternative energy sources such as hydroelectric power sources and nuclear energy.

Water Pollution

The contamination of water bodies, such as lakes, rivers, oceans, underground water and seas by harmful substances is known as water pollution. Water pollution is the degradation of the quality of water brought about by discharges into it of untreated sewage, industrial and agricultural waste (fertilizer, herbicides, pesticides), 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 fertilizers washed out of, phosphate detergents, untreated sewage, insecticides and herbicides, and heavy metal ions, acidic and/or basic residues released by industrial processes. Phosphate and nitrate fertilizers 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 behavioral 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

- Treatment of water before discharge into rivers and lakes.
- To avoid unnatural temperature changes in natural water systems, industries should not discharge heat-ladened water into them.
- Recycling industrial and agricultural wastes.
- Using moderate amounts of agricultural chemicals and increasing the use of organic fertilizers and biological methods to control pests.

Land (soil) pollution

Soil pollution is the contamination of soil due to harmful substances. Polluted soil becomes unfit for growing crops and plants, and is usually accompanied by water pollution.

The significant causes of soil pollution are over-irrigation, usage of pesticides, dumping of sewage and garbage, deforestation and mining.

The most common soil pollutants are heavy metals like lead and mercury, pesticide compounds, salt and mineral ores, the spillage of oil and dumping of non-biodegradable wastes such as plastics. These pollutants disturb the *soil profile,* spoil the soil fertility and make it unfit for growing crops.

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 fertilizers in agricultural activities also contributes towards land pollution.

Methods of reducing land or soil pollution

- Burning solid waste like wood.
- Recycling wastes like paper, plastics, glass of aluminum, tin cans and other metal articles.
- Reducing the use of non-biodegradable plastics.
- Converting potentially dangerous chemical wastes into harmless substances by combustion or by other chemical means.
- Using the waste product of one industry as raw material in another industry. for example, the slag formed during extraction of iron or copper can be used as raw material in the production of glass and cement.
- Using biodegradable plastics for packaging.

2.7 Biodegradable and non-biodegradable pollutants

The substance which contaminates air, water and soil are called pollutants. The pollutants can be classified into two groups:

- biodegradable pollutants.
- non-biodegradable pollutants.

Biodegradable pollutants

Those pollutants which can be broken down into simpler, harmless substances in nature in due course of time (by the action of micro-organisms like certain bacteria) are called biodegradable pollutants. Agents that facilitate this natural breakdown process include bacteria, microorganisms, sunlight, air, soil, water, ozone, and many more natural agents. Domestic wastes (garbage), urine, fecal matter, sewage, agriculture residues, paper, wood, cloth, cattle dung, animal bones, leather, wool, vegetable stuff or plants are biodegradable pollutants.

Non-biodegradable pollutants

Those pollutants which cannot be broken down into simpler, harmless substances in nature are called *non-biodegradable pollutants.*

DDT, plastics, polythene bags, insecticides, pesticides, mercury, lead, arsenic, metal articles like aluminum cans, synthetic fibers, glass objects, and silver foils are non-biodegradable pollutants. These pollutants may persist in the environment for several decades or hundreds of years.

The terms biodegradable and non-biodegradable generally refer to the effect a substance might have on the environment. Besides, understanding the difference between non-biodegradable and biodegradable materials will remarkably reduce the pollution levels as well as encourage the use of biodegradable materials.

Exercises

1. Visit different villages in your locality and see the presence of pollutants in the villages.
2. Classify the pollutants into biodegradable and non-biodegradable.
3. Give reasons why you classified each pollutant as biodegradable and non-biodegradable.

Field Trip

Your school will organize a field trip to waste treatment management site located at Wein town, Paynesville, Liberia. During your visit to waste management site, ask the workers at the site the following questions.

1. What type of waste is managed in the site?
2. Does the waste management site treats domestic and industrial sewage (liquid waste)?
3. If the management site treats sewage, what processes does it use for the treatment?
4. Does the management site also manage solid waste?
5. If so, does the site separate solid wastes and send them to different industries for recycling?
6. When did the management site begin its waste management activity?
7. What is the contribution of the waste management site in reducing environmental pollution?
8. To what percent did the management site reduced the extent of environmental pollution after its establishment?
9. Write a report about your visit of the site based on the information you gathered from the workers and present it to the class.

2.8 Biotechnology and Biotechnology services

After completing this topic, you will be able to:

- discuss biotechnology and applications of biotechnology

Biotechnology is the integration of natural sciences and engineering sciences in order to achieve the application of organisms, cells, parts thereof and molecular analogues for products and services. Nowadays, biotechnology has been applied in every sphere of life. The applications of biotechnology varies from the development of hybrid plants and genetically modified disease resistant mutant strain containing seeds for high yielding superior quality plants to the production of vaccines.

Biotechnology has a pivotal role in food processing sector, especially in cereal processing, fruits and vegetable processing, beverages, oils and fats, dairy, poultry, and confectionary processing. Biotechnology can improve the edibility, consistency, and shelf life of food by preventing the growth of unwanted toxin-producing microorganisms naturally present in foods, production of antimicrobial agent to kill undesirable putrefactive microorganisms. Fermentation process raises the dietary value of the food along with the biosynthesis of vitamins, necessary amino acids, food flavoring, additives, preservatives, and proteins by improving the protein and fiber digestibility.

One-third of the processed foods of the world are fermented foods either natural or intentional fermentation adding microbial strain. Although “fermented food” has a vaguely distasteful ring, bread, wine, cheese, and yogurt are all familiar fermented foods.

Another example of fermented food is *farina.* Farina is *a form of starch - flour - milled from a variety of vegetables such as potato and cassava*. In USA, the term is associated with wheat middling: the germ and endosperm of the grain, which are milled to a fine consistency and then sifted.

Other application of biotechnology is in the production of different alcoholic beverages by fermentation. Few examples are *palm wine* and *sugar cane alcohol*.

Palm wine. It is an alcoholic, sweet and tasty beverage obtained from the sap of various species of palm trees. The sap is usually extracted from the tallest sections of the plant. The white sap begins to ferment as soon as it oozes out. Two hours are enough to develop the alcoholic component in palm wine, with the same alcohol content as a regular beer. This alcoholic beverage is common in West African countries.

Sugar cane alcohol. It is alcohol made from the sugar cane plant. The alcohol is produced by fermenting and distilling the juice of the sugar cane. Sugar cane alcohol is used as a base for many alcoholic spirits. Even though it is made from sugar, its taste is rather neutral and not particularly sweet. This makes it perfect for almost all kinds of liquors.

Experiment 1

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.

Observations and analysis

(a) What is the purpose of adding yeast to the solution?
(b) Why do we add ammonium phosphate or ammonium sulfate 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 2. Pour 20 mL of the filtrate in a distilling flask, heat the solution, and collect the liquid in a receiver.

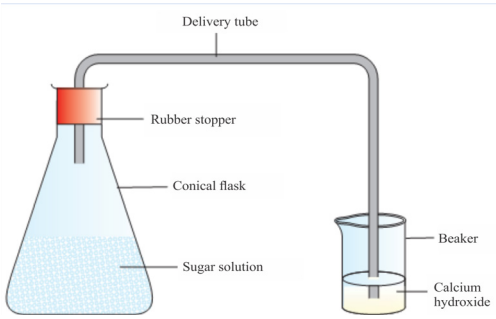


Figure 1. Fermentation of sugar solution

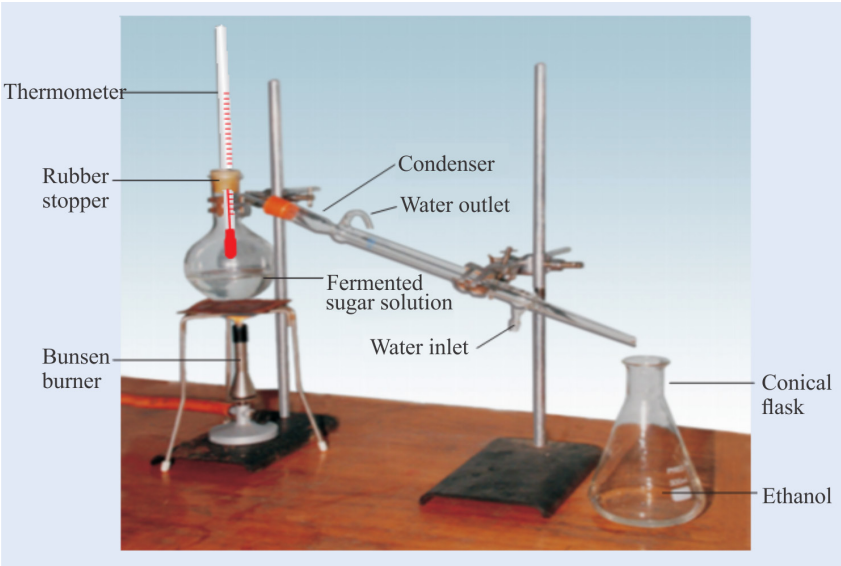


Figure 2. Separation of ethanol by distillation

Points to observe

(a) Observe the color 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?

Result: The purpose of adding yeast is to facilitate the rate of fermentation of sugar solution. Ammonium phosphate or ammonium sulfate is added to sugar solution to serve as food for the yeast.

- At the end of the first or second day of fermentation, the clear solution of calcium hydroxide turns milky. This is because carbon dioxide gas produced during fermentation reacts with calcium hydroxide to form calcium carbonate, $CaCO_3$.
- The sugar solution has a smell of an alcohol after three days.
- The distillate has a smell of an alcohol and it is ethanol. When the flame of the match stick is brought close to the distillate it catches fire.

Exercises

1. Write the balanced chemical equation for the break down of sucrose to glucose and fructose during fermentation.
2. Write the balanced chemical equation for the fermentation of glucose to produce ethanol and carbon dioxide gas.

Biotechnology also has an application in food testing. The tests usually carried out to detect proteins are:

- ninhydrin test,
- xanthoproteic test,
- biuret test and
- million's test.

Ninhydrin test is a chemical test performed to detect the presence of primary/ secondary amines, or *amino acids*. This test involves the addition of ninhydrin reagent to the test sample that results in the formation of deep blue color, often termed as *Ruhemann's purple*, in the presence of an amino group.

Xanthoproteic test is a biochemical test for the detection of amino acids containing aromatic amino acids like phenylalanine, tyrosine, and tryptophan . The test is named Xanthoproteic test due to the formation of a *yellow precipitate* of xanthoproteic acid. The term '*Xantho*' refers to '*yellow*', so the test is often termed as the Yellow Protein Test. The test gives a positive result for amino acids containing benzene rings or other aromatic groups. The xanthoproteic test is based on the fact that aromatic groups in the amino acids are nitrated by heating with concentrated HNO_3 to yield intensely yellow-colored nitro derivative.

Biuret test is considered as a general test for compounds (proteins and peptides) having two or more peptide (CO-NH) bonds. It is based on the Biuret reaction in which a peptide structure containing at least two peptide links produces a *violet color* when treated with alkaline copper sulfate solution. The Biuret reagent is a solution composed of sodium hydroxide (NaOH) or potassium hydroxide (KOH), hydrated copper (II) sulfate, and potassium or sodium tartrate.

Million's test is an analytical test used for the detection of the amino acid tyrosine, which is the only amino acid containing the phenol group. Millon's test is a specific test for tyrosine, but it is not a specific test for protein. This test is useful in the detection of proteins that contain tyrosine.

Biotechnology is also applied in brewery. Beer making or brewery involves processes called:

- malting,
- mashing and
- fermenting

Malting is a process that involves the activation of enzymes that are naturally found in the barley grains.

Mashing is the process by which the activated enzymes from the malting process break down starch into simple sugar, glucose.

Fermenting is the process of converting the simple sugar, glucose to ethyl alcohol or ethanol by the action of the enzyme called zymase. Brewery industries make use of microorganisms in producing a variety of beer.

Biotechnology has also a role in searching substances that can be used as food and finding their nutrient contents. For example, mushrooms.

Mushrooms are edible fungus that can provide several important nutrients. The many kinds of mushroom have varying compositions and nutritional profiles. Mushrooms contain *protein, vitamins, minerals,* and *antioxidants.* These can have various health benefits. For example, antioxidants are chemicals that help the body eliminate free radicals. Free radicals are toxic byproducts of metabolism and other bodily processes. They can accumulate in the body, harm body's cells, and may lead to various health problems. The antioxidant content in mushrooms may help to prevent lung, prostate, breast, and other types of cancer.

Biotechnology plays an important role in medicine in the production of hormone, insulin drugs and antibiotics like penicillin. Hormone insulin drug is typically prescribed for the management of diabetes mellitus. Insulin is a peptide hormone that promotes glucose metabolism. Insulin promotes the uptake of glucose from the blood into internal organs and tissues such as the liver, fat cells, and skeletal muscle. Absorption of glucose into cells allows for its transformation into glycogen or fat for storage. Without an adequate supply of insulin to promote absorption of glucose from the bloodstream, blood sugar levels can climb to dangerously high levels and can result in symptoms such as fatigue, headache, blurred vision, and increased thirst.

Antibiotics, penicillin

Antibiotics are used to treat or prevent some types of bacterial infections. They work by killing bacteria or preventing them from spreading. Antibiotics may be used to treat bacterial infections that:

- are unlikely to clear up without antibiotics
- could infect others
- could take too long to clear without treatment
- carry a risk of more serious complications

Biotechnology is also important in the production of biofuels like biogas which mainly contains methane, CH_4, *ethanol*, and *gasohol* (a mixture of ethanol and gasoline) and

Biogas

Methane can be produced in a biogas plant. The biogas plant produces biogas, mainly consisting of methane by anaerobic fermentation of organic materials such as human excreta, animal dung and agricultural residue. Materials used to produce biogas include dung from cattle and chickens, chopped green plants and other plant wastes.

Experiment 2

Production of biogas in the laboratory by anaerobic fermentation

Objective: To prepare biogas from cow dung.

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.

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?

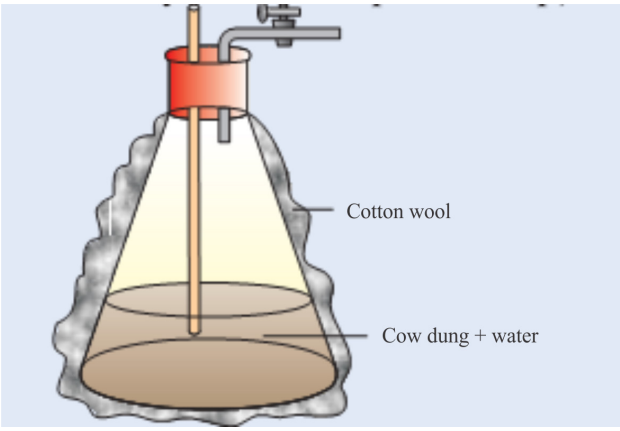


Figure 3. Preparation of biogas by fermentation

Result: The importance of covering the conical flask with cotton wool and placing it near the widow is to enhance the rate of fermentation of cow dung by keeping the flask warmer. When a burning splint is brought close to the outlet of the tube, the gas bursts into flame. This indicates the formation of biogas by the fermentation process that occurred in the flask.

Biotechnology Services

Biotechnology service delivery includes extraction of metals by bioleaching, treatment of waste that pollutes the environment, and enzyme technology.

Bioleaching is the extraction of metals from their ores through the use of microorganisms. This is much cleaner than the chemical leaching methods. For example, in the extraction of copper, some bacteria absorb copper compounds and produce solutions of copper compounds.

Bioleaching is one of several applications of biohydrometallurgy and several methods are used to recover metals like copper, zinc, lead, nickel, gold, silver and cobalt.

Biotechnology service deliveries for the treatment of environmental waste include the treatment of oil spill and domestic waste. Certain marine micro-organisms have the ability to breakdown hydrocarbons. They are capable of inserting an oxygen atom into hydrocarbons to form a degradable alcohol or carboxylic acid. The use of these micro-organisms paved the way for faster and more efficient ways to clean up oil spills.

Domestic waste produced in our locality may contain many harmful substances. If such harmful contaminants are released to river or any other water body, they will pollute our water systems. Biotechnology can provide proper management for the domestic waste and help us to become more eco-friendly. This is because microbes have the potential to break and biodegrade the waste toxins.

Biotechnology is also used for the treatment of sewage. Sewage is defined as the waste water resulting from the various human activities, agriculture, and industries which mainly contain organic and inorganic compounds, toxic substances, heavy metals and pathogenic organisms. The treatments of sewage rely on biotechnology. This is because biotechnology is more efficient, cost effective and uses simplified operations. During the biotechnological process, the sewage is treated to get rid of the undesirable substances by subjecting the organic matter to biodegradation by microorganisms. The biodegradation involves the break down of organic matter to smaller molecule. The process requires constant supply of oxygen. These can be achieved by growing microalgae in plants where sewage treatment is carried out. The algae release the O_2 required for the process while carrying out photosynthesis.

Key Terms

- Basic chemicals
- Biodegradable pollutants
- Biogas
- Biotechnology
- Biuret test
- Chemical industry
- Consumer chemicals
- Eutrophication
- Fermentation
- Fertilizers
- Gasohol
- Global warming
- Green house effect
- Green house gases
- Heavy chemicals
- Herbicides
- Insecticides

- Million's test
- Ninhydrin test
- Non-biodegradable pollutants
- Pollutant
- Pollution
- Specialty chemicals
- Xanthoproteic test

SUMMARY

- The historical development of industry shows rapid growth as of the late 18th century.
- The development of industries can be considered to have four phases.
- 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 qualities to satisfy social needs.
- Chemical industries are classified as Basic chemicals, Specialty chemicals, and Consumer chemicals.
- Basic chemicals, produced in large quantities, are mainly sold within the chemical industry and to other industries before becoming products for the general consumer.
- Specialty chemicals: This category covers a wide variety of chemicals for crop protection, paints and inks, colorants (dyes and pigments).
- Consumer chemicals are sold directly to the public.
- Heavy Chemicals are chemicals that plants can produce in large quantities because there's no need to tweak their composition.
- Fine chemicals are typically specially requested and only produced in limited quantities.
- Pollution is any discharge of a solid, liquid or gaseous substance or radiation (energy) into an environment that causes unwanted changes.
- 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 can be classified by the type of pollution they cause: air pollution, water pollution, and land (soil) pollution.
- 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 sulfur dioxide, nitrogen oxides, carbon monoxide, ozone, hydrocarbons, particulates, chlorofluorocarbons (CFCs), and lead compounds.
- Water pollution is the degradation of the quality of water brought about by the discharge into it of untreated sewage, industrial and agricultural waste (fertilizer, herbicides, pesticides), and oil spillage.
- Soil pollution is the contamination of soil due to harmful substances.
- The most common soil pollutants are heavy metals like lead and mercury, pesticide compounds, salt and mineral ores, spillage of oil and dumping of non-biodegradable wastes such as plastics.
- Those pollutants which can be broken down into simpler, harmless substances in nature in due course of time (by the action of micro-organisms) are called biodegradable pollutants.
- Those pollutants which cannot be broken down into simpler, harmless substances in nature are called non-biodegradable pollutants.
- Biotechnology is the integration of natural sciences and engineering sciences in order to achieve the application of organisms, cells, parts thereof and molecular analogues for products and services.
- Biotechnology has a variety of applications in the production of food by fermentation like bread and farina, alcoholic beverages such as beer, palm wine and cane juice alcohol.
- Biotechnology is applied in food testing such as Ninhydrin test, Xanthoproteic test, Biuret test and Million's test.
- Biotechnology service delivery includes extraction of metals by bioleaching, treatment of waste that pollutes the environment, and enzyme technology.

Exercises

Part I. Choose the correct answer

1. Which one of the following is not caused by acid rain?
   (a) Corrosion of structural metals, buildings and statues.
   (b) Water quality to increase for the survival of aquatic animals.
   (c) Tree defoliation and reduce vegetation coverage.
   (d) A decrease in pH of natural water systems.
2. Which one of the following is not useful in reducing air pollution?
   (a) Using sulfur and nitrogen free fossil fuels as a source of energy.
   (b) Banning the use of CFCs as aerosol propellant gases.
   (c) Using nuclear energy and hydroelectric power.
   (d) Increasing the emission of carbon dioxide to maximize vegetation coverage.

3. Which of the following is not a major factor for land or soil pollution?
   (a) Leaching of heavy metals from buried waste.
   (b) Dumping non-biodegradable wastes.
   (c) The use of organic fertilizers.
   (d) The spillage of oil from leaking pipelines.
4. Which air pollutants have much contribution for the depletion of ozone layer?
   (a) Oxides of nitrogen.
   (b) Chlorofluorocarbons.
   (c) Heavy metals.
   (d) Hydrocarbons.
5. Which one of the following methods is not used to reduce water pollution?
   (a) Reducing carbon dioxide emission.
   (b) Treatment of waste water before discharging into rivers.
   (c) Recycling industrial and agricultural wastes.
   (d) Using moderate amounts of agricultural chemicals.
6. Eutrophication is caused by excessive use of:
   (a) Heavy metals.
   (b) Insecticides and herbicides.
   (c) Hydrocarbons and ozone.
   (d) Phosphate and nitrate fertilizers.
7. A chemical industry:
   (a) Uses mainly physical means to produce new substances.
   (b) Uses naturally available raw materials to produce finished and semi-finished products.
   (c) Consumes relatively less energy.
   (d) Has no means for testing the quality of product.
8. Identify the biodegradable pollutant from the following.
   (a) Polyethene plastic
   (b) Pesticides like DDT
   (c) Pieces of glass
   (d) Pieces of card board
9. Which of the following gas affects human health by reducing the blood's ability to carry oxygen to different parts of the body?
   (a) Carbon monoxide
   (b) Nitrogen(IV) oxide
   (c) Sulfur(IV) oxide
   (d) Carbon(IV) oxide

10. Which of the following is not a major greenhouse gas?
    (a) Carbon(IV) oxide
    (b) Nitrogen gas
    (c) Methane
    (d) Water vapor
11. Which of the following gaseous pollutant is not a cause of acid rain?
    (a) Sulfur(IV)oxide
    (b) Nitrogen(IV) oxide
    (c) Ozone
    (d) Sulfur(VI) oxide
12. Which of the following is one of the prime health risks arises when much UV radiation enters the atmosphere due to depletion of stratospheric ozone?
    (a) Increased skin cancer
    (b) Increased immune system
    (c) Increased liver cancer
    (d) Improve vision of eyes
13. Lead accumulation in human body may primarily cause damage of the:
    (a) liver
    (b) brain
    (c) lung
    (d) kidney
14. Carbon dioxide and methane are similar in terms of:
    (a) being responsible for acid rain
    (b) being responsible for respiratory diseases
    (c) contribution to global warming
    (d) in reducing the pH of natural water systems
15. What is the main source of the pollutants nitrogen oxides, sulfur oxides and oxides of carbon?
    (a) Photochemical reactions in the atmosphere.
    (b) Industrial processes that use hydroelectric power as energy source.
    (c) Burning of fire wood and charcoal.
    (d) Burning fossil fuels containing nitrogen and sulfur at high temperatures.
16. Which one of the following substances is responsible for the formation of reddish- brown haze (photochemical smog) in the atmosphere?
    (a) Unburnt hydrocarbons and ozone
    (b) Particulates and dust

(c) Chlorofluorocarbons
(d) Nitrogen oxides

Part II. Attempt the following Questions.

1. What are the differences between the 1st, 2nd, 3rd, and 4th stages of industrialization?
2. What are the general characteristics of chemical industries?
3. Define the following terms:
   (a) Basic chemicals
   (b) Specialty chemicals
   (c) Consumer chemicals
   (d) Heavy chemicals
   (e) Fine chemicals
4. What factors should be considered to decide the site of a chemical industry?
5. Define global warming.
6. What methods are used to reduce:
   (a) Soil pollution
   (b) Air pollution
   (c) Water pollution
7. Define biotechnology.
8. What are the applications of biotechnology?
9. Explain the differences between biodegradable and non-biodegradable pollutants.

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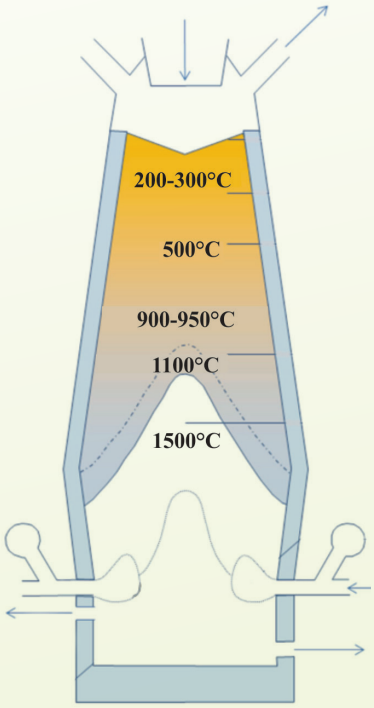
CHAPTER 3

CHEMISTRY OF SELECTED METALS AND THEIR COMPOUNDS

Chapter Contents



Chapter Outcomes

After completing this chapter, you will be able to:

- identify the properties and use of metals as well as their compounds,
- gain greater insights as well as the ability to discuss extensively the different extraction methods and production activities.

3.1 Properties and Uses of Sodium and its Compounds

After completing this topic, you will be able to:

- demonstrate the preparation of sodium,
- discuss the properties and use of sodium and its compounds such as NaCl, NaOH, Sodium trioxocarbonate(IV), Sodium hydrogen trioxocarbonate(IV), Sodium trioxonitrate(V), Sodium trioxochlorate(V) and Sodiumtetraoxosulfate(VI).

Metallurgy

Metallurgy is the science and technology of extracting metals from their natural sources and preparing them for practical use. Natural sources of metals are called ores. An ore is a mineral or mixture of minerals from which it is economically feasible to extract a metal.

Occurrence and extraction of sodium

Sodium is the sixth most abundant element in the earth's crust. It is the fourth most abundant metallic element in the earth's crust. It is never found in pure form in nature.Sodium exists in nature in the form of compounds such as sodium chloride as *rock salt (halite)* and in sea water. Other widely occurring minerals of sodium are sodium nitrate, Sodium trioxonitrate(V) (Chile saltpeter), sodium carbonate, Sodium trioxocarbonate(IV), sodium sulphate, Sodiumtetraoxosulfate(VI) and borax, Sodium heptaoxoborate(III).

Sodium metal is manufactured industrially by the electrolysis of molten sodium chloride with the apparatus called the Downs cell. The process used in the Downs cell requires the mixing of sodium chloride with some amount of calcium chloride. This results in the lowering of the melting point of sodium chloride from 801°C to 580°C. During electrolysis of molten sodium chloride, sodium ions, Na^+, move to the cathode and chloride ions, Cl^- migrate to the anode.The reactions that take place at the electrodes and the entire cell are as follows.

Dissocation: $2NaCl \longrightarrow 2Na^+ + 2Cl^-$

Cathode reaction: $2Na^+ + 2e^- \longrightarrow 2Na$

Anode reaction: $2Cl^- \longrightarrow Cl_2 + 2e^-$

Cell reaction: $2NaCl\ (l) \xrightarrow{\text{Electrolysis}} 2Na\ (l) + Cl_2\ (g)$

During electrolysis of molten sodium chloride, sodium metal is collected at the cathode and chlorine gas at the anode.

Properties of sodium

Sodium is silvery-white, lustrous metal. It is soft and can be cut with a knife or scissors. It has lower density than water and low melting point. Sodium is a very reactive metal. It is stored under liquid paraffin or kerosene to prevent its contact from air or moisture. It tarnishes in air rapidly due to the formation of an oxide layer on its surface.

Sodium reacts with water vigorously to form sodium hydroxide (basic solution) and hydrogen gas according to the following equation.

$$2Na\ (s) + 2H_2O\ (l) \longrightarrow 2NaOH\ (aq) + H_2\ (g)$$

When sodium is exposed to air, it unites with oxygen to form sodium peroxide. If sodium metal is reacted with excess oxygen some sodium oxide is formed. The equations for the reactions are as follows

$$2Na + O_2 \longrightarrow Na_2O_2 \text{ (Sodium peroxide)}$$

$$4Na + O_2 \longrightarrow 2Na_2O \text{ (Sodium oxide)}$$

Uses of sodium

Sodium metal is used to make sodium peroxide, Na_2O_2 (used in bleaching), sodium cyanide, NaCN(used for gold and silver extraction) and sodium amide, $NaNH_2$ (used to make dyes). Sodium is also used to make sodium vapor lamps that are responsible for the orange-yellowish lights on most highways in cities. It is also used to cool the fuel in nuclear reactors due to its high heat conductivity.

Uses of sodium compounds

Sodium chloride (NaCl): It is a white crystalline solid that is water soluble, it is used:

- as table salt in food preparation and preservation.
- as raw material in the manufacturing of sodium hydroxide, sodium metal, chlorine gas, sodium carbonate, sodium bicarbonate and hydrochloric acid.
- in medicine as component of Oral Rehydration Salt (ORS).

Sodium hydroxide (NaOH): It is also called *caustic soda* or *lye.* It is a white brittle solid, very soluble in water. It is used:

- in the production of soaps and detergents.
- in the purification of petroleum products.
- in the manufacturing of artificial silk, rayon.
- in the manufacturing of paper and pulp.
- in textile production.
- as household detergent in the cleaning of sinks and drains.
- as a drying agent in chemical industries due to its capacity of absorbing water.

Sodium carbonate, Sodium trioxocarbonate (IV) (Na_2CO_3): It is also called soda ash in the form of Sodium trioxocarbonate (IV). It is a white powder that is soluble in water. Sodium carbonate is also called *washing soda* in the form of decahydrate, Sodium trioxocarbonate (IV).$10H_2O$. Sodium carbonate is generally used:

- in manufacturing glass, soap, paper, leather and sodium hydroxide.
- in cleaning, in water softening , in petroleum refining and in dyeing.

Sodium bicarbonate ($NaHCO_3$): It is also known as sodium hydrogen carbonate, sodium hydrogen trioxocarbonate (IV) and is commonly called *baking soda*. It is a white powder that is water soluble. Sodium bicarbonate is used:

- to make baking powder.
- as a source of carbon dioxide gas in fire extinguishers.
- to manufacture sodium carbonate.

Sodium Nitrate ($NaNO_3$): It is also called sodium trioxonitrate(V) commonly called, Chile saltpeter. It is a white crystalline solid and very soluble in water. It is used:

- as a fertilizer .
- in the production of nitric acid and other nitrates.
- as meat preservative in former times.

Sodium Chlorate ($NaClO_3$): It is also called sodium trioxochlorate(V), it is a white solid soluble in water. It is used:

- as an oxidizing agent in chemical processes due to its capacity to generate oxygen on heating.

- in manufacturing explosives, to make match boxes.
- as a weed killer in agriculture and the textile industry.

Sodium sulfate ($Na_2SO_4.10H_2O$): Also called Glauber's salt in the form of sodiumtetraoxosulfate (VI).$10H_2O$. It is a white solid used:

- in making glass and paper.
- as a cathartic in medicine.

Exercises

1. Name common household compounds of sodium.
2. Write the chemical formulas of these common household sodium compounds.
3. Explain the use of each common house hold sodium compounds.

3.2 Properties and Uses of Calcium and its Compounds

After completing this topic, you will be able to:

- demonstrate the preparation of calcium.
- discuss the properties and use of calcium and its compounds such as $CaCO_3$, CaO, $CaSO_4$, $CaCl_2$ and $Ca(OH)_2$.

Occurrence and extraction of calcium

Calcium is the fifth most abundant element and the third most abundant metallic element in the earth's crust it is never found in the form of the pure metal in nature. It occurs naturally in the form of compounds such as calcium carbonate or *calcite*, $CaCO_3$ (lime stone or marble or chalk), calcium sulphate or gypsum, $CaSO_4.2H_2O$, dolomite, $CaCO_3.MgCO_3$, rock phosphate, $Ca_3(PO_4)_2$ and fluoroapatite, $Ca_{10}(PO_4)_6F_2$.

Calcium metal is manufactured industrially by the electrolysis of fused (molten) calcium chloride, $CaCl_2$. When $CaCl_2$ is fused it ionizes to Ca^{2+} and Cl^-. When this molten mass is electrolyzed, Ca^{2+} ions move to the cathode, gain two electrons each and become calcium metal atoms. On the other hand, Cl^- ions move to the anode, lose one electron each and become chlorine atoms which combine to form chlorine molecule. The overall processes that take place during electrolysis of molten calcium chloride are summarized as follows.

Dissocation: $CaCl_2 \longrightarrow Ca^{2+} + 2Cl^-$

Cathode reaction: $Ca^{2+} + 2e^- \longrightarrow Ca$

Anode reaction: $2Cl^- \longrightarrow Cl_2 + 2e^-$

Cell reaction: $CaCl_2\,(l) \xrightarrow{\text{Electrolysis}} Ca(l) + Cl_2\,(g)$

During electrolysis of molten calcium chloride, calcium metal is collected at the cathode and chlorine gas at the anode of the electrolytic cell.

Properties of calcium metal

Calcium is silvery white metal, harder and less reactive than sodium.

It reacts with cold water slowly to form calcium hydroxide liberating hydrogen gas according to the following equation.

$$Ca\,(s) + 2H_2O\,(l) \longrightarrow Ca(OH)_2\,(aq) + H_2\,(g)$$

When heated in air, it combines with oxygen to form an oxide.

$$2Ca\,(s) + O_2\,(g) \longrightarrow 2CaO\,(s)$$

Calcium reacts with dilute acids like hydrochloric acid to form salt and liberate hydrogen gas.

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

Uses of calcium metal

Calcium metal has little use in the form of the pure metal. It is used:

- to make an alloy with lead that serves as electrode in car batteries.
- as a reducing agent in the extraction of metals such as chromium, zirconium, thorium and uranium.

Uses of calcium compounds

Calcium carbonate ($CaCO_3$): It is a white solid that is insoluble in pure water. It is used:

- as building material in the form of marble and limestone.
- in manufacturing glass and cement.
- to remove soil acidity in the form of limestone.
- as a flux (to remove impurity) in the extraction of iron.
- as a source of carbon dioxide in the production of sodium carbonate by the Solvay process.
- to manufacture calcium oxide.

Calcium oxide (CaO): It is also called quick lime or simply lime. It is a white solid that dissolves in water and form calcium hydroxide. It is used:

- to make other calcium compounds like calcium carbide, bleaching agent and slaked lime or calcium hydroxide.
- in manufacturing paper, rubber and building materials.
- in the softening and purification of municipal water supplies.
- for producing Bordeaux mixture for the control of pests that damage crops.
- to lower agricultural soil acidity.

Calcium hydroxide $Ca(OH)_2$: It is also called slaked lime. It is a white powder that dissolves in water to form basic solution. In the form of water solution it is called lime water. It is used:

- in water softening.
- in agriculture to neutralize soil acidity.
- in removing hair from hides in the process of leather production.
- in the manufacture of bleaching powder.
- to check whether or not a gas is carbon dioxide in solution form.

Calcium sulphate ($CaSO_4$): It occurs in nature in the form of gypsum, $CaSO_4.2H_2O$. Gypsum is used in the production of cement and to make Plaster of Paris, $2CaSO_4.H_2O$.

Plaster of Paris is made by heating gypsum. The equation for the preparation is as follows

$$2CaSO_4.2H_2O \xrightarrow{\text{Heat}} 2CaSO_4.H_2O + 3H_2O$$

Plaster of Paris is used:

- for plastering walls of buildings.
- to make molds for sculptures and statues.
- to support fractured bones.

Calcium chloride ($CaCl_2$): Anhydrous (water free) calcium chloride is used:

- for the extraction of calcium metal.
- to dry gases and organic liquids except ammonia gas and ethyl alcohol.
- to make water solution that freezes at -55°C which is used for cooling in refrigeration plants.

Exercises

1. Name common household compounds of calcium.
2. Write the chemical formulas of these common household calcium compounds.
3. Explain the uses of each common house hold calcium compound.

3.3 Properties and Uses of Copper and its Compounds

After completing this topic, you will be able to:

- demonstrate the preparation of copper.
- discuss the properties and use of copper and its compounds such as $CuSO_4$, CuO and $CuCl_2$.

Occurrence and extraction of copper

Copper is found as native copper in nature. However, it is found mainly in the form of compounds. The most important sulphide ores are chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS) and bornite (Cu_5FeS_4). The principal oxideores are cuprite (Cu_2O) and tenorite (CuO). In the carbonated form, it exists as malachite ($CuCO_3.Cu(OH)_2$).

The principal ore used for the extraction of copper is *chalcopyrite*.

The amount of copper in the mineral ore (chalcopyrite) is very small. Thus, the crushed sulphide ore is first concentrated by *froth flotation*. In this process, the crushed ore is treated with oil, water and detergents. Air is blown through the mixture, the ore wetted with oil floats on the surface and the gauge (impurity) settle to the bottom. This treatment changes the concentration of the ore from 2% copper to 30% copper. The concentrated ore is then roasted with limited amount of oxygen.

The equation for the reaction is:

$$2CuFeS_2\,(s) + 4O_2\,(g) \longrightarrow Cu_2S\,(s) + 2FeO\,(s) + 3SO_2\,(g)$$

The mixture obtained by roasting the concentrated sulphide ore is smelted by adding limestone and silica. Iron(II) oxide, FeO, present in the roasted mixture is removed as slag in the form of iron silicate ($FeSiO_3$) and silica in the form of calcium silicate ($CaSiO_3$). The equations for the reactions are:

$$CaCO_3\,(s) + SiO_2\,(s) \longrightarrow CaSiO_3\,(l) + CO_2\,(g)$$

$$FeO\,(s) + SiO_2\,(s) \longrightarrow FeSiO_3\,(l)$$

The Cu_2S obtained by roasting chalcopyrite is finally reduced by heating in a limited supply of O_2. The equation for the reaction is:

$$Cu_2S\ (s) + O_2\ (g) \longrightarrow 2Cu\ (l) + SO_2\ (g)$$

The copper obtained by this process is called *blister copper* and it has 98.5 – 99.5% purity. Blister copper is impure and contains iron, silver, gold and sometimes zinc. It needs to be refined further by electro refining. In the refining process the impure copper is used as the anode, copper metal of high purity as cathode, $CuSO_4$ solution and aqueous H_2SO_4 as an electrolyte.

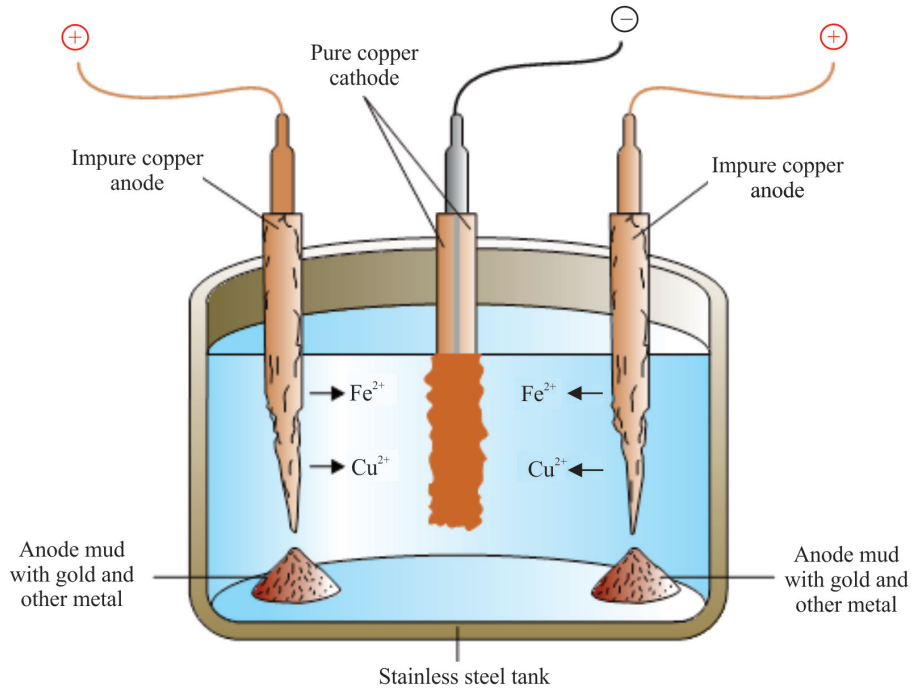


Figure 1. Refining of copper by electrolysis

Copper obtained after electro refining is 99.9% pure.

When electrolysis is carried out, copper and impurities that are oxidized more easily than copper such as nickel from the anode will goin to 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 as slag. The electrode reactions in the purifications of copper are the following;

Anode reaction: $Cu\ (s) \longrightarrow Cu^{2+}\ (aq)$

Cathode reaction: $Cu^{2+}\ (aq) + 2e^{-} \longrightarrow Cu\ (s)$

Properties of copper metal

Copper is a soft, ductile, malleable, reddish-brown metal with a density of 8.96 g / cm^3. It is best conductor of electricity next to silver.

Uses of copper metal:

- To make electric wires and cables.
- To make alloys like bronze (alloy of copper and tin) and brass (alloy of copper and zinc).
- In metal art work.
- To make compounds that are used as pesticides.

Uses of copper compounds

Copper sulfate ($CuSO_4$): Anhydrous (water free) copper sulfate is a white powder while hydrated copper sulfate is a blue crystalline solid. It is water soluble and forms blue solution. Copper sulfate is used:

- as electrolyte in copper refining and in electroplating of metal articles with copper.
- as wood preservative.
- in the dyeing industry.
- as fungicide in *Bordeaux mixture* (mixture of $CuSO_4$ and $Cu(OH)_2$).

Copper (I) oxide (Cu_2O): Copper (I) oxide is used:

- as fungicide.
- to make porcelain red glaze.
- in the production of red glass.

Copper(II) chloride ($CuCl_2$): Copper(II) chloride is used:

- as wood preservative
- in photography and electroplating
- as decolorizing, desulfurizing and purifying agent

Experiment 1

Qualitative analysis to identify cations of Group IA and IIA

Objective: To identify the pressence of cations of Group IA and IIA

Materials required: Platinum or nichrome wire, watch glass, Bunsen burner, distilled water, salt 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 plainum or Nichrome wire into the moist salt and then bring to the Bunsen flame.
2. Observe the color 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.

Observatioon and analysis

(a) Write the color of the flame produced in the following table:

Lithium (Li^+)	
Sodium (Na^+)	
Potassium (K^+)	
Calcium (Ca^{2+})	
Strontium (Sr^{2+})	
Barium (Ba^{2+})	

(b) Write a laboratory report and present to the class.

3.4 Extraction, Properties and Uses of Aluminum

After completing this topic, you will be able to:

- describe the extraction, properties and uses of aluminum.

Occurrence and extraction of aluminum

Aluminum is the most abundant metal and third most abundant element in the earth's crust next to oxygen and silicon. About 7% of the earth's crust by mass is aluminum. It is the second ranking metal next to iron in terms of global consumption. Aluminum does not exist as a free metal in nature. The major ore of aluminum is

bauxite (Al_2O_3). Other minerals of aluminum are orthoclase ($KAlSi_3O_8$), cryolite (Na_3AlF_6), corundum (Al_2O_3), beryl ($Be_3Al_2Si_6O_8$) and China clay ($Al_2Si_2O_7.2H_2O$).

Aluminum is extracted industrially by Hall process or Heroult process. In this process, first bauxite is purified. To isolate pure alumina, Al_2O_3, from silica, SiO_2, powdered ore is heated with sodium hydroxide solution to convert silica into soluble silicate. At the same time aluminum oxide is converted to soluble sodium aluminate.

$$SiO_2\,(s) + 2NaOH\,(aq) \longrightarrow Na_2SiO_3\,(aq) + H_2O(l)$$

$$Al_2O_3\,(s) + 2NaOH\,(aq) \longrightarrow 2NaAlO_2\,(aq) + H_2O\,(l)$$

Other impurities present in bauxite like oxides of iron and titanium remains unaffected by the base and filtered off.

The solution, is then acidified to precipitate $Al(OH)_3$.

$$AlO_2^-\,(aq) + H_3O^+\,(aq) \longrightarrow Al(OH)_3\,(s)$$

Aluminum hydroxide is then collected by filtration, washed, dried and heated in a furnace to get Al_2O_3

$$2Al(OH)_3 \xrightarrow{\text{Heat}} Al_2O_3$$

Hall process or Hall-Heroult process of aluminum extraction involves electrolysis 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. An iron vessel lined with carbon holds the molten mixture and also serves as cathode. Graphite rods that serve as anode are inserted into the melt.

Alumina, Al_2O_3 ionizes as follows

$$2Al_2O_3\,(s) \xrightarrow{\text{Melting}} 4Al^{+3}\,(l) + 6O^{2-}\,(l)$$

When a molten mixture of alumina and cryolite is electrolyzed, the cell reaction and electrode reactions are the following:

Cathode reaction: $4Al^{+3}\,(l) + 12e^- \longrightarrow 4Al\,(l)$

Anode reaction: $6O^{2-}\,(l) \longrightarrow 3O_2\,(g) + 12e^-$

Cell reaction: $2Al_2O_3\,(l) \xrightarrow{\text{Electrolysis}} 4Al\,(l) + 3O_2\,(g)$

Thus, aluminum ion is reduced and aluminum metal is produced at the cathode. Oxidation of oxide ion to oxygen gas takes place at the anode.

Properties of aluminum

Aluminum is silvery – white metal with a density of 2.7 g/cm^3. It melts at 660^{o}C. It is a good conductor of electricity. It can be shaped into wires or pressed into sheets.

Reactions of aluminum

(a) **Reaction with oxygen**

Aluminum reacts with atmospheric oxygen to form a thin film of aluminum oxide on its surface.

$$4Al\,(s) + 3O_2\,(g) \longrightarrow 2Al_2O_3(s)$$

(b) **Reaction with dilute acids**

Aluminum reacts with dilute acids like HCl and H_2SO_4 forming salt and liberating hydrogen gas.

$$2Al\,(s) + 6HCl\,(aq) \longrightarrow 2AlCl_3\,(aq) + 3H_2\,(g)$$

What is the formula of the salt that can be formed by the reaction of aluminum and sulfuric acid?

(c) **Reaction with water**

Cold water has no action on aluminum due to a layer of oxide on it. When steam is passed over heated aluminum, hydrogen gas is produced and aluminum oxide is formed according to the following equation.

$$2Al\,(s) + 3H_2O\,(g) \longrightarrow Al_2O_3\,(s) + 3H_2\,(g)$$

Use of aluminum

- To make alloys like duralumin which is an alloy of Al, Cu, and Mg.
- To make cooking utensils due to its high thermal conductivity and resistance to corrosion.
- As packaging materials in food industries and for electrical transmission lines.
- In the *thermite welding process*. This process uses a mixture of powdered aluminum mixed and iron (III) oxide. When this mixture is ignited, it produces a temperature of about 3000^{o}C that can be used to cut and weld metals.

The equation for the reaction in this process is as follows:

$$2Al\ (s) + Fe_2O_3\ (s) \longrightarrow Al_2O_3\ (s) + 2Fe\ (l)$$

Thermite is the name given to describe a mixture of powdered aluminum and iron (III) oxide

3.5 Extraction, Properties and Uses of Iron

After completing this topic, you will be able to:

- describe the extraction, properties and uses of iron

Iron is the second most abundant (by mass) metallic element and the fourth most abundant element in the earth's crust. Iron exists in earth's crust in many different minerals, such as iron pyrite (Fool's gold, FeS_2), siderite ($FeCO_3$), hematite (Fe_2O_3), and magnetite (Fe_3O_4, often represented as $FeO.Fe_2O_3$) and hydrated iron (III) oxide (Limonite, $Fe_2O_3.3H_2O$). Of these, hematite and magnetite are particularly suitable for the extraction of iron.

The metallurgical processing of iron involves the chemical reduction of the minerals by carbon (in the form of coke) in a blast furnace. The concentrated iron ore, limestone ($CaCO_3$), and coke are introduced into the furnace from the top. The role of limestone is to serve as a flux (to facilitate the removal of impurities like silica, SiO_2 and alumina, Al_2O_3). A blast of hot air is forced up the furnace from the bottom, hence the name *blast furnace.*

The oxygen gas in the air reacts with the carbon in the coke to form mostly carbon monoxide and some carbon dioxide. These reactions are highly exothermic, and as the hot CO gases rises, it reacts with the iron oxides in different temperature zones, The key steps in the extraction of iron are:

1.

(i) Oxidation of coke to carbon dioxide

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

(ii) Reduction of carbon dioxide to carbon monoxide by reacting with coke

$$CO_2\ (g) + C\ (s) \longrightarrow 2CO\ (g)$$

2. Reduction of iron oxides

$$3Fe_2O_3(s) + CO(g) \longrightarrow 2Fe_3O_4(s) + CO_2(g)$$

$$Fe_3O_4(s) + CO(g) \longrightarrow 3FeO(s) + CO_2(g)$$

$$FeO(s) + CO(g) \longrightarrow Fe(l) + CO_2(g)$$

3. Formation of slag

(iii) The limestone decomposes in the furnace as follows:

$$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$$

The calcium oxide then reacts with the impurities in the iron, which are mostly sand or silica(SiO_2) and aluminum oxide (Al_2O_3):

$$CaO(s) + SiO_2(s) \longrightarrow CaSiO_3(l)$$

$$CaO(s) + Al_2O_3(s) \longrightarrow Ca(AlO_2)_2(l)$$

The mixture of calcium silicate and calcium aluminate that remains molten at the furnace temperature is known as slag.

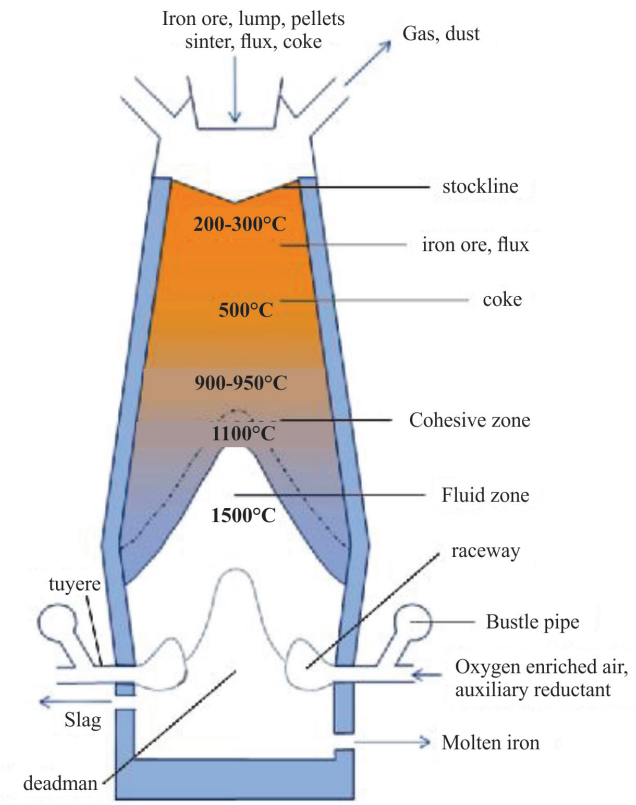


Figure 2. The Blast Furnace

By the time the ore works its way down to the bottom of the furnace, most of it has already been reduced to iron. The temperature of the lower part of the furnace is above the melting point of impure iron, and so the molten iron at the lower level can be run off to a receiver. The slag, is less dense, forms the top layer above the molten iron and can be run off at that level. The slag can be used as raw material for cement factories to manufacture cement.

The iron collected directly from the blast furnace is called pig iron. It is impure and needs to be purified further to obtain iron of desirable quality.

Other forms of iron are cast iron, wrought iron and steel.

Cast iron is obtained from pig iron that has been remelted after mixed with steel scraps. It is also impure iron.

Wrought iron is the purest form of iron obtained after removing most of the impurities from pig-iron.

Steel is the most important form of commercial iron. It is an alloy of iron containing small but definite amount of carbon (ranging from 0.15 – 1.5 %) and other metals.

The by-product, slag is used in the manufacturing of glass and cement.

Properties of iron

Pure iron is a grey lustrous, malleable and ductile metal. It is good conductor of heat and electricity. It has a density of 7.87 g/cm^3.

It is a ferromagnetic metal (can be permanently magnetized).

Iron forms hydrated iron(III) oxide or rust in the presence of air and moisture.

$$2Fe\,(s) + 3O_2(g) \xrightarrow{\text{Moisture}} Fe_2O_3 \cdot xH_2O\ (\text{Rust})$$

Iron reacts with dilute acids like HCl and H_2SO_4 forming iron(II) salts liberating hydrogen gas.

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

Iron has no reaction with cold or hot water. When steam is passed over heated iron, iron (II - III) oxide and hydrogen gas are formed according to the following equation.

$$3Fe(s) + 4H_2O\,(g) \longrightarrow Fe_3O_4\,(s) + 4H_2\,(g)$$

Use of iron

Iron takes first position in worldwide consumption. It is used as a structural metal in the construction of buildings and bridges.

Pig-iron or cast iron is used for producing stoves, Bunsen burner bases, radiators, car engine blocks, railing etc.

Wrought iron is used for making chains, nails, bolts, sheets, horse shoes, ornamental garden gates, farm machinery etc.

Steel is used to make nails, screws, hammers, car bodies, railway lines, ships, files, drills etc.`

Exercises

1. What mineral ores are found in Liberia? List their names.
2. What are the constituent metals of these mineral ores?

Field Trip

Let your teacher and your school administration arrange a trip to the nearby mining company. Visit how the mining process is carried out. Identify the type of mineral mined during your visit. Does the company perform the extraction process? What metal is manufactured by the company? How does the company perform the extraction process? Write a report about your trip and observation about the over all activities related to the mining company.

3.6 Extraction and Use of Gold

After completing this topic, you will be able to:

- describe the extraction, properties and uses of gold.

Gold has been known since ancient times. It was mainly used to make jewellary.

Occurrence of gold

The primary mineral of gold is the native metal and electrum (a gold - silver alloy).

It also exist in compound form in gold and tellurium known as gold telluride, $AuTe_2$.

Extraction of gold

Gold is extracted using two methods.

(i) **Mechanical separation:** The metal is separated from sand by washing the crushed mineral with water in devices in which the lighter sand is

separated from the heavy gold. In this process mercury can also be used with which the gold forms an amalgam. On heating, mercury evaporates leaving the gold behind.

(ii) **Cyanide process:** In this process the finely crushed ore of gold is treated with sodium cyanide, NaCN, solution which dissolves the gold. From the cyanide solution gold is recovered by precipitation with zinc or aluminum. The reactions taking place in the cyanide process are as follows;

$$4Au(s) + 8CN^{-}(aq) + O_2(g) + 2H_2O(l) \longrightarrow 4Au(CN)_2(aq) + 4OH^{-}(aq)$$

$$2Au(CN)_2(aq) + Zn(s) \longrightarrow 2Au(s) + Zn(CN)_2(aq)$$

Properties and uses of gold

Gold is a soft bright yellow metal with a density of 19.4 g/cm^3. It is a very good conductor of electricity. Gold is resistant to attack by air and other chemicals.

Gold is used to make jewelry and electrical wiring. The primary use of gold is as a monetary reserve for individuals and nations.

3.7 Extraction and Use of Tin

After completing this topic, you will be able to:

- describe the extraction, properties and uses of tin

Occurrence and extraction of tin

Tin doesn't exist in nature as a free element. It occurs in nature in the form of tin (IV) oxide, SnO_2 , called cassiterite. Tin is extracted by the reduction of cassiterite in a furnace with coke. The equation for the extraction process is as follows.

$$SnO_2 + C \xrightarrow{\text{Heat}} Sn + CO_2$$

Properties and uses of tin

Tin is silvery white metal with a density of 7.3 g/cm^3. It can be rolled or pressed to tin foil. Air has no action on tin at ordinary conditions.

Tin is used to coat steel. The thin film coating of tin protects the steel from reaction with air. Tin is used to make a number of alloys like solder (tin + lead) and bronze (tin + copper). It is also used corrugated tin sheet for roofing.

3.8 Alloys and their uses

After completing this section you will be able to:

- discuss alloys.
- discuss the common uses of brass, bronze and duralumin.

What is the purpose of alloying metals?

An alloy is defined as a solid solution which is a mixture of two or more metallic elements or metallic and non-metallic elements. Alloying metals is carried out to modify some physical properties of the metals.

The main purpose of alloying metals is to:

- modify the color of the metal.
- increase the elasticity, tensile strength and toughness of the metal.
- modify the electrical conductivity of the metal.
- make the metal to be more resistant to corrosion.

Table 1 **Composition, properties and uses of common alloys of copper, aluminum, lead and iron.**

Alloy	Constituent elements	Properties	Uses
Bronze	Copper and tin	Hard and tough, resistant to corrosion, yellow-brwn in color	To make coins, medals, bells, machine parts, etc
Brass	Copper and zinc	Yellowish and hard	For hardware tops, terminals, pipes,etc
Solder	Lead and tin	Silvery-gray in color and low melting solid	Used for joining metal metal frames
Duralumin	Aluminum, copper and magnesium or manganese	Silvery in color, very hard, has low density	In making air plane frame work
Type metal	Lead, tin, antimony and copper	Gray in color, heavy and hard	For making types for printing
Steel	Carbon and iron	Hard and hardness increases with carbon content	As structural metal, for hammers, chisels
Stainless steel	Iron carbon and chromium	Silvery white, resistant to corrosion	For making cutlery (knives, forks, spoons, etc
Phosphor bronze	Copper, tin and phosphorus	Has high density and hardness, resistant to corrosion	For making ship propellers

Exercises

1. Name the type alloys available in your locality.
2. What are the constituent metals of these alloys?

3.9 Cement and its Uses

After completing this topic, you will be able to:

- analyze the production process of cement.
- explain the uses of cement.

What do you know about the importance of cement? List some uses of cement.

Production of cement

Cement mainly consists of calcium silicate ($CaSiO_3$), calcium aluminate ($CaAl_2O_4$), iron(III) oxide (Fe_2O_3), magnesium oxide (MgO) and other silicates.

Raw Materials: the raw materials for the production of Portland cement are limestone, alumina and silica-bearing materials such as clay.

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.

Manufacturing Process: First, limestone, alumina, iron (III) oxide 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. The over all process taking place in the rotary kiln is as follows.

Upper part of the kiln

$$\text{Raw material heated} \xrightarrow{\text{Heat}} \text{complete elimination of moisture}$$

Middle part of the kiln

Limestone decomposes to calcium oxide.

$$CaCO_3\,(s) \xrightarrow{\text{Heat}} CaO\,(s) + CO_2\,(g)$$

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.

$$2CaO + 2SiO_2 \longrightarrow 2CaO \cdot SiO_2 \text{ (di-calcium silicate)}$$

$$3CaO + 3SiO_2 \longrightarrow 3CaO \cdot SiO_2 \text{ (tri-calcium silicate)}$$

$$3CaO + 3Al_2O_3 \longrightarrow 3CaO \cdot Al_2O_3 \text{ (tri-calcium aluminate).}$$

$$4CaO + 4Al_2O_3 + 4Fe_2O_3 \longrightarrow 4CaO \cdot Al_2O_3 \cdot Fe_2O_3$$
(tetra-calcium aluminum ferrate)

$$MgO + SiO_2 \longrightarrow MgSiO_3 \text{ (magnesium silicate)}$$

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 grounded to a fine powder. Gypsum slows down the rate of setting of cement, so that the cement hardens adequately. When mixed with water cement first forms a plastic mass that hardens after sometime. In the hardening process of cement, the transition from plastic to solid state is called *setting of cement.*

Uses of cement

Cement is mainly used as a binder in concrete, which is a basic material for all types of constructions, including housing. roads, schools, hospitals, dams and ports, as well as for decorative applications (for floors. staircases, driveways, pool decks) and items like tables, sculptures or book cases.

Environmental impacts of cement

The cement industry produces about 5% of global man made CO_2 emissions. Carbon dioxide is a greenhouse gas that causes global warming.

Cement industries release cement dust to the atmosphere that causes breathing problems. The industries also cause resource depletion (for example affecting biodiversity) due to raw material extraction.

Concrete causes damage to the most fertile layer of the earth, the top soil. Concrete is used to create hard surfaces which contribute to surface runoff that may cause soil erosion, water pollution and flooding.

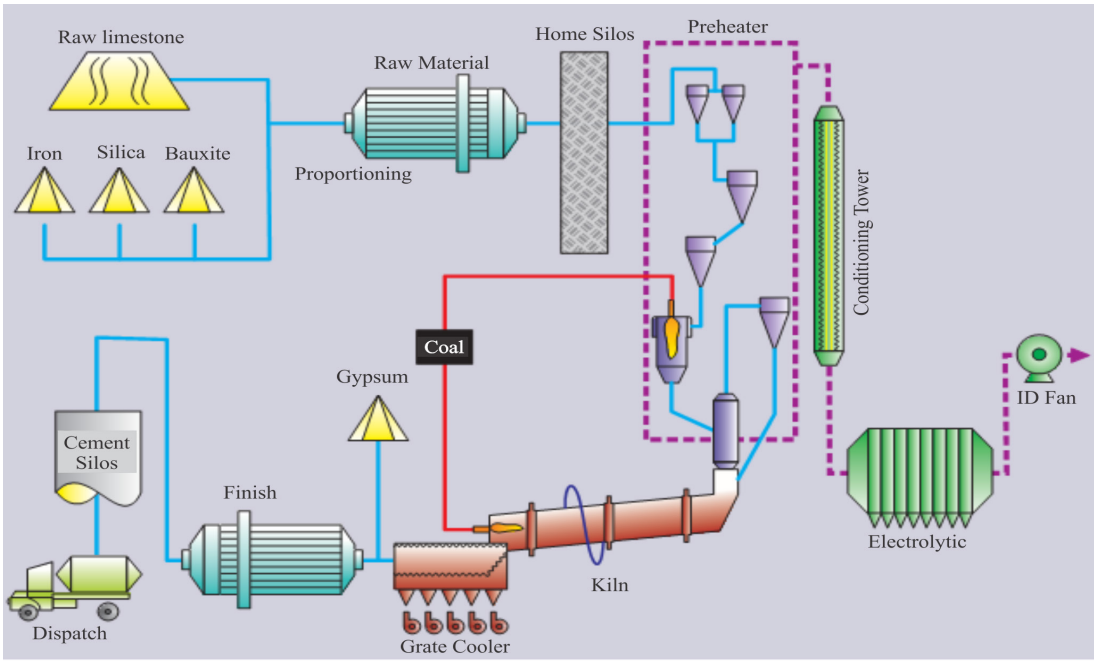


Figure 3. Cement Manufacturing Process

Field Trip

Let your teacher and the school administration arrange a field trip to CEMENCO. During your visit;

1. Ask the person in charge at CEMENCO what raw materials they use for the production of cement and from where they get the raw materials.
2. Observe different parts of the manufacturing plant and see how the raw materials are processed. Ask workers what the function of each part is and what processes are taking place.
3. Write a report about your observation. Your report should include the raw materials used, how the raw materials are processed and duty of each unit of the manufacturing plant. Present your report to your classmates.

Key Terms

- Baking soda
- Bauxite
- Blast furnace
- Blister copper
- Bordeaux mixture

- Brass
- Bronze
- Calcite
- Cassiterite
- Cast iron
- Caustic soda
- Cement
- Chalcopyrite
- Chile saltpeter
- Cryolite
- Cyanide process
- Downs cell
- Duralumin
- Fluoroapatite
- Flux
- Froth flotation
- Glauber's salt
- Gypsum
- Hall process
- Hematite
- Limonite
- Magnetite
- Malachite
- Metallurgy
- Pig iron
- Plaster of Paris
- Quick lime
- Rock phosphate
- Siderite
- Slag
- Stainless steel
- Thermite process
- Washing soda
- Wrought iron

SUMMARY

- Sodium is the sixth most abundant element in the earth's crust. It is never found in pure form in nature.
- Sodium metal is manufactured industrially by the electrolysis of molten sodium chloride with the apparatus called the Downs cell.
- Sodium is silvery-white, lustrous metal, with low density.
- It is highly reactive and kept under liquid hydrocarbon.
- Calcium is the fifth most abundant element and the third most abundant metallic element in the earth's crust.
- Calcium metal is manufactured industrially by the electrolysis of fused (molten) calcium chloride, $CaCl_2$.
- Calcium is silvery white metal, harder and less reactive than sodium.
- Calcium Oxide, CaO: is also called Quick lime or simply lime.
- Calcium hydroxide, $Ca(OH)_2$ is also called slaked lime. In the form of water solution it is called lime water.
- Copper is found as native copper in nature.
- The principal ore used for the extraction of copper is chalcopyrite.
- Metallurgyis the science and technology of extracting metals from their natural sources and preparing them for practical use.
- Aluminum is the most abundant metal and third most abundant element in the earth's crust.
- Hall process or Hall-Heroult process of aluminum extraction involves electrolysis molten alumina (Al_2O_3) mixed with some amount of cryolite.
- Thermite process is the heating of aluminum with Iron (III) oxide.
- Iron is the second most abundant metallic element and the fourth most abundant element in the earth's crust.
- Hematite and magnetite are particularly suitable for the extraction of iron.
- The metallurgical processing of iron involves the chemical reduction of the minerals by carbon (in the form of coke) in a blast furnace.
- The iron collected directly from the blast furnace is called pig iron.
- Cast iron is formed when pig iron that has been remelted after mixed with steel scraps.
- Wrought iron is the purest form of iron obtained after removing most of the impurities from pig-iron.
- The primary mineral of gold is the native metal and electrum (a gold - silver alloy).
- Gold is extracted by the cyanide process.
- Gold is used to make jewelry and electrical wiring. The primary use of gold is as a monetary reserve for individuals and nations.

- Tin occurs in nature in the form of tin (IV) oxide, SnO_2 called Cassiterite.Tin is extracted by the reduction of cassiterite in a furnace with coke.
- Tin is used to coat steel, to make a number of alloys like solder and brass.
- An alloy is defined as a solid solution which is a mixture of two or more metallic elements or metallic and non-metallic elements.
- Cement is a mixture of calcium silicates and calcium aluminates, iron (III) oxide and magnesium oxide.
- The raw materials for the production of cement are lime stone, alumina. Clay and iron (III) oxide.
- Environmental impacts of cement include carbon dioxide emission, global warming, water pollution, etc.

Exercises

Part I. Choose the correct answer.

1. The metal ranking first in global consumption is:
   (a) aluminum
   (b) iron
   (c) copper
   (d) sodium
2. Which one of the following is not a mineral of copper?
   (a) chalcocite
   (b) chalcopyrite
   (c) siderite
   (d) malachite
3. The most abundant metallic element in the earth's crust is:
   (a) calcium
   (b) sodium
   (c) iron
   (d) aluminum
4. Aluminum metal is not used to:
   (a) absorb dangerous rays in atomic energy stations
   (b) make electric cables
   (c) make alloys that is used in air craft construction
   (d) make cooking utensils
5. Cement is manufactured by heating a mixture of:
   (a) slaked lime sand and water
   (b) sodium carbonate, sand and limestone

(c) limestone, alumina, iron (III)oxide and clay
(d) potassium carbonate and silica.

6. Which one of the following is the purest form of iron?
   (a) pig iron
   (b) cast iron
   (c) stainless steel
   (d) wrought iron
7. Which compound of sodium is a component of baking powder?
   (a) sodium carbonate
   (b) sodium hydrogen carbonate
   (c) sodium sulfate
   (d) sodium chloride
8. The name Glauber's salt refers to:
   (a) sodium sulfate
   (b) sodium nitrate
   (c) sodium phosphate
   (d) sodium carbonate
9. Of the following minerals, which one doesn't contain calcium?
   (a) lime stone
   (b) dolomite
   (c) gypsum
   (d) hematite
10. Bordeaux mixture is a fungicide that contains the metal:
   (a) sodium
   (b) iron
   (c) copper
   (d) calcium
11. The basic raw materials used in the extraction of iron are:
   (a) lime stone and coke
   (b) lime stone, hematite or magnetite and coke
   (c) sand, lime stone and hematite
   (d) limestone, hot air and hematite
12. What is the role of calcium carbonate in the blast furnace during the extraction of iron?
   (a) to facilitate removal of impurities
   (b) to reduce the iron oxides to metallic iron
   (c) to reduce the sand to silicon
   (d) to increase the furnace temperature

13. Which one of the following is not a step in the Hall process of aluminum extraction?
    (a) Heating powdered bauxite with sodium hydroxide.
    (b) Heating aluminum hydroxide strongly to get aluminum oxide.
    (c) Melting a mixture of cryolite and aluminum hydroxide.
    (d) Electrolyzing the molten mixture of aluminum oxide and cryolite.
14. In the Hall process of aluminum production, the importance of adding cryolite, Na_3AlF_6, to aluminum oxide is to:
    (a) lower the oxidation of the copper anode.
    (b) get aluminum – sodium alloy at the cathode.
    (c) hinder the oxidation of oxide ion at the anode.
    (d) lower the melting point of Al_2O_3 from 2045°C to 1000°C.
15. Which one of the following is not true about electrolysis of molten mixture of aluminum oxide and cryolite in the electrolytic cell of the Hall process?
    (a) Al^{3+} ions move to the cathode and gain three electrons.
    (b) reduction of Na^+ occurs at the cathode.
    (c) oxide ions, O^{2-} move to the anode.
    (d) aluminum metal is produced at the cathode.
16. Aluminum does not corrode in atmospheric air as compared to sodium and calcium metals. This is due to the:
    (a) formation of a thin film of aluminum oxide on its surface.
    (b) formation of a thin film of aluminum nitride on its surface.
    (c) higher reactivity of Al as compared to sodium and calcium metals.
    (d) inertness of aluminum towards many reagents.
17. The metal used in the thermite welding process is:
    (a) magnesium
    (b) lead
    (c) sodium
    (d) aluminum
18. Of the following, which one is not a mineral ore of iron?
    (a) corundum
    (b) hematite
    (c) magnetite
    (d) siderite
19. The iron obtained directly from the blast furnace is:
    (a) pig iron
    (b) cast iron

(c) wrought iron
(d) steel

20. Copper is principally extracted from the mineral ore called:
(a) chlcocite
(b) malachite
(c) bornite
(d) chalcopyrite

21. The process carried out to increase the concentration of copper in the ore is:
(a) roasting
(b) froth flotation
(c) disproportionation
(d) tempering

22. The purpose of adding limestone and sand to the mixture obtained by roasting the concentrated ore of copper is to:
(a) reduce Cu_2S to metallic copper
(b) increase the reaction temperature
(c) remove impurities present in the form of slag
(d) to oxidize Cu_2S to CuO

23. Blister copper contains impurities and can be purified further by:
(a) reduction with coke
(b) heating it with hydrogen
(c) smelting it with limestone
(d) electrolytic refining

24. Which substance is mixed with cement clinker and ground to slow down the rate of setting of cement?
(a) sodium carbonate
(b) limestone
(c) gypsum
(d) sodium nitrate

25. Which of the following is an alloy of copper and tin?
(a) brass
(b) bronze
(c) solder
(d) steel

26. Which of the following is true of pig (cast) iron?
(a) It is malleable and ductile
(b) It is hard and brittle

(c) It contains less carbon than wrought iron
(d) It is the most pure form of iron

27. Tin metal is extracted from the mineral:
(a) chalcocite
(b) cassiterite
(c) limonite
(d) malachite

28. Hematite is used in the blast furnace as a:
(a) flux
(b) solvent
(c) reducing agent
(d) source of iron

29. The extraction or purification of which one of the following elements doesn't involve electrolysis?
(a) sodium
(b) copper
(c) iron
(d) calcium

30. Which one of the following is not an impact of cement manufacturing process on the environment?
(a) The release of cement dust to the atmosphere that create breathing problem.
(b) Increasing the concentration of carbon dioxide due to emission from cement factories
(c) Resource depletion due to mining of raw materials for cement factories.
(d) Reducing global warming due to the use of fossil fuels as energy source in the industries.

31. Of the following alloys, which one doesn't contain copper?
(a) brass
(b) solder
(c) duralumin
(d) phosphor bronze

32. The process used in the industrial production of gold is:
(a) cyanide process
(b) frasch process
(c) hall-Heroult process
(d) down's process

33. Which one of the following chemical reaction doesn't take place in the blast furnace during the extraction of iron?
    (a) $C + O_2 \longrightarrow CO_2$
    (b) $CaO + SiO_2 \longrightarrow CaSiO_3$
    (c) $FeO + CO \longrightarrow Fe + CO_2$
    (d) $CaO + CO_2 \longrightarrow CaCO_3$
34. The salt known by the common name Chile saltpeter is:
    (a) $NaNO_3$
    (b) Na_2CO_3
    (c) $NaHCO_3$
    (d) $Ca(NO_3)_2$
35. The formula that represents gypsum is:
    (a) $Ca(OH)_2$
    (b) $CaSO_4.2H_2O$
    (c) $CaCO_3$
    (d) $Ca_3(PO_4)_2$
36. Calcium hydroxide is not used in:
    (a) the production of bleaching powder
    (b) removing hair from hides in leather production
    (c) controlling the damage caused by pests on crops
    (d) the process of water softening
37. Which compound of sodium is used as cathartic in medicine?
    (a) Na_2CO_3
    (b) Na_2SO_4
    (c) NaCl
    (d) $NaNO_3$
38. The compound of calcium used as a drying agent for gases and organic liquids is:
    (a) $2CaSO_4.H_2O$
    (b) $Ca(OH)_2$
    (c) $CaCl_2$
    (d) CaO
39. The word "Thermite" refers to a mixture of:
    (a) calcium silicate and calcium aluminate
    (b) slaked lime, sand and water
    (c) sand, cement and water
    (d) powdered aluminum and iron (III) oxide

40. Slag is a by-product obtained during the extraction of iron in the blast furnace. This by-product is used as raw material in the manufacturing of:
    (a) soaps and detergents
    (b) plaster of Paris
    (c) cement
    (d) plastic materials

Part II. Attempt the following questions

1. Why is it necessary to store sodium metal in bottles under liquid hydrocarbon?
2. List down important uses of sodium metal
3. What are the uses of:
    (a) sodium chloride
    (b) sodium hydroxide
    (c) sodium carbonate
    (d) sodium bicarbonate
    (e) sodium nitrate
    (f) sodium chlorate
4. What are the uses of calcium metal?
5. Describe the uses of:
    (a) calcium carbonate
    (b) calcium oxide
    (c) calcium hydroxide
    (d) calcium sulphate (gypsum)
    (e) plaster of Paris
    (f) calcium chloride
6. Define the terms (a) Metallurgy (b) Ore
7. What are the mineral ores of aluminum?
8. Describe the uses of aluminum metal.
9. What is the importance of mixing aluminum oxide with some cryolite in the process of aluminum extraction?
10. In what form(s) does copper exist in nature.
11. What are the mineral ores of copper?
12. What is meant by froth flotation?
13. Outline the purification of copper by electrolysis.
14. Name the mineral ores of iron and write their chemical formulas.

15. Write chemical equations to show the formation of slag in the blast furnace during extraction of iron.
16. What is the most important commercial form of iron?
17. Describe the uses of gold and tin.
18. Define alloy.
19. What are the raw materials used to manufacture cement?
20. What is meant by setting of cement?

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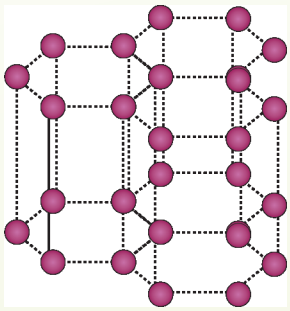
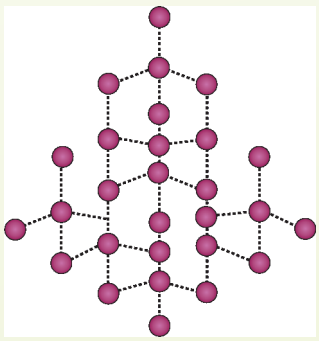
CHAPTER 4

CHEMISTRY OF SELECTED NON-METALS AND THEIR COMPOUNDS

Chapter Contents





Chapter Outcome

After completing this chapter, you will be able to:

- discuss the occurrence, properties, preparation, reactions as well as the uses of non-metals and their compounds.

Nearly 20% of the known elements are non-metals. Non-metals can be either gases, liquids or solids.

Example- oxygen, nitrogen, chlorine, hydrogen are gases. Bromine is a liquid, carbon, sulfur, phosphorus, etc, are solids.

4.1 Carbon and its compounds

After completing this topic, you will be able to:

- apply the laboratory methods of preparing as well as testing for carbon as well as its compounds,
- discuss the uses of carbon,
- discuss the reactions of compounds of carbon,
- apply laboratory techniques to prepare and test for coal and coke.

Occurrence of carbon

Carbon occurs in nature in native form or elemental state and in the form of compounds. In elemental state it occurs in the form of *diamond* and *graphite*. In the combined state it oocurs in the form of calcium carbonate and magnesium carbonate, rocks such as calcite, limestone, dolomite, marble and chalk, as carbon dioxide (in the air), petroleum and natural gas, mineral coal, in plant and animal tissues.

Allotropic forms of carbon

Allotropes are different forms of the same element in the same physical state having different physical properties. The existence of an element in two or more different forms in the same physical state is called allotropy. Carbon has crystalline and amorphous forms. Diamond and graphite are natural crystalline forms.

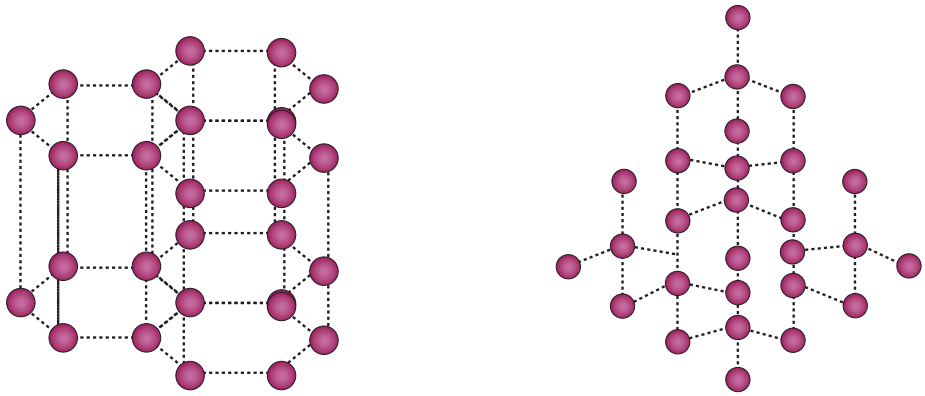
Diamond is the hardest natural substance known. The cause of its hardness is the tetrahedral arrangement of the carbon atoms in three dimensional net work which also resulted in high melting point of about 3570ºC. Pure diamond is colorless, transparent and brilliant. Diamond sparkle in light because light entering the crystal is reflected from face to face in the crystal before being reflected out again.

- It is non-conductor of electricity and insoluble in all common solvents.
- Diamond is mostly used as a jewel, as tip of rock drilling machinery and in making metal polishing and glass cutting tools.
- The density of diamond is 3.51 g/cm^3 and the bond length between carbon atoms is 1.54 Å.

Graphite is a soft, shiny black crystalline form of carbon. The carbon atoms in graphite are arranged in hexagonal layers in which each carbon atom is bonded to other three carbon atoms and every carbon atom possess one unpaired electron that are mobile in the ring. Due to these delocalized (mobile) electrons graphite is good conductor of electricity. The hexagonal layers in graphite can slide horizontally one over the other due to weak forces between them known as *Vander Waal's forces.* The capacity of the hexagonal layers to slide one over the other is the main cause for the slipperiness of graphite. Due to this reason graphite finds use as lubricant for slow moving machinery, as additive for motor fuel and, in lead pencil. Graphite is also used as electrode in electric furnance.

The density of graphite is 2.25 g/cm^3 and the bond length between two carbon atoms in a hexagonal ring is 1.42 Å and between carbon atoms in two hexagonal layers is 3.4 Å.

The density of graphite is 2.25 g/cm^3 and the bond length between two carbon atoms in a hexagonal ring is 1.42 Å and between carbon atoms in two hexagonal layers is 3.4 Å.



Structure of Graphite

Structure of Diamond

Figure 1. Structures of Diamond and Graphite

Amorphous forms of carbon include coke, wood charcoal, bone charcoal and lamp-black. Coke is obtained by distillation of mineral coal.

Carbon black, lampblack or soot – purest form of amorphous carbon and prepared by burning substances rich in carbon in limited supply of oxygen.

Carbon black is used in the manufacturing of black paint, printer's ink as a filler and strengthener in rubber production for tires and in making carbon paper.

Oxides of carbon

A. Carbon(II) oxide (CO)

(i) **Laboratory preparation:** Carbon monoxide can be obtained pure by dehydrating formic acid with concentrated sulphuric acid.

$$HCOOH + H_2SO_4 \longrightarrow CO + H_2SO_4 + H_2O$$

(ii) **Industrial preparation:** Carbon monoxide is produced commercially by passing steam over hot coke or by incomplete combustion of hydrocarbons, or by reduction of CO_2 by hot coke.

$$H_2O\,(g) + C \longrightarrow CO + H_2$$

or

$$2CH_4 + 3O_2 \longrightarrow 2CO + 4H_2O$$

or

$$CO_2 + C \longrightarrow 2CO$$

Physical properties of carbon monoxide

- It is colorless, odorless and tasteless gas.
- It is almost insoluble in water.
- It is less dense than air and neutral to litmus.
- It is extremely poisonous because it combines with the oxygen carrier protein, hemoglobin in red blood cells and inhibit the hemoglobin from combining with oxygen in the lungs and carrying it to the tissues. So carbon monoxide causes headache in small concentration and is fatal in a higher concentration.
- Carbon monoxide liquefies at -192ºC and solidifies at -207ºC.

Reaction of carbon monoxide

1. Carbon monoxide is inflammable gas and burns in air with a blue flame to form carbon dioxide.

$$2CO + O_2 \longrightarrow 2CO_2$$

2. Carbon monoxide is a reducing agent and it reduces heated metallic oxides to their respective metals.

Examples

$$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$$

$$PbO + CO \longrightarrow Pb + CO_2$$

$$CuO + CO \longrightarrow Cu + CO_2$$

Uses of carbon monoxide

- Used as a reducing agent in metallurgy (extraction of metals)
- As component of industrial gaseous fuels such as water gas and producer gas.
- Used as starting material for the synthesis of methyl alcohol and methane

$$CO + 2H_2 \longrightarrow CH_3OH$$

Methyl alcohol

$$CO + 3H_2 \longrightarrow CH_4 + H_2O$$

Methane

B. Carbon(IV) oxide (CO_2)

Carbon dioxide is a minor component of the atmosphere (0.04%) and natural processes of oxidation accounts for most of the atmosphere CO_2 such as decay and decomposition of animal and plants by bacteria, volcanoes, respiration of animals, etc. Other processes which add CO_2 to the atmosphere are decomposition of carbonates, combustion of wood, mineral coal and petroleum products to get energy, etc.

Most of the carbon dioxide used commercially is a by-product of cement mills, iron – blast furnance and the fermentation of sugar or starch for production of ethyl alcohol and alcoholic beverages.

It is prepared industrially by the Bosch process

$$CO + H_2O \longrightarrow CO_2 + H_2$$

Laboratory preparation

Carbon dioxide can be prepared by burning carbon or carbon containing compounds (hydrocarbons) in excess of oxygen.

$$C + O_2 \longrightarrow CO_2$$

$$2C_2H_6 + 7O_2 \longrightarrow 4CO_2 + 6H_2O$$

(a) By the action of heat on carbonates or hydrogen carbonates

Examples:- $CaCO_3 \xrightarrow{Heat} CaO + CO_2$

$Mg(HCO_3) \xrightarrow{Heat} MgO + H_2O + 2CO_2$

(b) By the action of dilute acid on carbonates

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$$

$$MgCO_3 + H_2SO_4 \longrightarrow MgSO_4 + H_2O + CO_2$$

Properties of carbon dioxide

- It is colorless, odorless and tasteless.
- It is about 1 ½ times as dense as air.
- It is moderately soluble in water and its solubility increases with increasing pressure.
- If cooled under high pressure, it turns straight into a solid known as **dry ice** which sublimes at -78.5ºC.
- It extinguishes a lighted splint. It doesn't support combustion as well as it is non - combustible.
- When added to water form weakly acidic solution. Thus it is acidic oxide.

  $H_2O + CO_2 \rightleftharpoons H_2CO_3$

  Carbonic acid

  Carbon dioxide is reduced by burning magnesium.

  $CO_2 + 2Mg \longrightarrow C + 2MgO$

  CO_2 also reacts with bases to form salts known as carbonates.

  Example:- $CO_2 + 2NaOH \longrightarrow Na_2CO_3 + H_2O$

Test for CO_2: Lime water ($Ca(OH)_2$ solution is used to identify carbon dioxide. Lime water turns milky when CO_2 is passed through it due to the formation of calcium carbonate**.**

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

Uses of CO_2

- $CO_2$is used in photosynthesis, in the production of soda (Na_2CO_3) by Solvay process and $NaHCO_3$ (baking soda) which is used in the manufacture of baking powder.
- Carbon dioxide is used to pressurize soft drinks, mineral water and alcoholic beverages.
- Solid CO_2 (dry ice) is used as refrigerant to cool substances like ice cream and other perishables.
- Since CO_2 doesn't support combustion, it is used to extinguish fire.

C. Mineral coal

Coal is a complex mixture of compounds of carbon, hydrogen and oxygen together with a small amount of nitrogen, sulphur and phosphorous compounds. Mineral coal is formed in nature by bacterial decomposition of plant remains followed by the action of intense heat and pressure over a period of 250-300 millions of years.

Types of coal

There are varieties of coal which differ in age, hardness, carbon content and use. These varieties are named as *peat, lignite, bituminous and anthracite*.

1. **Peat:** It is formed during 1st stage of geological formation of mineral coal. It is soft and spongy. It contains about 55% carbon.
2. **Lignite or brown coal:** Contains too much water and gas and 65 - 70% carbon. It burns with smoky flame and used as local fuel.
3. **Bituminous:** A compact black substance containing 75-90% carbon. It is the most widely used of all varieties of mineral coal and it also burns with smoky flame.
4. **Anthracite:** Type of coal formed in the last stage of geological formation of mineral coal. It is the hardest and the oldest of all mineral coals, have high density and contains the highest percentage of carbon (about 95%) compared to other forms. Anthracite is low in water and volatile matter which burns with steady, clean hot, blue flame producing large amount of heat.

Coking of coal

Coking of coal is the process of converting mineral coal to coke and volatile products by destructive distillation at about 1000ºC. Destructive distillation is a process of heating a substance in absence of air or oxygen. When coal is destructively distilled, the products are *coal gas, ammonical liquor, coal tar* and *coke.*

(i) **Coal gas** contains 50% hydrogen, 30% methane, 8% carbon monoxide, 4% ethylene, 3.2% ethane and small amounts of N_2, CO_2, etc. It is used as fuel.

(ii) **Ammonical liquor** when distilled with lime, ammonia is evolved and absorbed in dilute sulphuric acid to yield ammonium sulfate, which is used as fertilizer.

(iii) **Coal tar** is used as a source of aromatic compounds. When coal tar is fractionally distilled, different aromatic compounds such as benzene, toluene, phenol, pitch, etc. are obtained.

(iv) **Coke** is used as a reducing agent in metallurgy and in producing gaseous fuels.

Gasification of coke

Coke is also used in producing gaseous fuels such as water gas and producer gas.

Water gas: It is a mixture of equal volumes of carbon monoxide and hydrogen made by passing steam over hot coke.

$$C + H_2O(g) \longrightarrow CO(g) + H_2(g)$$

Producer gas: It is a mixture of two volumes of carbon monoxide and one volume of nitrogen made by passing limited supply of air over cheap grade of coal or coke.

$$2C + \underset{\text{Air}}{O_2/N_2} \longrightarrow 2CO(g) + N_2(g)$$

Producer gas burns with a hot flame and used in the manufacture of glass, pottery and steel.

Activity 1

Form groups and make preparation on the following points

(a) Occurrence of carbon.

(b) Define allotropy and allotropes.

(c) List crystalline and amorphous allotropic forms of carbon. Explain their properties and uses.

(d) Write the occurrences, methods of preparation (industrial as well as laboratory) of carbon monoxide and carbon dioxide, their properties and uses.

(e) Name the different varieties of mineral coal and describe their uses.

(f) Define destructive distillation and name different products of destructive distillation of coal and the use of each product.

(g) Explain what water gas and producer gas means. Describe how these gaseous fuels are prepared.

(h) After you complete your preparations on the above points, produce presentation to your classmates.

Experiment 1

Laboratory preparation of carbon dioxide

Objective: To prepare carbon dioxide and perform chemical test for its identification.

Materials required: Sodium carbonate, calcium carbonate, 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 two conical flasks and add powdered Na_2CO_3 to the first, powdered $CaCO_3$ to the second. Pour dilute HCl into each of the two conical flasks until the acid covers the carbonates. 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 below

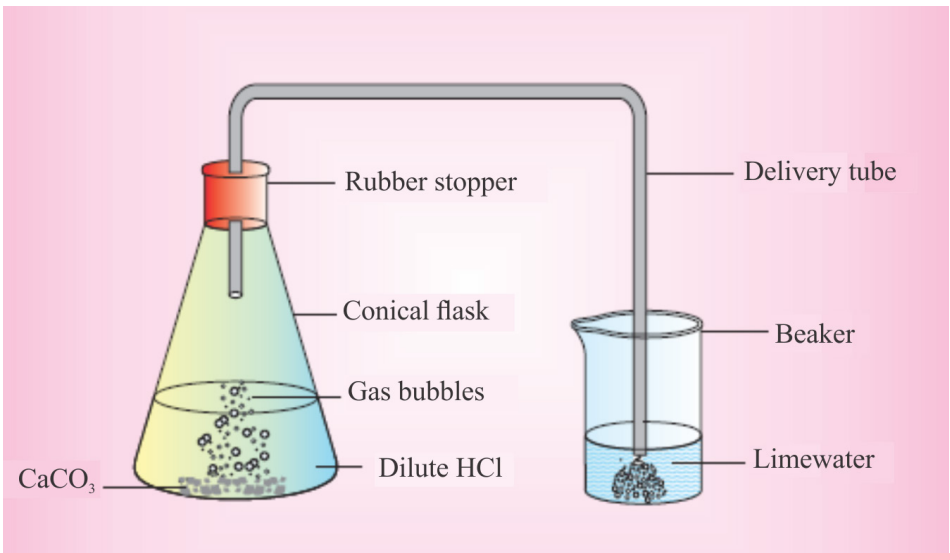


Figure 2. Test for carbon dioxide

2. Repeat the experiment using the same carbonates 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 color of the damp blue litmus paper change when you hold it close to the mouth of the conical flasks? What about the color of damp red litmus?

(c) What happened to the color 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.

4.2 Nitrogen and its Compounds

After completing this topic, you will be able to:

- apply the laboratory methods of preparing as well as testing for nitrogen as well as its compounds.
- discuss the uses of nitrogen.
- discuss the reactions of compounds of nitrogen.
- apply laboratory techniques to prepare and test for ammonia and nitric acid.
- occurrence and manufacturing of nitrogen.

Nitrogen is a non-metallic element. It occurs in nature in elemental state and in the form of compounds. In the elemental state, nitrogen gas constitutes about 78.08% by volume of the atmosphere.

In the form of compounds it occurs in the earth's crust as sodium nitrate ($NaNO_3$) also known as Chile salt peter and potassium nitrate (KNO_3) called salt peter.

It is also found in all living matter in proteins. The presence of fewer amounts of nitrogen compounds in the earth's crust is due to the inertness of nitrogen molecule.

Nitrogen is manufactured in industries by fractional distillation of liquid air or *fractional liquefaction of air*.

The separation of nitrogen and oxygen by fractional distillation of liquid air is based on the differences in their boiling points, nitrogen boils at -196ºC and solidifies at -210ºC and oxygen boils at -183ºC and solidifies at -214.4ºC.

In the laboratory pure nitrogen can be prepared by passing ammonia over heated copper (II) oxide.

$$2NH_3 + 3CuO \longrightarrow 3H_2O + 3Cu + N_2$$

Properties of nitrogen

- Nitrogen is colorless, odorless and tasteless gas.
- It is very slightly soluble in water.
- It is less dense than air.
- N_2 can be liquefied under high pressure and liquid nitrogen is stored in steel cylinder.

Experiment 2

Laboratory preparation of nitrogen

Objective: Prepare oxygen gas in the laboratory.

Materials required: NH_4Cl, $NaNO_2$, water, stand and clamp, gas jar and gas jar lid, Beehive shelf, delivery tube, Bunsen burner.

Procedure

1. Mix equivalents quantities of NH_4Cl and $NaNO_2$ and dissolve it in water.
2. Pour the mixture in a boiling tube and assemble the setup as in Figure 3.
3. Collect the gas by downward displacement of water.

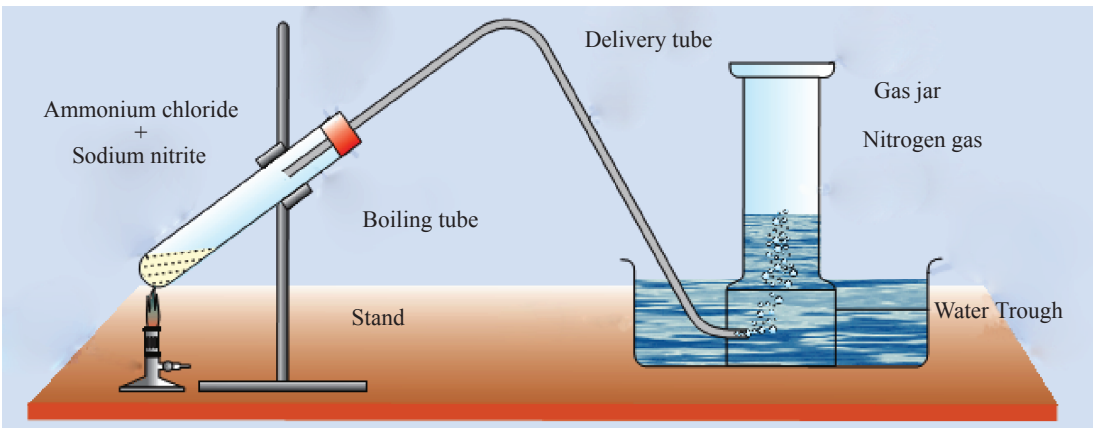


Figure 3. Laboratory Preparation of Nitrogen

Observation and analysis

(a) Do you observe formation of bubbles when a solution of NH_4Cl and $NaNO_2$ solution is heated?

(b) What gas is collected in the gas jar?

Ammonia

The name ammonia is derived from the Greek word "*ammoniac*" meaning *'salt of the sand'* which refers to ammonium chloride (NH_4Cl) a naturally occurring substance that would yield the gas.

Occurrence of NH_3

Traces of ammonia are found in the atmosphere and in the soil. Proteins in animals and plants produce ammonia on decay and decomposition. It is also found as ammonium salts in nature.

Laboratory preparation of ammonia

NH_3 is prepared in the laboratory by heating ammonium salt with a base.

$$2NH_4Cl + Ca(OH)_2 \xrightarrow{\text{Heat}} CaCl_2 + 2NH_3 + 2H_2O$$

Ammonia is lighter than air and is highly soluble in water.

Therefore, it is collected by downward displacement of air and not over water.

Experiment 3

Laboratory preparation and test for ammonia

Objective: Prepare ammonia gas in the laboratory.

Materials required: NH_4Cl, $Ca(OH)_2$, boiling tube, rubber stopper, delivery tube, drying tower, lime, stand and clamp, litmus paper.

Procedure

1. Mix equal masses of ammonium chloride and calcium hydroxide.
2. Moisten the mixture with water to make paste.
3. Place the mixture in a boiling tube and arrange the setup as shown in Figure 4.
4. Heat the mixture of ammonium chloride and calcium hydroxide on a Bunsen flame.
5. Collect two or three jars of ammonia gas by downward displacement of air, hold moist red litmus paper closer to the mouth of the gas jar.

Observation and analysis

1. Why is ammonia gas collected by downward displacement of air instead of downward displacement of water?
2. Does the color of wet red litmus changes when you bring it closer to the mouth of the jar?

3. Is the smell of the gas pleasant or unpleasant?

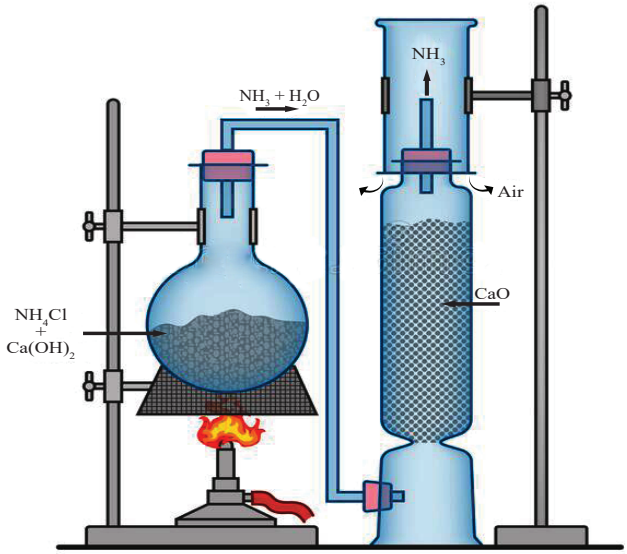


Figure 4. Laboratory Preparation of Ammonia

Result: When a mixture of ammonium chloride and calcium hydroxide is heated a pungent smelling gas is liberated. The gas is ammonia. It is collected by downward displacement of air but not by downward displacement of water. Because it is highly soluble in water. Ammonia changes the color of moist red litmus to blue indicating that it is basic.

Commercial production of NH_3

Ammonia is manufactured industrially by the *Haber's Process*. In this process ammonia is produced by direct combination of hydrogen and nitrogen in the volume ratio of 3:1, respectively, at high temperature and pressure in the presence of iron catalyst (A temperature of about 450-500ºC and pressure of 200-1000 atm is required)

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The reaction that forms ammonia is reversible. Thus, the ammonia gas is periodically removed by Liquefaction.

Physical properties of ammonia

- NH_3 is colorless gas with a choking (pungent) smell.
- It is lighter than air, turns damp red litmus blue.

- It is extremely soluble in water and water solution of ammonia is called ammonia water (ammonium hydroxide)
- Ammonia liquefies at -33.4ºC and solidifies at -78ºC.
- Liquid NH_3 is a clear colorless liquid.

Chemical properties of ammonia

1. Ammonia dissolves in water and react with it to form ammonium hydroxide which is a weak base and ionize only slightly.

$$NH_3(g) + H_2O(l) \rightleftharpoons NH_4OH(aq)$$

$$NH_4OH(aq) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

2. Ammonia burns in oxygen when heated to produce nitrogen monoxide.

$$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O$$

3. Ammonia gas reacts with hydrogen chloride gas to form a white fume (smoke) of solid ammonium chloride.

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

4. Ammonia is a reducing agent when passed over heated metallic oxides.

Examples

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

$$3PbO(s) + 2NH_3(g) \longrightarrow 3Pb(s) + N_2(g) + 3H_2O(g)$$

5. Ammonia or its aqueous solution reacts with acids to form ammonium salts.

Examples

$$NH_3(g) + H_2SO_4(aq) \longrightarrow (NH_4)_2SO_4(aq)$$

$$NH_4OH(aq) + HNO_3(aq) \longrightarrow NH_4NO_3(aq) + H_2O(l)$$

Uses of ammonia

Ammonia is used:

- in the manufacture of nitric acid by Ostwald process.
- in the production of soda by Solvay process.
- as a cleaning agent, to remove temporary hardness of water in refrigeration.
- in the production of ammonium fertilizers, dyes, explosives synthetic fibers, etc.

Nitric acid (HNO_3)

Laboratory preparation

Nitric acid is prepared by heating nitrate salt with concentrated sulfuric acid in a pyrex glass tube. nitric acid is formed as a vapor and should be condensed to get the liquid form.

$$NaNO_2(s) + H_2SO_4(l) \longrightarrow NaHSO_4(aq) + \underset{\text{Nitric acid vapor}}{HNO_3(g)}$$

Industrial preparation

Nitric acid is commercially prepared by the *Ostwald process.* This process involves catalytic oxidation of ammonia with oxygen from the air to form nitric oxide. Ammonia oxidizes to nitric oxide when passed through platinum wire gauze heated to a temperature of 900-1000ºC. The nitric oxide (NO) produced by the oxidation of ammonia reacts with excess oxygen to form nitrogen dioxide which is absorbed in water to form nitric acid.

$$4NH_3(g) + 5O_2(g) \xrightarrow{Pt} 4NO(g) + 6H_2O(g) \quad \text{.... step 1}$$

$$2NO(g) + O_2(g) \longrightarrow 2NO_2(g) \quad \text{.... step 2}$$

$$4NO_2(g) + O_2(g) + 2H_2O(l) \longrightarrow 4HNO_3(aq) \quad \text{.... step 3}$$

Arc method is also used for the production of nitric acid. In this process a mixture of elemental nitrogen and excess oxygen is subjected to strong electric discharge which causes nitrogen to combine with oxygen to form nitric oxide and the nitric oxide formed react with excess oxygen and form nitrogen dioxide. The nitrogen dioxide is then absorbed in water producing nitric acid.

Physical properties of nitric acid

- Pure nitric acid is a colorless liquid that boils at 83ºC and freezes at -42ºC. Ordinary concentrated nitric acid is 68% HNO_3 while fuming nitric acid is 96 - 98% HNO_3 and it is yellowish in color due to excess NO_2dissolved in it.
- It is miscible with water in all proportion. It fumes in air when the container is open.

Chemical properties of nitric acid

1. Nitric acid is one of the strongest acids and ionize almost completely to H^+ and NO_3^- ions.

$$HNO_3 \longrightarrow H^+ + NO_3^-$$

2. Nitric acid is stable in aqueous solution. When pure and heated it decomposes at higher temperature to give nitrogen dioxide, oxygen and water.

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

Nitric acid decompose slightly even at room temperature in presence of light.

3. Nitric acid is a powerful oxidizing agent. It oxidizes metals to salts called nitrates and it is reduced to nitrogen dioxide and water when concentrated, nitric oxide (NO) and water when diluted.

Examples

$$Cu(s) + 4HNO_3 \longrightarrow Cu(NO_3)_2(aq) + 2NO_2(g) + 2H_2O(g)$$

Concentrated

$$3Cu + 8HNO_3 \longrightarrow 3Cu(NO_3)_2(aq) + 2NO(g) + 4H_2O(l)$$

Dilute

- Dilute nitric acid does not liberate hydrogen gas when reacted with metals as other dilute acids do. However, reactive metals like calcium and magnesium, displace hydrogen from a very dilute nitric acid.

$$Mg\ (s) + 2HNO_3 \longrightarrow Mg(NO_3)_2(aq) + H_2(g)$$

4. A glowing splint begins to burn in fuming nitric acid, decomposing the acid into reddish - brown nitrogen dioxide gas and water.
5. Nitric acid reacts with bases to form salt and water, with carbonates to form salt, carbon dioxide and water.

Examples

$$Ca(OH)_2 + 2HNO_3 \longrightarrow Ca(NO_3)_2 + 2H_2O$$

$$MgCO_3 + 2HNO_3 \longrightarrow Mg(NO_3)_2 + CO_2 + H_2O$$

6. Aqua-regia, a mixture of three volumes of hydrochloric acid and one volume of nitric acid, dissolve metals like gold forming chloride salts of the metals.

Example

$$Au + 3HCl + HNO_3 \longrightarrow AuCl_3 + NO + 2H_2O$$

Uses of trioxonitrate(V) acid

Nitric acid is used in the manufacture of nitrogen fertilizers, plastics, artificial fiber, dyes, drugs, and explosives like nitroglycerine and trinitrotoluene (TNT).

Activity 2

Form groups and prepare group presentations on the following points:

(a) Occurrence of nitrogen.

(b) Laboratory preparation and industrial production of nitrogen.

(c) Properties and uses of nitrogen.

(d) Laboratory preparation and industrial production, properties and uses of ammonia.

(e) Laboratory preparation, industrial production (Ostwald process) of nitric acid.

(f) Properties, reactions, uses and salts of nitric acid.

After preparing appropriate note on the above points, produce presentations to the rest of the class.

Experiment 4

Test for nitrates

Objectives: To identify the presence of nitrate in a solution.

Materials Required: Test tube, test tube rack, beaker, nitrate salt solution, iron(II) sulfate 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) sulfate 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 the 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?

4.3 Oxygen

After completing this topic, you will be able to:

- apply the laboratory methods of preparing as well as testing for oxygen as well as its compounds,
- discuss the uses of oxygen,
- discuss the reactions of compounds of oxygen,
- discuss the industrial method of preparation of oxygen.

Occurrence of oxygen

Oxygen occurs in nature in the free state and in the form of compounds. In elemental state it occurs in atmospheric air in the form of molecular oxygen, O_2 and ozone O_3. It make up about 21% of the atmospheric air by volume. It constitutes about 49% by weight of the earth's crust in the form of compounds such as oxides, silicates, carbonates, phosphates, etc.

Preparation of oxygen

A. Laboratory preparation

Oxygen gas can be prepared in the laboratory by decomposition of hydrogen peroxide, H_2O_2 or mercury(II) oxide, HgO or potassium chlorate, $KClO_3$.

(i) Oxygen gas is prepared by decomposing hydrogen peroxide in the presence of manganese(IV) oxide as a catalyst.

$$2H_2O_2 \xrightarrow{MnO_2} 2H_2O + O_2$$

(ii) When mercury(II) oxide is heated, it decomposes to mercury and oxygen gas.

$$2HgO \xrightarrow{Heat} 2Hg + O_2$$

(iii) Oxygen is prepared by gently heating potassium chlorate mixed with some manganese(IV) oxide catalyst. Gentle heat is required because potassium chlorate is explosive.

$$2KClO_3 \xrightarrow{MnO_2} 2KCl + 3O_2$$

Oxygen gas prepared in all these methods is collected by downward displacement of water.

Experiment 5

Laboratory preparation and test for oxygen

Objective: To prepare oxygen gas and carryout a simple test for its identification.

Materials required: Manganese(IV) oxide, hydrogen peroxide, round bottom flask, stand and clamp, delivery tube, rubber stopper, water, three or four gas jar and gas jar lid, Pneumatic trough, Beehive shelf and spatula.

Procedure

1. Take two spatula full of manganese(IV) oxide and add into the round bottom flask
2. Fill the dropping funnel with hydrogen peroxide and arrange the setup as shown in Figure 3

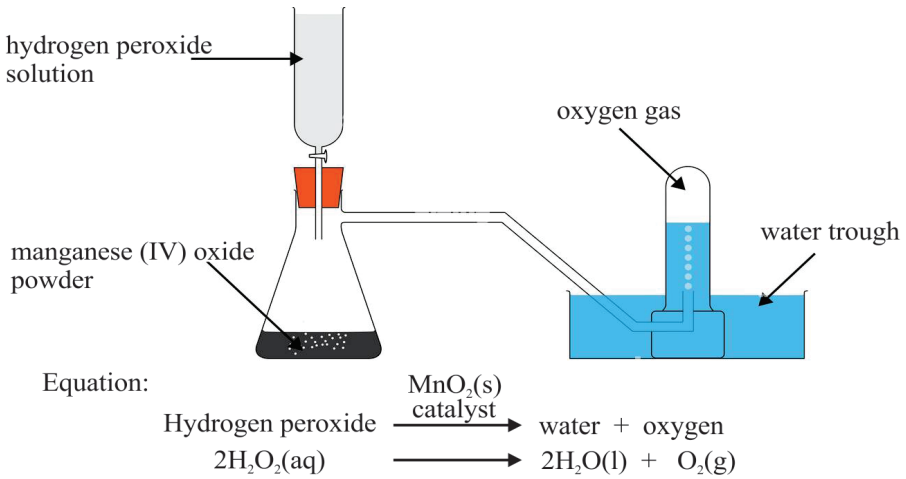


Figure 5. Laboratory preparation of oxygen

3. Start pouring hydrogen peroxide from the dropping funnel by opening the stopcock and collect two or three jars of oxygen gas by downward displacement of water.
4. Take one gas jar full of oxygen and insert a glowing splint of wood into it, repeat the same procedure using a burning splint.

Observation and analysis

(a) What did you observe when hydrogen peroxide is poured on to manganese(IV) oxide?

(b) What happened to the glowing splint of wood when you insert it into the gas jar?

(c) What did you observe when you insert a burning splint of wood into the jar of oxygen?

Result: When hydrogen peroxide is poured on manganese(IV) oxide, bubbles of gas escape from the surface. This shows that a gas is liberated. When a glowing splint of wood is inserted into a jar of oxygen gas, the splint will be relighted. A burning splint continues to burn with a bright light when inserted in a gas jar of oxygen gas.

Industrial production of oxygen

Oxygen is manufactured on industrial scale by fractional distillation of liquid air. To obtain liquid air, first carbon dioxide and water vapor are removed from the air using lime water and silica gel, respectively.

The air which is free of water vapor and carbon dioxide is then compressed to a very high pressure of about 200 atmospheres. As cooling continues, the air liquefies to a pale-blue liquid containing nitrogen (boiling point -196°C) and oxygen (boiling point -183°C). Fractional distillation is carried out in a very cold fractionating tower and nitrogen boils off first and the remaining pale-blue liquid is oxygen.

Properties of oxygen

- Oxygen is colorless, odorless and tasteless gas at ordinary temperature.
- It is slightly soluble in water and slightly denser than air.
- Oxygen doesn't burn but it supports combustion (causes other substances to burn.
- Oxygen relights a glowing splint of wood and a candle burns with a bright light in oxygen. This can be used as method of identification of oxygen gas.

Uses of oxygen

- It is essential for burning substances.
- It is used in oxyacetylene flame (flame used for cutting and welding metals).
- It oxidizes the organic matter in foods that we eat and supply energy to our body.
- It is used to remove impurities such as carbon, sulfur, phosphorus, etc. during iron and steel production.
- It is used to support breathing to help patients in hospitals, astronauts, divers, mountain climbers, etc.
- Liquid oxygen is used to burn the fuels in space rockets.

Oxides

Chemically, 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 two elements only. Oxides are classified as:

- acidic oxides,
- basic oxides,
- amphoteric oxides,
- neutral oxides and
- peroxides.

Acidic oxides

Acidic oxides are oxides formed by the chemical combination of oxygen with non-metals. Thus, mostly acidic oxides are non-metal oxides and a few metal oxides are acidic, for example, CrO_3. These oxides are also called *acid anhydrides*, since they form acidic solutions when reacted or dissolved in water. Acid anhydride means acid without water.

Examples of acidic oxides include carbon dioxide, CO_2, nitrogen dioxide, NO_2, and sulfur 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 (acid anhydrides) dissolve in water to form acidic solutions (acids).

$$\text{Acid anhydride} + \text{Water} \longrightarrow \text{Acid}$$

Examples

$$CO_2 + H_2O \longrightarrow H_2CO_3 \quad \text{(Carbonic acid)}$$

$$N_2O_3 + H_2O \longrightarrow 2HNO_2 \quad \text{(Nitrous acid)}$$

$$SO_2 + H_2O \longrightarrow H_2SO_3 \quad \text{(Sulphurous acid)}$$

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

$$\text{Acidic oxide} + \text{Basic oxide} \longrightarrow \text{Salt}$$

Examples

$$CO_2 + Na_2O \longrightarrow Na_2CO_3$$

$$SO_3 + CaO \longrightarrow CaSO_4$$

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

$$\text{Acidic oxide} + \text{Base} \longrightarrow \text{Salt} + \text{Water}$$

Examples

$$SO_2 + 2NaOH \longrightarrow Na_2SO_3 + H_2O$$

$$CO_2 + 2LiOH \longrightarrow Li_2CO_3 + H_2O$$

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 later section. 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.

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

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

$$\text{Basic oxide} + \text{Water} \longrightarrow \text{Base (Alkali)}$$

Examples

$$Li_2O + H_2O \longrightarrow 2LiOH$$

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

Basic oxides react with acidic oxides to form salts.

$$\text{Basic oxide} + \text{Acidic oxide} \longrightarrow \text{Salt}$$

Examples

$$BaO + SO_3 \longrightarrow BaSO_4$$
$$CaO + CO_2 \longrightarrow CaCO_3$$

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

$$\text{Basic oxide} + \text{Acid} \longrightarrow \text{Salt} + \text{Water}$$

Examples

$$CaO + 2HCl \longrightarrow CaCl_2 + H_2O$$
$$CuO + H_2SO_4 \longrightarrow CuSO_4 + H_2O$$

Amphoteric oxides

There are oxides which exhibit both acidic and basic properties. They 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 behavior of aluminum oxide, Al_2O_3.

$$\text{Amphoteric oxide} + \text{Acid} \longrightarrow \text{Salt} + \text{Water}$$
$$Al_2O_3\,(s) + 6HCl\,(aq) \longrightarrow 2AlCl_3\,(aq) + 3H_2O\,(l)$$
$$\text{Amphoteric oxide} + \text{Base} \longrightarrow \text{Water} + \text{Salt}$$
$$Al_2O_3\,(s) + 2NaOH\,(aq) \longrightarrow \underset{\text{Sodium aluminate}}{2NaAlO_2\,(aq)} + H_2O\,(l)$$

Some other examples of amphoteric oxides are ZnO, PbO, PbO_2, SnO, and SnO_2.

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.

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.

4.4 SULFUR

After completing this topic, you will be able to:

- discuss the uses of sulfur,
- discuss the reactions of compounds of sulfur,
- discuss the industrial method of extraction of sulfur.

Sulfur is one of the elements known to the ancient. It was used by Egyptians as yellow coloring and by alchemists in attempts to produce gold. It is a non-metallic element which belongs to group VIA (oxygen family)

Occurrence of sulfur

Sulfur makes up about 0.05% of the earth's crust. It exists in nature in elemental state and in the form of compounds. In elemental state it is found on the surface of the earth in volcanic areas and underground deposits. In the form of compounds it exists mainly as sulfides and sulfates such as galena (PbS), cinnabar (HgS), iron pyrite (FeS_2), gypsum ($CaSO_4 \cdot 2H_2O$) and in volcanic gases as hydrogen sulfide (H_2S), sulfur dioxide (SO_2) and as constituent of naturally occurring organic matter.

Extraction of sulfur

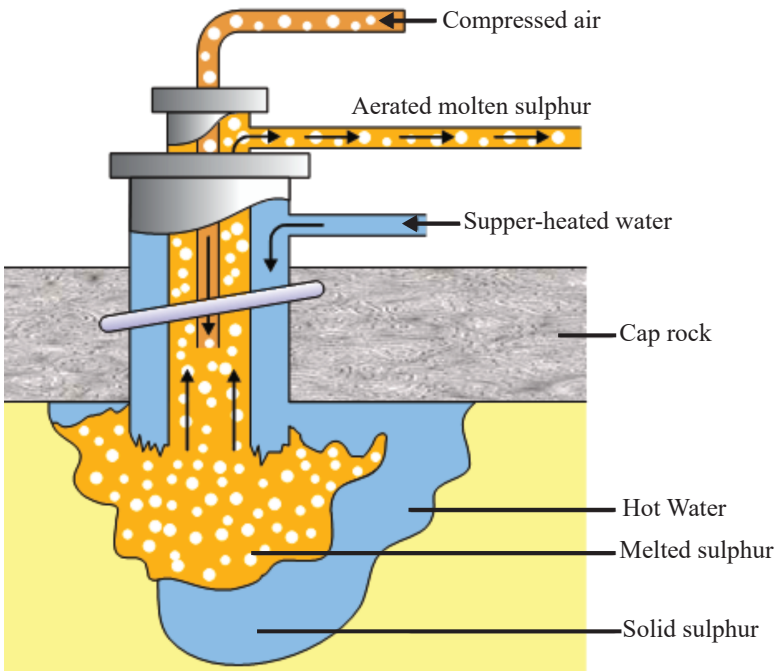


Figure 6. Frasch Process for Extraction of Sulfur

Sulfur is extracted by the *Frasch process* (named after the German-American chemist and engineer Herman Frasch). In this process, a hole is drilled into the sulfur bed and three concentric pipes are sent down till they reach the deposit. Super heated water at a temperature of 170°C and a pressure of 7 atmospheres is forced through the outer most pipe to melt the sulfur at the bottom (melting point of sulfur is 114.5°C). Hot compressed air is pumped down through the inner most pipe and mixes with the molten sulfur to form a froth that rises through the middle pipe up to the surface of the earth and pumped into large vats where it cools and solidifies.

Physical properties of sulfur

- Sulfur is a pale yellow, brittle solid and tasteless.
- It melts at a temperature of 114.5°C and boils at 444°C producing dark brown vapor.
- It is soluble in carbon disulfide (CS_2).
- Sulfur is one of the elements exhibiting allotropy. The allotropic forms of sulfur are rhombic sulfur, monoclinic sulfur and plastic sulfur.

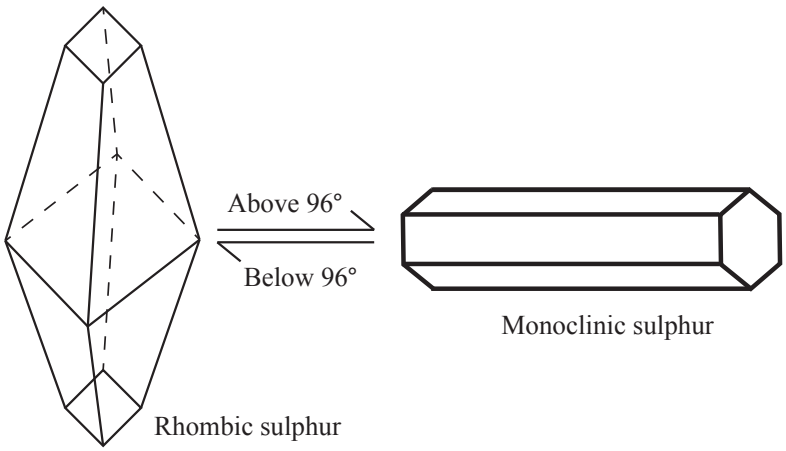


Figure 7. Structures of rhombic and monoclinic sulfur

A. Rhombic (α) sulfur is the common type of sulfur. It is the most stable crystalline form into which all other forms change at room temperature.

- It melts at 112°C and has a density of 2 g/cm^3.
- It is insoluble in water but soluble in carbon disulfide.

- It is stable form of sulfur below 96ºC. At 96ºC it changes slowly to the monoclinic form.

B. Monoclinic (prismatic or β) sulfur is made when sulfur is melted and cooled. It crystallizes in the form of long, needle-like transparent crystals of monoclinic sulfur.

- Monoclinic sulfur is stable between 96°C and melting point of sulfur (114.5°C) below 96ºC it changes to the rhombic form.
- It is also soluble in carbon disulfide.
- Both crystalline forms of sulfur, rhombic and monoclinic sulfur consists of S_8 molecules containing eight sulfur atoms per molecule, but they have different crystalline shapes.

C. Amorphous (plastic) sulfur is a non-crystalline or amorphous modification of sulfur. It is made when boiling sulfur is poured into cold water. It is a rubber like mass and named as plastic sulfur. When allowed to stand for some time at room temperature it changes to the rhombic form.

Chemical properties of sulfur

Sulfur burns in air when heated with pale–blue flame forming sulfur dioxide.

$$S + O_2 \longrightarrow SO_2$$

Sulfur dioxide is readily soluble in water and reacts with it to form sulfurous acid which is a weak acid and exists only in aqueous solution.

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

Salts of sulfurous acid are called sulfites. For example, calcium sulfite, $CaSO_3$ is a salt of sulfurous acid.

Uses of sulfur

Sulfur is used:

- In the manufacture of sulfuric acid.
- In producing compounds used in bleaching wood pulp in paper industry.
- In the manufacture of fungicides, insecticides, dyes, explosives, gun powder, matches, carbon disulfide and in vulcanization of rubber.

Sulfuric acid (H_2SO_4)

Manufacturing of sulfuric acid

Most of the world's supply of sulfuric acid is manufactured by *Contact process*. In this process, sulfur dioxide and oxygen are the starting materials. The sulfur oxide may be made either by burning sulfur or by roasting sulfide ores.

In Contact process

(i) Both SO_2 and O_2 (from the air) are cleaned, dried and then allowed to react in presence of vanadium (V) oxide (vanadium pentoxide, (V_2O_5) at high temperature to form SO_3.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

(ii) The sulfur trioxide produce is absorbed in concentrated sulfuric acid (96-98% by mass) to form fuming sulfuric acid or pyrosulfuric acid or oleum.

$$SO_3(g) + H_2SO_4(l) \rightleftharpoons H_2S_2O_7\ (oleum)$$

(iii) The oleum is diluted with water to form commercial sulfuric acid (oil of vitriol) or concentrated sulfuric acid which is 96 – 98% H_2SO_4 by mass and 18 molar H_2SO_4

$$H_2S_2O_7 + H_2O \longrightarrow 2H_2SO_4$$

Properties of sulfuric acid

Pure H_2SO_4 is colorless, heavy oily liquid with specific gravity of 1.84 g/cm^3 that freezes at 10.4°C and boils at 290°C. It is extremely hygroscopic (absorb water) from the air. Hot concentrated sulfuric acid is an oxidizing agent. It reacts with many metals to liberate sulfur dioxide gas

Example

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

Concentrated sulfuric acid is dehydrating agent. It removes water from other substances.

Examples

(i) $CuSO_4 \cdot 5H_2O \xrightarrow[H_2SO_4]{\text{Concentated}} CuSO_4 + 5H_2O$

Blue White

(ii) When concentrated sulfuric acid is added to sugar (sucrose), the sugar turns black due to removal of water from its molecules.

(iii) $C_{12}H_{22}O_{11} \xrightarrow[H_2SO_4]{\text{Concentated}} 12C + H_2SO_4 \cdot 11H_2O$

Sucrose

It also reacts with organic acids and liberates CO or CO_2.

Examples

$HCOOH \xrightarrow[H_2SO_4]{\text{Concentated}} CO + H_2O$

Formic acid

$HOOC - COOH \xrightarrow[H_2SO_4]{\text{Concentated}} H_2O + CO + CO_2$

Oxalic acid

Sulfuric acid is one of the strongest acids. It neutralizes most bases and basic oxides to form sulfate and hydrogen sulfate salts. Examples are calcium sulfate, $CaSO_4$, magnesium hydrogen sulfate, $Mg(HSO_4)_2$, etc.

Experiment 6

Test for sulfates

Objective: To identify for the presence of sulfate using barium salts.

Materials required: Beakers, test tubes, and test tube rack, any soluble sulfate salt (such as sodium sulfate), 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. What is the name of 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.

Result: Formation of white precipitate, $BaSO_4$, indicates the presence of sulfate ions in the solution. Few drops of dilute HCl are added to the solution to be tested to avoid confusion. That is, ions like CO_3^{2-} can form a white precipitate with Ba^{2+}. However, HCl dissolves compounds like $BaCO_3$ but not $BaSO_4$.

Uses of sulfuric acid

Sulfuric acid is the leading industrial chemical in global consumption. It is used:

- In the manufacturing of sulfate fertilizers, explosives, dyes, paints, artificial fibers, detergents, plastics and drugs.
- In petroleum refining, as electrolyte in lead storage (car) batteries and as drying agent for non-basic gases.

Hydrogen sulfide (H_2S)

Hydrogen sulfide is a constituent of volcanic gases. It is prepared in the laboratory by the action of hydrochloric acid on sulfide salts such as iron(II) sulfide

$$FeS + 2HCl \longrightarrow FeCl_2 + H_2S$$

Hydrogen sulfide gas is collected by upward displacement of air or downward displacement of hot water. H_2S is insoluble in hot water.

Properties of hydrogen sulfide

- It is colorless gas with a smell of rotten eggs.
- Denser than air, fairly soluble in cold water forming weakly acidic solution.
- It is poisonous and causes headache and nausea in small amounts and can cause fainting in a large amount.
- It is identified by its odor or using lead acetate solution which forms a black precipitate of lead sulfide, PbS when bubbled through the solution.

Experiment 7

Laboratory preparation of hydrogen sulfide

Objective: To prepare hydrogen sulfide gas in a laboratory.

Materials required: FeS, dilute hydrochloric acid, stand and clamp, thistle funnel, delivery tube rubber stopper, gas jar and gas jar lid, litmus paper.

Procedure

1. Add iron(II) sulfide in a conical flask and arrange the setup as shown in Figure 8.
2. Add some dilute HCl solution through the thistle funnel.
3. Collect the gas produced in a gas jar by upward displacement of air.
4. Insert moist blue litmus paper into the gas jar and observe the change.

5. Insert strip of filter paper soaked in lead nitrate solution into another gas jar and see what happens.

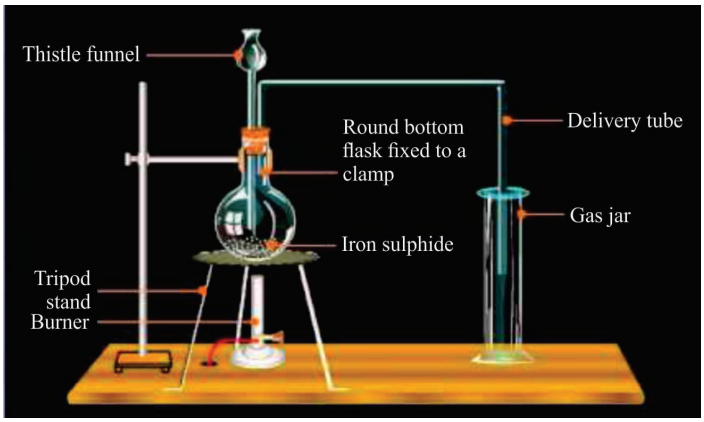


Figure 8. Laboratory Preparation of hydrogen sulfide

Observation and analysis

1. What is the smell of the gas produced?
2. What happened to the color of moist blue litmus when inserted into the gas jar?
3. Do you see any change on the filter paper when introduced in to the gas jar?

Result: Hydrogen sulfide gas has a smell of rotten eggs. It changes the color of moist blue litmus to red indicating that H_2S is acidic. There is formation of black substance on the filter paper which is lead sulfide, PbS.

4.5 The Halogens

After completing this topic, you will be able to:

- discuss the halogens and their means of identification,
- discuss methods of production of halogens, their uses and uses of their compounds.

The elements Fluorine, Chlorine, Bromine, Iodine and Astatine are elements belonging to group VIIA of the Periodic Table.

Their atoms all have seven valence electrons and collectively known as halogens. Halogen is a Greek word which means salt producer. All the halogens occur in nature as halide salts with the exception of astatine which is radioactive element and short lived. All of them with the exception of astatine are non-metallic reactive elements.

A. Occurrence and extraction of Fluorine

Fluorine The name fluorine is derived from the Latin word "fluor" meaning to flow. Fluorine occurs in nature in the form of compounds such as fluorite (CaF_2), fluoroaptite $Ca_{10}(PO_4)_6 \cdot F_2$, cryolite ($Na_3AlF_6$) and also in sea water, teeth, bones and blood.

Since fluorine is a strong oxidizing agent it can not be produced by chemical oxidation of fluorine ion. In industries fluorine is manufactured by electrolysis of a molten mixture of KF and HF in a monel cell (monel metal is an alloy of Ni, Cu, Fe and Al)

$$2KHF_2 \xrightarrow{\text{Electrolysis}} \underset{\text{Anode}}{F_2(g)} + \underset{\text{Cathode}}{H_2(g)} + 2KF$$

Properties of fluorine

In the elemental state all halogens exists as diatomic molecules (X_2). Fluorine is pale – yellow gas with melting point of -218ºC and boiling point of -188ºC and 1.3 times as dense as air.

Uses of fluorine and its compounds

Fluorine

- Is used to make fluorinated organic compounds which are used as refrigerants (example, CCl_2F_2), plastic such as PTFE $(-CF_2-CF_2-)_n$, which is used for non - stick surface on cooking utensils) and insecticides (CCl_3F).
- Gaseous fluorine is used in producing uranium hexafluoride (UF_6) which is used to separate isotopes of uranium for nuclear reactors.
- It is used to produce hydrofluoric acid.

Modern researchers have proved that the use of chloro – fluoro carbon compounds cause series pollution problems, since they damage the ozone layer of the atmosphere.

B. Occurrence and extraction of Bromine

The word bromine is derived from the Greek word "*bromos*" meaning "*stench*" (stench means very unpleasant). It is less abundant than chlorine and fluorine. It occurs mainly as NaBr, KBr, $MgBr_2$ and $CaBr_2$ in salt water and salt beds.

Bromine is commercially prepared by the oxidation of the bromide ion of sea water with chlorine. It is recovered commercially through the treatment of sea water with chlorine gas and flushing through with air.

$$Cl_2(g) + 2Br^-(aq) \longrightarrow 2Cl^-(aq) + Br_2(l)$$

Properties of bromine

Bromine is easily volatile, dark reddish-brown liquid with a strong disagreeable odor and an irritating effect on the eyes and throat.

It produces painful sores when spilled on the skin. It melts at -7.1ºC and boils at -59ºC.

Uses of bromine and its compounds

Bromine is used in the production of 1,2-dibromo ethane (C_2H_4Br) a component of leaded gasoline, in producing silver bromide (AgBr) for light sensitive eye-glasses and photographic film, sodium bromide (NaBr) a mild sedative and methyl bromide (CH_3Br) a fumigant insecticide and to produce hydrobromic acid, HBr.

C. Occurrence and extraction of Iodine

The word iodine is originated from the Greek word "*iodos*" meaning "*violet* or *purple*". Iodine occurs in small amount in sea water as I^-, sodium iodate ($NaIO_3$) in deposits of Chile salt peter ($NaNO_3$) and in the thyroid gland.

Iodine can be recovered through the oxidation of I^- from salt water with chlorine gas and flushing though with air.

$$2I^-(aq) + Cl_2(g) \longrightarrow 2Cl^-(aq) + I_2(l)$$

Iodine is manufactured commercially by the reduction of sodium iodate with sodium hydrogen sulfite ($NaHSO_3$).

$$2NaIO_3 + 5NaHSO_3 \longrightarrow 3NaHSO_4 + 2Na_2SO_4 + H_2O + I_2$$

Properties of iodine

Iodine is a black crystalline solid with metallic luster. On gentle warming, it sublimes to give a beautiful blue-violet vapor. It is almost insoluble in water but readily soluble in chloroform ($CHCl_3$), carbon disulfide, CS_2, alcohol and ether. Iodine melts at 114ºC and boils at 184ºC.

Uses of iodine and its compounds

- Iodine is used as antiseptic and germicide in the form of iodine tincture (solution of iodine in alcohol).
- KI present in iodized salt prevents goiter.
- Silver iodide (AgI) is used in making photographic films and in 'cloud seeding' to cause artificial rain.
- I_2 is used to produce hydroiodic acid, HI.

D. Occurrence and Production of Chlorine

The word chlorine is originated from the Greek word "*chloros*" meaning "*yellowish-green*". Chlorine is the most abundant element among the halogens. It occurs in nature largely as NaCl and also as KCl, $MgCl_2$, $CaCl_2$ in sea water and in gastric juice as HCl.

Commercially, chlorine is manufactured by electrolysis of concentrated aqueous sodium chloride solution. When concentrated NaCl solution is electrolyzed, chlorine gas is liberated at the anode, hydrogen gas at the cathode and caustic soda (NaOH) is formed in the solution. The equation for the electrolysis process is as follows

$$2NaCl + 2H_2O \xrightarrow{\text{Electrolysis}} \underset{\text{Cathode}}{H_2(g)} + \underset{\text{Anode}}{Cl_2(g)} + 2NaOH(aq)$$

Chlorine gas is also manufactured during the extraction of sodium by the electrolysis of molten sodium chloride.

Laboratory preparation of chlorine

Chlorine is prepared in the laboratory by:

1. Heating a mixture of concentrated hydrochloric acid, HCl, and manganese (IV) oxide.

$$4HCl(aq) + MnO_2(s) \xrightarrow{\text{Heat}} MnCl_2(aq) + Cl_2(g) + 2H_2O(l)$$

2. Heating a mixture of manganese(IV) oxide, sodium chloride, NaCl and concentrated sulfuric acid, H_2SO_4. The equation for the reaction is:

$$2NaCl(s) + 2H_2SO_4(aq) + MnO_2(s) \xrightarrow{\text{Heat}} Na_2SO_4(aq) + MnSO_4(aq) + 2H_2O(l) + Cl_2(g)$$

Chlorine gas produced by the above reactions can be collected by upward displacement of air.

Note

The laboratory preparation of chlorine should be performed under a fume hood not in an open air.

Experiment 8

Laboratory preparation of chlorine

In this method, manganese(IV) oxide is taken in a flask and concentrated hydrochloric acid is added drop by drop with the help of thistle funnel.

By doing this, chlorine gas starts forming rapidly, which is first passed into water and then passed into concentrated sulfuric acid and collected in a gas jar by upward displacement of air.

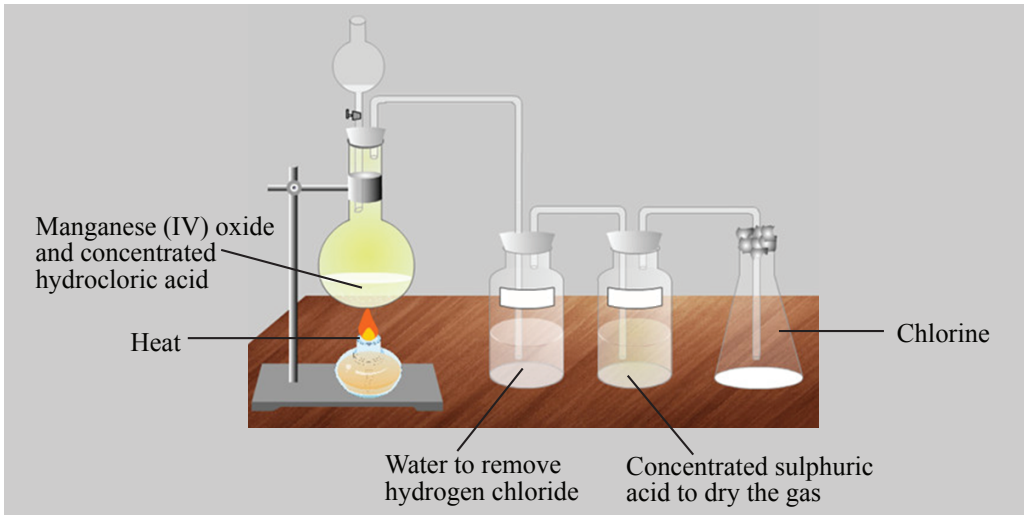


Figure 9. Laboratory preparation of chlorine

Properties of chlorine

Chlorine is greenish yellow gas with a sharp irritating and suffocating odor. It melts at -101ºC and boils at -35ºC and it is about 2½ times as dense as air.

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

$$2Fe\ (s) + 3Cl_2\ (g) \longrightarrow 2FeCl_3\ (s)$$

$$2Al\ (s) + 3Cl_2\ (g) \longrightarrow 2AlCl_3\ (s)$$

Chlorine reacts smoothly with hydrogen, in the presence of a charcoal as a catalyst, at room temperature to form hydrogen chloride.

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

Chlorine displaces less reactive halogens (Br_2 and I_2) from aqueous solutions of their compounds.

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

$$Cl_2\ (g) + 2Kl\ (aq) \longrightarrow 2KCl\ (aq) + l_2\ (s)$$

Chlorine dissolves in water and reacts with it, forming an acidic solution containing hydrochloric acid (HCl) and hypochlorous acid (HOCl).

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

This type of reaction is called a *disproportionation* reaction, where chlorine is itself reduced and oxidized.

Activity 3

Determine the oxidation number of chlorine in HCl and HOCl. Do you see any difference in oxidation number of chlorine in the two compounds? Can you explain why the above reaction is said to be disproportionation reaction?

Uses of chlorine and its compounds

- Chlorine is a germicide and used to disinfect drinking water and water in swimming baths.
- It is used in the production of solvents for dry cleaning such as carbon tetrachloride (CCl_4) and tetrachloroethylene (C_2Cl_4), antiseptic like chloroform ($CHCl_3$), plastics like polyvinyl chloride (PVC), insecticides like D.D.T, gammexane (benzene hexachloride, $C_6H_6Cl_6$), in the production of HCl.
- Cl_2 is used to bleach various substances and to produce bleaching powders like sodium hypochlorite (NaClO), calcium hypochlorite ($Ca(ClO)_2$) or

Ca(ClO)Cl which are used in house hold bleaches and in industries as bleaches for wood pulp, textiles, like cotton and linen.

- NaCl is used to prepare food and as medicine, KCl is used as a fertilizer, AgCl in making photographic films.

Experiment 9

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?
3. Name the compound formed as the yellow precipitate.
4. What did the formation of the deep-yellow precipitate in the third test tube confirm? Name the compound formed as the yellow precipitate.
5. What happened to the contents in the three test tubes, when ammonia solution was added to each of the test tubes?
6. Write balanced chemical equations for the reactions taking place in each test tube.

Result: The formation of the white precipitate in the first test tube indicates the presence of chloride ions. The white precipitate is silver chloride, AgCl.

The formation of the yellow precipitate in the second test tube indicates the presence of bromide ions. The yellow precipitate is silver bromide, AgBr.

The formation of the yellowish-green precipitate in the third test tube indicates the presence of iodide ions. The white precipitate is silver iodide, AgI.

If ammonia solution is added to each test tube the precipitate in the first test tube AgCl, will dissolve, the precipitate in the second, AgBr will dissolve partly, while the precipitate in the third, AgI, will remain unaffected (undissolved).

4.6 The Noble Gases

The elements helium, neon, argon, krypton, xenon and radon are called noble gases or inert gases. This is because they are inert towards most chemical substances and do not react to form compounds under ordinary conditions.

The first indication of the existence of an inert constituent in the atmosphere came in 1785 when Henry Cavendish found that he could not convert atmospheric nitrogen completely to nitrous acid.

In 1894, however Lord Rayleigh and William Ramsay showed that the "atmospheric" nitrogen was a mixture of nitrogen and a heavier, previously undiscovered gas. This gas turned out to be a new element that was given the name "argon", on account of its chemical inactivity (from the Greek word, *argon,* meaning inactive, Helium), He, another noble gas, had been detected earlier by Pierre Janssen in 1868 using the spectrum of sunlight. However, it was not accepted as an element until William Ramsay discovered in 1894 that helium also exists on earth.

The discovery of the other noble gases followed rapidly by 1900 they had all been isolated and identified. Ramsay and his assistant, Morris Travers, in continuing their research on argon, made use of newly developed methods for liquefying gases. The earth's atmosphere consists mainly of nitrogen (78%), oxygen (21%), and argon (1%), which have boiling points sufficiently different (-195.8°C, -182.96°C, and -185.7°C, respectively) that they can readily be separated by fractional distillation of liquid air. As Ramsay and Travers improved their techniques, they found that they could obtain several more fractions when distilling liquid air. Three of these fractions contained elements never before isolated, namely, neon (Greek, *neos,* new), krypton (Greek, *kryptos,* hidden), and xenon (Greek, *xenon,* stranger). The final noble gas to be discovered was radon.

Occurrence and production

The atmosphere is our major source for neon, argon, krypton, and xenon, and these gases are now produced commercially as a by-product during fractional distillation of liquid air to produce liquid oxygen and nitrogen. Liquefaction of thousands

of tons of air per day makes these four gases available in sufficient quantities for present needs.

Uses

Many of the uses of these gases are outgrowths of their inertness. The greater abundances, and hence lower costs of helium and argon result in their use as inert atmospheres in which to weld and fabricate metals. The electrical and other properties of the noble gases make most of them ideal gases for filling numerous types of electronic tubes and in lasers. For this, the gases may be used singly or mixed with one or more of the others. Perhaps the best known use is in the familiar "neon" advertising signs. The glow produced by neon alone is red. The other gases produce less brilliant colors: helium (pale pink), argon (blue), krypton (pale blue), and xenon, (blue-green). Helium, because of its lightness, finds use as a lifting gas for balloons and airships, although it is heavier than hydrogen. This weight disadvantage, however, is far overbalanced by the fact that helium is nonflammable. Recently, helium has been used as a cooling medium in nuclear reactors, and it is also a diluents for oxygen in breathing systems for deep-sea divers. Helium being less soluble in the blood than nitrogen, the helium-oxygen mixture is preferable to normal air for persons working under pressure, since its use tends to prevent "the bends", a serious condition caused by gas bubbles in the body fluids and tissues.

Radon has been used as a source of *gamma rays* for treatment of cancer, but more convenient gamma-ray sources produced in nuclear reactors now are more frequently chosen for medical therapy.

4.7 Water and Solution

After completing this topic you will be able to:

- demonstrate laboratory methods in testing for softness and hardness of water.

When one substance dissolves into another, a solution is formed.

- A solution is a homogenous mixture consisting of a solute dissolved into a solvent.
- The solute is the substance that is being dissolved
- Solvent is the dissolving medium.

Solutions can be formed with many different types and forms of solutes and solvents. In this section, we will focus on solution where the solvent is water. Water is very

important solvent used to make solutions. Most chemical processes take place in living organisms in water solutions. Water is considered as a universal solvent as it dissolves many substances.

An aqueous solution *is water that contains one or more dissolved substance.* The dissolved substances in an aqueous solution may be solids, gases, or other liquids. For example, sugar dissolves in water to make aqueous solution of sugar. Ethyl alcohol dissolves in water to make an aqueous solution of ethyl alcohol, etc. Water sample that contains dissolved solid, liquid or gas is considered as an aqueous solution.

Regardless of its place of origin, water contains the elements hydrogen and oxygen combined chemically in 1: 8 ratios by mass. The percentages of hydrogen and oxygen in water are 11.1% and 88.9% by mass, respectively. A water sample containing hydrogen and oxygen in these mass ratios is said to be chemically pure water. Samples of water from different natural sources may not be chemical pure water. This is because the samples may contain dissolved solids, liquids or gases.

Water samples from natural sources may be classified as soft water and hard water. The softness and hardness of water is associated with ability of the water to form lather with soap.

The water that forms lather, readily with soap is called *soft water*. When soap dissolves in soft water lather may form immediately. Very good examples of soft water are rain water, distilled water, etc. The water that does not readily form lather with soap is called *hard water*.

When soap dissolves in hard water lather may not form immediately. For hard water to form lather, enough soap must be dissolved in it. Hard water requires more soap to produce lather than the same amount of soft water.

Solid soap may be represented by the formula $C_{17}H_{35}COO^{-}Na^{+}$. Its chemical name is sodium stearate or sodium octadecanoate. When this soap dissolves in water, it ionizes to stearate ion, $C_{17}H_{35}COO^{-}$ and sodium ion, Na^{+} according to the following equation.

$$C_{17}H_{35}COO^{-}Na^{+}(aq) + H_2O(l) \longrightarrow C_{17}H_{35}COO^{-}(aq) + Na^{+}(aq)$$

Hardness of water is caused by the presence of calcium ion, Ca^{2+} or magnesium of ion, Mg^{2+} or both. Hard water doesn't readily form lather with soap due to the reaction of stearate ion of the soap with calcium ion and/or magnesium ion. This reaction results in the formation of dirt like white solid called scum which floats on the surface of the water. The formation of scum in hard water containing calcium ion is given by the following equation.

$$Ca^{2+}(aq) + 2C_{17}H_{35}COO^{-}(aq) \longrightarrow Ca(C_{17}H_{35}COO^{-})_2(s)$$

Calcium stearate (Scum)

Can you write the equation for the formation of scum in hard water that contains magnesium ion?

Hardness of water is classified into two groups as:

- temporary hardness and
- permanent hardness.

Temporary hardness of water is caused by the presence of dissolved calcium hydrogen carbonate (bicarbonate, $Ca(HCO_3)_2$) and/or magnesium hydrogen carbonate (bicarbonate, $Mg(HCO_3)_2$).

Permanent hardness of water is caused by the presence of dissolved calcium chloride, $CaCl_2$, magnesium chloride, $MgCl_2$ and/or calcium sulfate, $CaSO_4$ and magnesium sulfate, $MgSO_4$.

How can we convert hard water into soft water?

The process of removing hardness of water is called *softening of water*. This process involves the removal of calcium ions and/or magnesium ions from water that are the causes of hardness.

Temporary hardness of water can be removed by boiling. When temporary hard water is boiled, the soluble hydrogen carbonate of calcium and/or magnesium decompose by heat to form insoluble carbonate of calcium and/or magnesium, carbon dioxide and water. The following equation shows the change that takes place when soft water containing calcium hydrogen carbonate is boiled.

$$Ca(HCO_3)_2(aq) \xrightarrow{\text{Heat}} CaCO_3(s) + CO_2(g)$$

Write an equation to show the change that takes place when temporary hard water containing magnesium hydrogen carbonate is boiled.

Permanent hardness of water cannot be removed by boiling. Permanent hardness of water can be removed by the addition of sodium carbonate (washing soda, Na_2CO_3). The addition of sodium carbonate to permanent hard water converts soluble sulfates or chlorides of calcium and/or magnesium into insoluble carbonates. This happens by the reaction of magnesium ions and/or calcium ions with carbonate ion, CO_3^{2-} derived from sodium carbonate. As an example the reaction of calcium ion in hard water with carbonate ion of washing soda is given as follows:

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \longrightarrow CaCO_3(s)$$

Experiment 10

Test for softness and hardness of water

Objective: To test for hardness and softness of water.

Materials required: Rain water, tap water, ground water, distilled water, four test tubes, test tube rack, measuring cylinder and scissors.

Procedure

1. Pour about 20 mL of rain water in the first test tube, 20 mL of tap water in the second, 20 mL of ground water in the third and 20 mL of distilled water in the fourth test tube.
2. Cut pieces of soap with scissors and add into the water sample of each test tube.
3. Shake each of the test tubes by closing its mouth with your thumb.

Observation and analysis

(a) In which test tubes does the water sample forms lather more rapidly?

(b) In which test tube does the water sample form lather slowly?

(c) Which water samples are soft and which samples are hard?

Result: Rain water and distilled water samples form lather with soap readily. Thus they are soft water. Ground water and tap water may form lather slowly and thus are samples of hard water.

Key Terms

- Acidic oxide
- Allotropes
- Allotropy
- Ammonical liquor
- Amorphous carbon
- Amphoteric oxide
- Argon
- Basic oxide
- Bleaching agent
- Bromine
- Coal gas
- Carbon dioxide
- Carbon monoxide
- Charcoal
- Chlorine
- Coal tar
- Coke
- Contact process
- Destructive distillation
- Diamond
- Fluorine
- Graphite
- Haber process
- Hard water
- Helium
- Iodine

- Krypton
- Lamp black
- Monoclinic sulfur
- Neon
- Neutral oxide
- Nitrates
- Nitric acid
- Nitrogen
- Oleum
- Ostwald process
- Oxygen
- Ozone
- Peroxide
- Producer gas
- Radon
- Rhombic sulfur
- Silver chloride
- Silver iodide
- Soft water
- Softening of water
- Solute
- Solvent
- Sulfates
- Sulfites
- Sulfur dioxide
- Sulfuric acid
- Sulfurous acid
- Water gas

SUMMARY

- Allotropes are different forms of the same element in the same physical state having different physical properties.
- The existence of an element in two or more different forms in the same physical state is called allotropy.
- Carbon exists in crystalline and amorphous forms. Diamond and graphite are natural crystalline allotropic forms of carbon.
- Diamond is the hardest natural substance known.
- Graphite is a soft, shiny black crystalline form of carbon.
- The amorphous allotropic forms of carbon include coke, Wood charcoal, bone charcoal and lamp black or soot.
- The different varieties of mineral coal are peat, lignite, bituminous and anthracite.
- Coking of coal is a process of converting mineral coal into coke and volatile products.
- Mineral coal is converted into coke and volatile products by destructive distillation.
- Products of destructive distillation of mineral coal are coke, coal gas, ammonical liquor and coal tar.
- Water gas is a mixture of equal volumes of carbon monoxide and hydrogen made by passing steam over hot coke.

- Producer gas is a mixture of two volumes of carbon monoxide and one volume of nitrogen made by passing limited supply of air over cheap grade of coal or coke.
- Nitrogen occurs in nature in elemental state and in the form of compounds. In the free State, nitrogen gas constitutes about 78.08% by volume of the atmosphere.
- Nitrogen is manufactured in industries by fractional distillation of liquid air or fractional liquefaction of air.
- In the laboratory pure nitrogen can be prepared by passing ammonia over heated copper (II) oxide.
- Ammonia is manufactured industrially by the Haber's process. In this process ammonia is produced by direct combination of hydrogen and nitrogen.
- Nitric acid is prepared in the laboratory by heating nitrate salt with concentrated sulphuric acid in a glass retort.
- Nitric acid is commercially prepared by the Ostwald process.
- Oxygen occurs in nature in the free state and in the form of compounds. In elemental state it occurs in atmospheric air in the form of molecular oxygen, O_2 and ozone O_3. It make up about 21% of the atmospheric air by volume.
- Oxygen gas can be prepared in the laboratory by decomposition of hydrogen peroxide, H_2O_2 or mercury (II) oxide, HgO or potassium chlorate, $KClO_3$.
- Oxygen is manufactured on industrial scale by fractional distillation of liquid air.
- Chemically, 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 two elements only. Oxides are classified as acidic oxides, basic oxides, amphoteric oxides, neutral oxides and peroxides.
- Acidic oxides are oxides formed by the chemical combination of oxygen with non-metals. These oxides are also called acid anhydrides.
- Neutral Oxides react neither with acids nor with bases to form salt and water. Neutral oxides do not show basic and acidic properties.
- In peroxides the oxidation state of oxygen is –1. They contain the peroxide, "– O – O –" link.
- Sulfur exists in nature in elemental state and in the form of compounds. In elemental state it is found on the surface of the earth in volcanic areas and underground deposits. In the form of compounds it exists mainly as sulfides and sulfates.
- Sulfur is extracted from underground sulfur deposits by the Frasch process.

- Sulfur exhibits allotropy. The allotropic forms of sulfur are rhombic sulfur, monoclinic sulfur and plastic sulfur.
- Rhombic sulfur is the most stable crystalline form into which all other forms change at room temperature.
- The elements fluorine, chlorine, bromine, iodine and astatine are elements collectively known as halogens.
- All the halogens occur in nature as halide salts with the exception of astatine.
- In industries fluorine is manufactured by electrolysis of a molten mixture of KF and HF in a monel cell (monel metal is an alloy of Ni, Cu, Fe and Al)
- Bromine is commercially prepared by the oxidation of the bromide ion of sea water with chlorine.
- Iodine can be recovered from its compounds using chlorine gas.
- Iodine is manufactured commercially by the reduction of sodium iodate with sodium hydrogen sulfite ($NaHSO_3$).
- Commercially, chlorine is manufactured by electrolysis of concentrated aqueous sodium chloride solution.
- Chlorine is prepared in the laboratory by heating a mixture of concentrated hydrochloric acid, HCl and manganese(IV) oxide or by heating a mixture of manganese(IV) oxide, sodium chloride, NaCl and concentrated sulfuric acid, H_2SO_4.
- The elements helium, neon, argon, krypton, xenon and radon are called noble gases or inert gases.
- The atmosphere is our major source for the noble gases and these gases are now produced commercially as a by-product during fractional distillation of liquid air to produce liquid oxygen and nitrogen.
- The best known use of the noble gases is in the familiar “neon” advertising signs.
- A solution is a homogenous mixture consisting of a solute dissolved into a solvent.
- Water sample that contains dissolved solid, liquid or gas is considered as an aqueous solution.
- Water samples from natural sources may be classified as soft water and hard water.

Exercises

Part 1. Choose the correct answers

1. Which one of the following elements doesn't show allotropy?
   (a) Sulfur
   (b) Oxygen
   (c) Nitrogen
   (d) Carbon
2. Which one of the following substance is not used as a bleaching agent?
   (a) Cl_2
   (b) NaClO
   (c) SO_2
   (d) $CaCl_2$
3. Which one of the following salts causes temporary hardness of water?
   (a) $MgSO_4$
   (b) $Ca(HCO_3)$
   (c) KCl
   (d) $CaCl_2$
4. Hard water containing calcium ion form an insoluble scum when soap dissolves in it. The formula for the scum is:
   (a) $Ca(C_{17}H_{35}COO)_2$
   (b) $Ca(C_{17}H_{35})_2$
   (c) $CaC_{17}H_{35}COO$
   (d) $CaCO_3$
5. Which of the following is not an important use of sulphuric acid?
   (a) In manufacturing fertilizers
   (b) In lead storage batteries
   (c) In manufacturing soda
   (d) As dehydrating agent
6. Which product is not obtained by destructive distillation of mineral coal?
   (a) Coal gas
   (b) Ammonical liquor
   (c) Coke
   (d) Methanol
7. Which one of the following forms of carbon is used in removing coloring matter from solutions?
   (a) Graphite
   (b) Bone charcoal

(c) Magnesium
(d) Diamond

8. In contact process of sulphuric acid production, sulfur trioxide obtained by the oxidation of sulfur dioxide is absorbed in:
   (a) 98% sulphuric acid
   (b) Fuming sulfuric acid
   (c) Water
   (d) Dilute sulfuric acid
9. The formula which represents ammonia water is:
   (a) NH_4OH
   (b) $(NH_4)_2CO_3$
   (c) $NH_4(l)$
   (d) NH_4NO_3
10. Which one of the following is not used in photography?
   (a) AgBr
   (b) AgCl
   (c) AgI
   (d) HNO_3
11. Ammonia may not be used:
   (a) in Ostwald and Solvay process
   (b) in Contact process
   (c) as cleaning agent and in refrigeration
   (d) to produce fertilizers
12. The non-metal whose industrial production involves electrolysis among the following is:
   (a) Br_2
   (b) F_2
   (c) S
   (d) I_2
13. The catalyst used in industrial production of ammonia by the Haber process is:
   (a) V_2O_5
   (b) Cu
   (c) Fe
   (d) MnO_2
14. Oxygen is manufactured industrially by:
   (a) heating potassium chlorate
   (b) decomposition of mercury(II) oxide

(c) electrolysis of water
(d) fractional distillation of liquid air

15. Carbon dioxide may not be used:
    (a) in producing baking soda
    (b) as component of gaseous fuels
    (c) to pressurize alcoholic and soft drinks
    (d) as refrigerant
16. Which of the following statements is wrong about graphite?
    (a) It is the hardest natural substance known
    (b) It is used as electrode in electric furnace
    (c) It is used as lubricant
    (d) It is a non – metal with good electrical conductivity
17. What is the raw material used for the industrial production of nitric acid?
    (a) Sulfur dioxide
    (b) Sulfur
    (c) Ammonia
    (d) NH_4Cl and $Ca(OH)_2$
18. The most abundant noble gas is:
    (a) xenon
    (b) argon
    (c) krypton
    (d) helium
19. Ostwald process is an industrial method for the production of:
    (a) sulphuric acid
    (b) ammonia
    (c) sulfur
    (d) nitric acid
20. Which one of the following statements is correct about the production of iodine?
    (a) It is produced by the oxidation of iodide, I^- ion with chlorine gas.
    (b) It is extracted by the electrolysis of molten iodide salt.
    (c) It is produced by the reduction of iodide ion with fluorine gas
    (d) It is produced by reduction of iodide salt with hydrogen
21. Which form of mineral coal contains the greatest percentage of carbon as compared to others?
    (a) Lignite
    (b) Anthracite

(c) Peat
(d) Bituminous

22. The halogen that exists in the liquid state at room temperature is:
(a) fluorine
(b) iodine
(c) chlorine
(d) bromine

23. Of all the halogens, the most abundant one is:
(a) chlorine
(b) iodine
(c) bromine
(d) fluorine

24. Contact process is an industrial method for the production of:
(a) ammonia
(b) nitric acid
(c) sulphuric acid
(d) liquid oxygen

25. Which chemical is added to permanent hard water to remove its hardness?
(a) Sodium carbonate
(b) Sodium sulfate
(c) Chlorine gas
(d) Solid carbon dioxide

26. The name “dry ice” refers to:
(a) solid ice
(b) solid carbon dioxide
(c) super cooled water
(d) powdered graphite

27. Which reagent is used to detect whether or not a gas is carbon dioxide?
(a) Silver nitrate solution
(b) Calcium hydroxide solution
(c) Litmus paper
(d) Barium chloride solution

28. Which group of oxides behaves both as an acid and a base?
(a) Acid anhydrides
(b) Peroxides
(c) Basic anhydrides
(d) Amphoteric oxides

29. Of the following oxides, which one does not form acidic or basic solution in water?
    (a) NO
    (b) CaO
    (c) SO_2
    (d) Li_2O
30. The presence of chloride ion, bromide ion or iodide ion in a solution of salt is detected by the addition of:
    (a) barium chloride solution
    (b) silver nitrate solution
    (c) ammonia solution
    (d) iron (II) sulfate solution
31. Which gaseous substance is prepared in the laboratory by heating a mixture of ammonium chloride and calcium hydroxide?
    (a) Chlorine gas
    (b) Nitrogen gas
    (c) Ammonia gas
    (d) Carbon dioxide gas
32. The brown ring test is an experimental procedure for the identification of:
    (a) halide salts
    (b) sulphate salts
    (c) carbonate salts
    (d) nitrate salts
33. In the industrial production of sulphuric acid, the catalyst used during the oxidation of sulfur dioxide to sulfur trioxide is:
    (a) manganese(IV) oxide
    (b) vanadium(V) oxide
    (c) iron metal
    (d) potassium dichromate
34. A gaseous fuel containing a mixture of equal volumes of carbon monoxide and hydrogen gas is:
    (a) producer gas
    (b) natural gas
    (c) coal gas
    (d) water gas

35. Which non-metallic element is not manufactured by fractional distillation of liquid air?
    (a) Nitrogen
    (b) Hydrogen
    (c) Argon
    (d) Oxygen
36. Which one of the following is not a step in contact process of sulphuric acid production?
    (a) Oxidation of Sulphur to sulfur dioxide
    (b) Absorption of SO_3 into 98% sulphuric acid
    (c) Dissolution of SO_3 in water
    (d) Dilution of oleum with water

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CHAPTER 5

REVIEW OF SOME FUNDAMENTAL TOPICS PREVIOUSLY TREATED (GRADES 10 - 12)

Chapter Contents

Chapter Outcomes

After completing this chapter, you will be able to:

- review topics in chemistry as well as the WASSCE past papers,
- correctly answer questions set in the WASSCE chemistry examination.
- utilize your skills to review fundamental topics previously treated, including the WASSCE chemistry papers.

Part I. Choose the correct answer from the given alternatives

1. Which one of the following is not SI base unit?
   (a) kelvin
   (b) litre
   (c) ampere
   (d) meter
2. Which of the following is a derived SI unit?
   (a) ampere
   (b) kelvin
   (c) newton
   (d) candela
3. How many picometers is one micrometer?
   (a) 10^4 pm
   (b) 10^8 pm
   (c) 10^{-6} pm
   (d) 10^6 pm
4. The closeness in values among several measurements of the same quantity is referred to:
   (a) precision
   (b) accuracy
   (c) error
   (d) uncertainty
5. The units nanometer (nm), angstrom (Å), picometer (pm) and micrometer (μm), when arranged in decreasing order of magnitude, the correct sequence is;
   (a) pm, Å, nm, μm
   (b) μm, nm, Å, pm
   (c) pm, μm, nm, Å
   (d) pm, nm, μm, Å
6. What is the SI unit of temperature?
   (a) degree centigrade
   (b) degree Fahrenheit
   (c) degree Celsius
   (d) kelvin
7. Of the following physical quantities, which one has a derived unit?
   (a) volume of a given matter
   (b) amount of substance

(c) luminous intensity
(d) mass of a substance

8. Which one of the following is not agricultural chemical?
   (a) fertilizers
   (b) herbicides
   (c) pesticides
   (d) drugs
9. Which of the following are the correct steps of the Scientific method?
   (a) Observation – Hypothesis – Experimentation – Formulation of law – Theory
   (b) Observation – Formulation of law – Experimentation – Hypothesis – Theory
   (c) Observation – Experimentation – Hypothesis – Formulation of law – Theory
   (d) Observation – Experimentation – Formulation of law – Hypothesis – Theory
10. Which branch of chemistry is concerned with the qualitative identification and quantitative determination of composition of a substance?
   (a) organic chemistry
   (b) analytical chemistry
   (c) organic chemistry
   (d) inorganic chemistry
11. All of the following are true about Dalton's atomic theory, except:
   (a) Atoms are indivisible and indestructible.
   (b) All atoms of a given element are identical.
   (c) All substances are made up of atoms.
   (d) Atoms of the same element may not be exactly alike.
12. The precision of measurement is low if:
   (a) Each measurement is close to the true value.
   (b) There is a wide deviation from average value.
   (c) There is a wide deviation from the true value.
   (d) Each measurement is close to the average value.
13. How many significant digits are there in the measurement 0.0030469 m?
   (a) 6
   (b) 7
   (c) 5
   (d) 8

14. The term that describes the transition from solid state directly to gaseous state is:
    (a) sublimation
    (b) freezing
    (c) condensation
    (d) vaporization
15. Which of the following is not a measurable physical property of a substance?
    (a) melting point
    (b) odor
    (c) boiling point
    (d) density
16. Which one of the following physical properties of matter is not perceived by the sense organs?
    (a) color
    (b) odor
    (c) taste
    (d) density
17. Of the following, which statement describes chemical property of the given substance?
    (a) Copper is reddish- brown metal.
    (b) Silver is the best conductor of electricity among metals.
    (c) Magnesium burns in oxygen to form magnesium oxide.
    (d) Water boils at $100^{o}C$.
18. Of the following changes, which one is a physical change?
    (a) dissolution of salt in water
    (b) fermentation of starch
    (c) rusting of iron
    (d) decaying of wood
19. Which one of the following combinations of substances forms a homogeneous mixture?
    (a) salt and sand
    (b) iron filings and sulfur
    (c) ethanol and water
    (d) kerosene and water
20. Which statement is not correct about a heterogeneous mixture?
    (a) It is a mixture that has more than one phase.
    (b) This mixture has a uniform composition throughout the sample.

(c) Each component of this mixture retains its identity.
(d) Each component of this mixture can be seen with naked eyes or with the aid of magnifying glass

21. Which one of the following sequence of steps is most appropriate to isolate components from a mixture containing ammonium chloride, iron filings, table salt and sand?
(a) dissolution, filtration, sublimation, distillation.
(b) sublimation, filtration, magnetic separation, dissolution.
(c) magnetic separation, sublimation, filtration, dissolution.
(d) magnetic separation, sublimation, dissolution, filtration, evaporation.

22. Two miscible liquids can be separated by:
(a) evaporation
(b) decantation
(c) distillation
(d) filtration

23. Rutherford's alpha-particles experiment on a gold foil led to the conclusion that each atom in the foil was composed mostly of empty space because most alpha particles directed at the foil:
(a) remained trapped in the foil.
(b) were deflected by the electrons in gold atoms.
(c) passed through the foil.
(d) were deflected by the nuclei in gold atoms.

24. Which of the following ideas is introduced by the quantum mechanical model of an atom?
(a) Each electrons in an atom is described by four quantum numbers.
(b) The structure of an atom resembles the solar system.
(c) Electrons are embedded in positively charged sphere.
(d) Electrons revolve around the nucleus in circular orbit called shell.

25. An arbitrary element "X" has two naturally occurring isotopes. Information about the two isotopes is given in the table below.

Isotope	Atomic mass (atomic mass unit, a.m.u)	Percent natural abundance (%)
X - 40	40	80
X - 44	44	20

What is the average atomic mass of element X?

(a) 41.5
(b) 40.8
(c) 42
(d) 40

26. The scientist who determined the magnitude of the electron charge by using an oil drop experiment is:
(a) Ernest Rutherford
(b) John Dalton
(c) Joseph John Thomson
(d) Robert Millikan

27. The quantum number that determines the shape of an atomic orbital is:
(a) Principal quantum number
(b) Magnetic quantum number
(c) Azimuthal quantum number
(d) Spin quantum number

28. Which one of the following is a permissible set of quantum numbers for an electron in an atom?
(a) $n = 4, l = 1, m_l = 0, m_s = +1/2$
(b) $n = 1, l = 2, m_l = -1, m_s = -1/2$
(c) $n = 3, l = -3\ m_l = 0, m_s = +1/2$
(d) $n = 2, l = 2, m_l = -1, m_s = -1/2$

29. Which statement is correct about the atom $^{80}_{29}Br$?
(a) The atom has 35 neutrons.
(b) The mass number of the atom is 45
(c) The atom has 35 protons in its nucleus.
(d) The atomic number of the atom is 45

30. Which one of the following is the correct electron configuration of the copper atom ($^{63}_{29}Cu$)?
(a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9\ 4s^2$
(b) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 4s^1\ 3p6\ 3d^{10}$
(c) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^9$
(d) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1\ 3d^{10}$

31. "No two electrons in an atom can have the same four quantum numbers." This statement is:
(a) Aufbau principle
(b) Pauli's exclusion principle

(c) Heisenberg's uncertainty principle
(d) Hund's rule

32. Which sub-shell is occupied by the last electron(s) in potassium atom (Z = 19)?
(a) 4*s*
(b) 3*p*
(c) 3*d*
(d) 3*s*

33. Two electrons occupying the same atomic orbital differ in their:
(a) Principal quantum numbers
(b) Magnetic quantum numbers
(c) Azimuthal quantum numbers
(d) Spin quantum numbers

34. If the electronic configuration of an atom of a certain element is given as $1s^2$, $2s^2$, $2p^6$, $3s^2$, $3p^6$, $4s^2$, $3d^{10}$, $4p^5$, what are the block, the period and group number of the element in the periodic table respectively?
(a) *s*, 3 and IVA
(b) *d*, 4 and IIB
(c) *p*, 4 and VIIA
(d) *f*, 3 and VIIIB

35. Which one of the following comes first in the classification of elements?
(a) Newlands law of octaves
(b) Dobereiner's triads
(c) Meyer`s classification
(d) Mendeleev`s periodic classification

36. Which property of elements generally decreases down (top to bottom) a given group of the Periodic Table?
(a) ionization energy
(b) nuclear charge
(c) atomic radius
(d) metallic character

37. If an element has very high ionization energy, very high electron affinity and high electronegativity, this element is most likely classified as:
(a) metalloid
(b) non-metal
(c) nobel gas
(d) metal

38. "The properties of elements are periodic functions of their atomic masses." This statement is:
    (a) Law of Octaves
    (b) Law of Triads
    (c) Modern Periodic Law
    (d) Mendeleev' s Periodic Law
39. Which property of elements generally decreases from left to right along a given period of the periodic table?
    (a) nuclear charge
    (b) electronegativity
    (c) metallic character
    (d) electron affinity.
40. The prediction of molecular geometry using the VSEPR theory is based on:
    (a) Maximum repulsion between valence shell electron pairs
    (b) Maximum distance of separation between valence shell electron pairs
    (c) Minimum distance of separation between electron pairs
    (d) Minimum angle of separation between pairs of valence electrons.
41. The hybridization of the central atom and the molecular geometry of IF_5 is:
    (a) sp^3d^2, square pyramidal
    (b) sp^3d^2, octahedral
    (c) sp^3d, square planar
    (d) p^3d, trigonal pyramid
42. A pi (π) bond can be formed by the overlap of two:
    (a) *s*-orbitals of different atoms.
    (b) hybrid orbitals of different lying in the same plane.
    (c) *p*-orbitals on different atoms lying side by side in the same plane.
    (d) *p*-orbitals of the same atom lying side by side in the same plane.
43. The formation of an ionic bond is favored by:
    (a) high ionization energy of the metal and high electron affinity of the non-metal.
    (b) low ionization energy of the metal and low electron affinityof the non-metal
    (c) high ionization energy of the metal and low electron affinity of the non-metal
    (d) low ionization energy of the metal and high electron affinity of the non-metal.

44. Which one of the following is NOT true about the properties of covalent molecules?
    (a) They have relatively low melting and boiling points.
    (b) They conduct electricity in the molten state.
    (c) They are neither hard nor brittle.
    (d) They are aggregates of discrete molecules.
45. Which one of the following is the correct arrangement in increasing order of strength of intermolecular forces?
    (a) Hydrogen bond, dipole-dipole interaction, London forces
    (b) Hydrogen bond, London force and dipole-dipole interaction
    (c) Dipole-dipole interaction, hydrogen bond, London force
    (d) London force, dipole-dipole interaction, hydrogen bond
46. Which one of the following bonds is non-polar covalent bond?
    (a) The H – I bond in HI
    (b) The N – H bond in NH_3
    (c) The Cl – Cl bond in Cl_2
    (d) The O – H bond in H_2O
47. What is the oxidation number of chromium in $Cr_2O_7^{-}$?
    (a) +7
    (b) +6
    (c) +4
    (d) -6
48. What is the coefficient for $H^+(aq)$ when the following equation is correctly balanced?

$$Mn^{2+}(aq) + BiO_3^-(aq) + H^+(aq) \longrightarrow Bi^{3+}(aq) + MnO_4^-(aq) + H_2O(l)$$

    (a) +14
    (b) +4
    (c) +7
    (d) +3
49. In a redox reaction, an oxidizing agent is a species:
    (a) that is oxidized in the reaction.
    (b) whose oxidation number decreases.
    (c) that loses electron.
    (d) whose oxidation number increases.

50. 10g of hydrogen reacts with 18g of nitrogen according to the following equation representing the reaction:

$$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$$

Which of the following statement is NOT true? (Atomic masses: N = 14, H = 1)

(a) Nitrogen is the limiting reactant.
(b) Hydrogen is the excess reactant.
(c) 6.14g of hydrogen left unreacted.
(d) 56.67g of ammonia is formed.

51. The oxidation of ammonia to nitric oxide is given by the following equation.:

$$NH_3 + O_2 \longrightarrow NO + H_2O \text{ (unbalanced)}$$

What volume of O_2 is required to produce 18.3 L of NO at standard temperature and pressure (STP)?

(a) 22.9 L
(b) 7.5 L
(c) 22.4 L
(d) 18.3 L

52. 148 g of iron were obtained when a mixture of 108 g aluminum and 240 g Fe_2O_3 were ignited according to the equation;

$$2Al + Fe_2O_3 \longrightarrow Al_2O_3 + 2Fe$$

(Atomic mass: Al = 27, Fe = 56, O = 16)
What is the percentage yield of Fe?

(a) 72.5%
(b) 66%
(c) 88%
(d) 97%

53. Which of the following reactions is an example of a double displacement?

(a) $ZnCO_3 + \text{heat} \longrightarrow ZnO + CO_2$
(b) $Ca + 2H_2O \longrightarrow Ca(OH)_2 + H_2$
(c) $2NaHCO_3 + \text{heat} \longrightarrow Na_2CO_3 + CO_2 + H_2O$
(d) $BaCl_2 + Na_2SO_4 \longrightarrow BaSO_4 + 2NaCl$

54. Two gases A and B were applied to the two ends of a 40 cm long glass tube. The two gases met at a distance of 30 cm from the side where B is applied. Which statement is true about these gases?
    (a) The density of A is smaller than the density of B.
    (b) The rate of effusion of B is smaller than the rate of effusion of A.
    (c) The molar mass of A is bigger than the molar mass of B.
    (d) The rate of diffusion of A is bigger than the rate of diffusion of B.
55. Which of the following statements is not consistent with the kinetic molecular theory of gases?
    (a) Individual gas molecules are relatively far apart.
    (b) The average kinetic energies of different gases are different at the same temperature.
    (c) The actual volume of gas molecules is very small compared to the volume occupied by the gas at ordinary temperature and pressure
    (d) The average kinetic energy of a gas is directly proportional to the absolute temperature of the gas.
56. A 60L balloon is required to be filled with a helium gas at 27°C and a pressure of 8.2 atm. What mass of helium gas is needed?
    (Atomic mass: He = 4, R = 0.082L. atm/ K. mol)
    (a) 20g
    (b) 200g
    (c) 9g
    (d) 80g
57. Under the same conditions of temperature and pressure, equal volumes different gases:
    (a) have equal masses.
    (b) contain equal number of atoms.
    (c) have equal densities.
    (d) contain the same number of molecules.
58. If a student wishes to prepare 100 milliliters of an aqueous solution of 6 M HCl using 12.0 M HCl, which procedure is correct?
    (a) Adding 50 mL of 12 M HCl to 50 mL of water while stirring the mixture steadily.
    (b) Adding 25 mL of 12 M HCl to 50 mL of water while stirring the mixture steadily.

(c) Adding 50 mL of water to 50 mL of 12 M HCl while stirring the mixture steadily.
(d) Adding 25 mL of water to 50 mL of 12 M HCl while stirring the mixture steadily

59. Which one of the following interactions is responsible for the solubility of ethanol, C_2H_5OH, in water?
(a) Ion–ion interaction
(b) Ion–dipole interaction
(c) Hydrogen bonding
(d) London forces

60. Concentrated sulfuric acid is 98% H_2SO_4 by mass. The density of this acid is 1.84 g/cm^3. What is the concentration of the acid in molarity and normality respectively? (molar mass: H_2SO_4 = 98g)
(a) 36.8 M, 18.4 N
(b) 18.4 M, 36.8 N
(c) 18.4 M, 9.2 N
(d) 9,2 M, 18.4 N

61. A solution is prepared by mixing 1 mol of ethanol and 2 mol of water at 25^{o}C. What is the total vapor pressure above the solution? (At 25^{o}C, the vapor pressure of pure ethanol and pure water are 44 and 23.8 torr respectively)
(a) 67.8 torr
(b) 33.9 torr
(c) 45 torr
(d) 30.5 torr

62. Given the following aqueous solutions:

0.15m $CaCl_2$ 0.050m NaCl 0.10m H_2SO_4 0.30m $C_6H_{12}O_6$

When these solutions are arranged in increasing order of freezing point from lowest to highest, the correct sequence is:
(a) 0.15 m $CaCl_2$ > 0.050 m NaCl > 0.10 m H_2SO_4 > 0.30 m $C_6H_{12}O_6$
(b) 0.30 m $C_6H_{12}O_6$ > 0.10 m H_2SO_4 > 0.050 m NaCl > 0.15 m $CaCl_2$
(c) 0.10 m H_2SO_4 > 0.30 m $C_6H_{12}O_6$ > 0.15 m $CaCl_2$ = 0.050 m NaCl
(d) 0.15 m $CaCl_2$ > 0.10 m H_2SO_4 = 0.30 m $C_6H_{12}O_6$ > 0.050 m NaCl

63. When a small amount of crystal solute is added to a saturated solution, the solute crystals will:
(a) grow bigger
(b) remain unchanged

(c) slightly dissolve
(d) dissolve completely

64. For the acid–base equilibrium:

$$HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^-$$

The Bronsted–Lowry acids are:
(a) H_2O and OH^-
(b) HCO_3^- and OH^-
(c) H_2O and H_2CO_3
(d) HCO_3^- and H_2CO_3

65. A 0.2 M solution of a weak acid HA is 1% ionized at 25°C. K_a for acid is equal to:
(a) $\frac{0.01 \times 0.01}{0.19}$
(b) $\frac{0.02 \times 0.02}{0.18}$
(c) $\frac{0.002 \times 0.002}{0.198}$
(d) $\frac{0.19}{0.01 \times 0.01}$

66. Which one of the following salts produces an aqueous solution whose *p*H is less than 7?
(a) $CH_3COO^-Na^+$
(b) NH_4Cl
(c) KNO_3
(d) Na_2CO_3

67. Acetic acid undergoes dissociation in aqueous solution according to the following equation.

$$CH_3COOH\,(aq) \rightleftharpoons CH_3CO_2^-\,(aq) + H^+\,(aq)$$

What is the effect of adding solution of $CH_3COO^-Na^+$ to the solution of CH_3COOH?
(a) Shifting the equilibrium to the left.
(b) Decreasing the pH of CH_3COOH solution.
(c) Increasing the dissociation of CH_3COOH.
(d) Has no effect on the dissociation of CH_3COOH

68. Which statement is correct about the equivalence point for the titration of 10.0 mL of 2.00 M CH_3COOH with 0.500 M KOH?
    (a) The volumes of the acid and the base used in the titration are equal.
    (b) The *p*H at the equivalence point is less than 7.
    (c) The *p*H at the equivalence point is exactly 7
    (d) The number of equivalents of the acid is equal to that of the base.
69. What is the purpose of a salt bridge in an electrochemical cell?
    (a) To provide a source of ions to react at the anode and cathode
    (b) To maintain electrical neutrality in the two half-cell through migration of ions.
    (c) To provide means of electrons to travel from the cathode to the anode
    (d) To provide means of electrons to travel from the anode to the cathode
70. Which statement is not correct about electrolysis of concentrated solution of NaCl?
    (a) Chlorine gas is liberated at the anode.
    (b) The solution becomes more basic as the time of electrolysis increases.
    (c) Sodium metal is formed at the cathode.
    (d) The *p*H of the solution increases.
71. The half–reaction for formation of magnesium metal on electrolysis of molten $MgCl_2$ is:

$$Mg^{2+} + 2e^- \longrightarrow Mg$$

    What mass of magnesium is formed if a current of 60.0 amperes is passed for a period of 2.0×10^3 s?
    (a) 5.0g
    (b) 10.0g
    (c) 30.2g
    (d) 15.1g
72. What is the change in internal energy, ΔE, of a system if it absorbs 400 kJ of heat from the surroundings and does 500 kJ of work on the surroundings?
    (a) 100 kJ
    (b) -100 kJ
    (c) -900 kJ
    (d) 900 kJ

73. The enthalpies of formation of gaseous N_2O and NO at 298 K are 82 and 90 kJ respectively. The enthalpy change for the reaction;

$$N_2O\ (g)\ +\ \frac{1}{2}O_2 \longrightarrow 2NO\ (g),\ \text{is:}$$

(a) -8 kJ
(b) 8 kJ
(c) -74kJ
(d) 98 kJ

74. The equation for the radioactive decay of thorium nucleus is given as follows.

$$^{234}_{90}\text{Th} \longrightarrow ^{234}_{91}\text{Pa} + \text{particle}$$

The particle emitted in this radioactive decay is:
(a) alpha particle
(b) beta particle
(c) gamma ray
(d) neutron

75. Which one of the following is not the application of radioactivity?
(a) In generating electricity in hydroelectric power stations.
(b) In medical therapy and diagnosis.
(c) In preserving food by irradiation.
(d) In environment–friendly insect and pest control.

76. Which one of the following is not characteristic of a chemical equilibrium?
(a) Concentrations of the various species in the reaction mixture remain constant.
(b) The actual forward and reverse reactions do not stop.
(c) Equilibrium condition can be affected with the presence of catalyst.
(d) The forward and reverse reaction rates are equal.

77. The hydrogen used in the Haber process is made by the following reaction:

$$CH_4\ (g) + H_2O\ (g) \rightleftharpoons CO\ (g) + 3H_2\ (g)\ H^0 = +206\ \text{kJ}$$

Which of the following sets of conditions will favor the formation of H_2?
(a) low pressure and low temperature.
(b) high pressure and low temperature.
(c) high pressure and high temperature.
(d) low pressure and high temperature.

78. For the reaction ;

$$BrO_3^- + 5Br^- + 6H^+ \longrightarrow 3Br_2 + 3H_2O$$

at a particular time, the $-\Delta[BrO_3^-]/\Delta t = 1.5 \times 10^{-2}$ M/s. What is the $-\Delta [Br^-]/\Delta t$ at the same instant?

(a) 3.0×10^{-3} M/s
(b) 7.5×10^{-2} M/s
(c) 4.5×10^{-2} M/s
(d) 1.5×10^{-2} M/s

79. In the reaction; *B* ⟶ *products*, the concentration of B at 298 K decreases from 1.0 M to 0.5 M in 240 seconds. How long will it take for the concentration of B to fall from 0.5 M to 0.25 M assuming that the reaction is second order?

(a) 240 seconds
(b) 120 seconds
(c) 480 seconds
(d) 960 seconds

80. For the reaction; 3A + B ⟶ C, the following rate data were recorded during the reaction.

Experiment	$[A]_o$	$[B]_o$	Rate(M/s)
1	8.0	1.2	1.6
2	2.0	1.2	0.4
3	2.0	2.4	0.8

What is the overall order of the reaction?

(a) Zero order
(b) 1st order
(c) 3rd order
(d) 2nd order

C12CH06

CHAPTER 6

REVIEW OF SOME FUNDAMENTAL TOPICS PREVIOUSLY TREATED (GRADES 10 -12)

Chapter Contents

Chapter Outcomes

After completing this chapter, you will be able to:

- review topics in chemistry as well as the WASSCE past papers.
- correctly answer questions set in the WASSCE chemistry examination.
- utilize your skills to review fundamental topics previously treated, including the WASSCE chemistry papers.

Part II. Choose the correct answer for each question from the suggested options:

1. As compared to inorganic compounds, organic compounds have complex structures. This is because:
   (a) carbon atom doesn't react with most of the elements at ordinary conditions.
   (b) organic compounds are prepared only by plants and animals.
   (c) carbon atoms link with one another to form short or long chains and ring structures.
   (d) organic compounds originate from mineral constituents of the earth.
2. If an organic compound contains one or more benzene rings then is classified as:
   (a) alicyclic organic compound
   (b) aromatic organic compound
   (c) acyclic organic compound
   (d) open chain organic compound
3. Which one of the following is not general characteristic of organic compounds? They:
   (a) are generally volatile and combustible.
   (b) exhibit isomerism.
   (c) are non-polar compounds and almost insoluble in water.
   (d) are compounds of all the known elements.
4. Which group of organic compounds is represented by the general structure RCHO?
   (a) Aldehydes
   (b) Ketones
   (c) Carboxylic acids
   (d) Esters
5. A group of organic compounds whose consecutive members differ by methylene, $–CH_2–$ group is known as:
   (a) homologous series
   (b) aliphatic compounds
   (c) isomers
   (d) monomers
6. The existence of two or more organic compounds with the same molecular formula but different structures is:
   (a) polymerization
   (b) aromaticity

(c) isomerism
(d) resonance

7. Part of an organic molecule that determines the chemical properties and some of its physical properties is called:
   (a) homologue
   (b) functional group
   (c) isomerism
   (d) allotropy
8. What is meant by the term "saturated" when describing hydrocarbons?
   (a) The hydrocarbons are saturated with water and are wet.
   (b) The hydrocarbons are saturated with carbons in its parent chain.
   (c) The hydrocarbons are saturated with hydrogen and have only single bonds between carbons.
   (d) The compound is pure.
9. Which one of the following compounds is not organic compound?
   (a) $CH_3CH_2CH_2OH$
   (b) HCOOH
   (c) $CH_3CH_2CH_3$
   (d) $NaHCO_3$
10. A hydrocarbon is classified as unsaturated hydrocarbon if it:
   (a) has cyclic structure.
   (b) contains one or more double or triple bonds.
   (c) contains carbon atoms linked in closed chains.
   (d) contains carbon atoms covalently bonded to one another by single covalent bonds.
11. The molecular formula of an alkane that contains 9 carbon atoms is:
   (a) C_9H_{18}
   (b) C_8H_{16}
   (c) C_9H_{20}
   (d) C_9H_{17}
12. If each of the following is an open chain hydrocarbon, which one is saturated?
   (a) C_8H_{16}
   (b) C_6H_8
   (c) C_4H_6
   (d) $C_{10}H_{22}$
13. Of the following alkanes, which one has five possible structures?
   (a) C_6H_{14}
   (b) C_5H_{12}

(c) C_7H_{16}
(d) C_4H_{10}

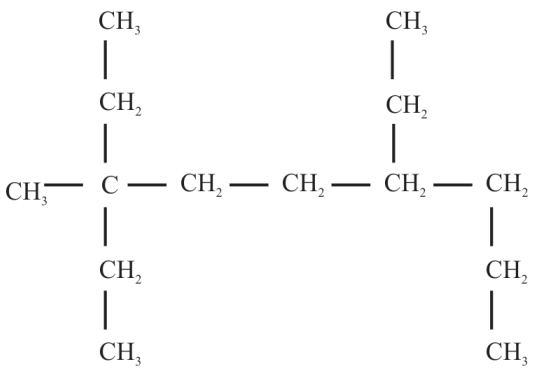
14. Which general formula represents alkyl radicals?
(a) C_nH_{2n}
(b) C_nH_{2n+1}
(c) C_nH_{2n+2}
(d) C_nH_{2n-2}

15. Which one of the following alkane is found in the liquid state at room temperature?
(a) Butane
(b) Nonane
(c) Ethane
(d) Methane

16. Of the following isomers of C_6H_{14}, which one has the highest boiling point?
(a) *n*-Hexane
(b) 2,2-Dimethylbutane
(c) 2-Methylpentane
(d) 3-Methylpentane

17. In the names of alkanes, the suffix "*ane*-" indicates that alkanes:
(a) Have only straight chain structure.
(b) May contain one or more multiple bonds.
(c) Have cyclic structure.
(d) Contains carbon atoms linked to one another only by single bonds.

18. What is the IUPAC name of the hydrocarbon whose structure given below?



(a) 6-Ethyl-3,3-dimethylnonane
(b) 3,6-Diethyl-3-methyloctane

(c) 3,6-Diethyl-3-methylnonane
(d) 4,7-Diethyl-7-methylnonane

19. Alkanes undergo the following reactions except:
(a) combustion reaction
(b) elimination reaction
(c) substitution reaction
(d) addition reaction

20. Heptanes burns in oxygen to form carbon dioxide and water. When the equation for this combustion reaction is balanced, the coefficient of oxygen would be:
(a) 7
(b) 11
(c) 8
(d) 22

21. The reaction given by the equation; $CH_3 - CH_3 + Cl_2 \longrightarrow CH_3 - CH_2Cl + HCl$ is classified as:
(a) substitution reaction
(b) oxidation reaction
(c) elimination reaction
(d) decomposition reaction

22. What is the product of the following reaction?

$CH_3 - CH_2CH = CHCH_2CH_3 + H_2$

(a) Pentane
(b) *n*-Hexane
(c) 2-Hexene
(d) *n*-Heptane

23. Methane is prepared in the laboratory by:
(a) the reaction of water and calcium carbide
(b) dehydration of ethanol
(c) heating a mixture of sodium ethanoate and soda lime
(d) hydrogenation of ethene in the presence of platinum catalyst and heat

24. Which process is carried out to maximize the output of petrol or gasoline during fractional distillation of crude oil?
(a) dehydration
(b) sulfonation
(c) polymerization
(d) cracking

25. Which chemical added as anti-knocking agent to petroleum products?
    (a) Tetraethyl lead
    (b) Liquid hydrogen
    (c) Ethyl alcohol
    (d) Concentrated H_2SO_4
26. The hydrocarbon that is given an octane rating of 100 is:
    (a) *n*-Octane
    (b) 2,2,4-Trimethyloctane
    (c) 2,2,4-Trimethylpentane
    (d) 2,2,4-Trimethylhexane
27. When crude oil is heated in a furnace to about 400°C and introduced into the fractionating tower, the product obtained first is:
    (a) kerosene
    (b) bitumen or asphalt
    (c) diesel oil
    (d) bottled gas
28. Which general formula represents the group of hydrocarbons called olefins?
    (a) C_nH_{2n+1}
    (b) C_nH_{2n-2}
    (c) C_nH_{2n+2}
    (d) C_nH_{2n}
29. 1-Hexene and 2-Hexene are represented by the formula C_6H_{12}. Thus they are:
    (a) chain isomers
    (b) position isomers
    (c) geometrical isomers
    (d) skeletal isomers
30. Which one of the following compounds exhibits geometric isomerism?
    (a) 2-Methyl-2-butene
    (b) 2,3-Dimethyl-2-butene
    (c) 1,1,2-Trichloropropene
    (d) 2,3-Dichloro-2-butene
31. The principal reaction that alkenes undergo is:
    (a) elimination reaction
    (b) substitution reaction
    (c) addition reaction
    (d) sulfonation

32. Which one of the following reactions does not result in the formation of alkenes?
    (a) Halogenations of alkanes.
    (b) Dehydrohalogenation of alkyl halides with a base (NaOH).
    (c) Dehydration of alcohols.
    (d) Hydrogenation of alkynes in the presence of Lindlar's catalyst.
33. Propene decolorizes the reddish brown color of bromine in carbon tetrachloride. This is due to the formation of:
    (a) 1,1-Dibromopropane
    (b) 1,2-Dibromopropene
    (c) 1,2-Dibromopropane
    (d) 1,3-Dibromopropane
34. The purple color of alkaline potassium permanganate solution disappears when added to alkenes. This is due to the oxidation of alkenes to:
    (a) carboxylic acid
    (b) dicarboxylic acids
    (c) triesters
    (d) dihydric alcohol
35. Which alkene is commonly used for the preservation and artificial ripening of fruits?
    (a) Butylene
    (b) Ethylene
    (c) Propylene
    (d) Propene
36. What product is formed in the following chemical reaction?

    $CH_3CH_2CH = CH_2 + H_2O \longrightarrow$

    (a) 2-Butanol
    (b) Butanal
    (c) 1-Butanol
    (d) 2-Buten-1-ol
37. What product is formed if ethanol is heated to a temperature of 170°C in the presence of concentrated H_2SO_4?
    (a) Ethanoic acid
    (b) Ethene
    (c) Ethanal
    (d) 1-Butene

38. Consider the reaction: $CH_3CH_2\ CH_2\ CH_2Cl + KOH \longrightarrow X + KCl + H_2O$, what is the missing product 'X'?
    (a) Butane
    (b) 2-Butene
    (c) 1-Butanol
    (d) 1-Butene
39. What is the molecular formula of an alkene known by the common name "Butylene"?
    (a) C_4H_6
    (b) C_4H_7
    (c) C_4H_8
    (d) C_4H_{10}
40. The correct IUPAC name for the compound $CH_3 - C \equiv C - CH_2 - CH_2Br$ is:
    (a) 5-Bromo-2-pentyne
    (b) 5-Bromo-2-pentene
    (c) 1-Bromo-3-pentyne
    (d) 1-Bromo-3-pentene
41. What is the molecular formula of ethyl methyl acetylene?
    (a) C_5H_{10}
    (b) C_5H_8
    (c) C_6H_{10}
    (d) C_6H_{12}
42. Which hydrocarbon is prepared by the reaction of calcium carbide and water?
    (a) Methane
    (b) Ethene
    (c) Acetylene
    (d) Propyne
43. When alkanes, alkens and alkynes are arranged in increasing order of reactivity, the correct sequence is:
    (a) Alkynes < Alkenes < Alkanes
    (b) Alkanes < Alkynes < Alkenes
    (c) Alkenes < Alkanes < alkynes
    (d) Alkanes < Alkenes < Alkynes
44. Trimerization of ethyne at a temperature of about 600–700°C gives:
    (a) Benzene
    (b) Cyclohexane
    (c) *n*-Hexane
    (d) *n*-Butane

45. When the equation; $C_5H_{10} + O_2 \longrightarrow CO_2 + H_2O$, is balanced, the coefficient of CO_2 would be:
    (a) 5
    (b) 15
    (c) 10
    (d) 1
46. Which one of the following hydrocarbons serves as a fuel to produce a flame that is used to cut and weld metals?
    (a) Methane
    (b) Ethyne
    (c) Ethene
    (d) Butane
47. Which one of the following statements is not true about benzene?
    (a) The carbon-carbon bonds in bezene are alternating single and double bonds.
    (b) It is chemically more stable than alkanes and alkynes.
    (c) It is carcinogenic substance.
    (d) It is represented by a resonance hybrid structure.
48. When a mixture of benzene vapor and hydrogen gas is passed over powdered nickel catalyst at 200°C, the reaction that takes place is:
    (a) Elimination reaction
    (b) Oxidation reaction
    (c) Substitution reaction
    (d) Addition reaction
49. The term "sulfonation" refers to the reaction of benzene with:
    (a) Concentrated sulfuric acid
    (b) Elemental sulfur
    (c) Concentrated nitric acid
    (d) Hydrogen in presence of Platinum catalyst
50. Alcohols are classified as monohydric, dihydric, etc, based on:
    (a) The type of carbon atom to which –OH group is attached.
    (b) The type hydrocarbon chain the alcohol contains.
    (c) The number of hydroxyl group the alcohol contains.
    (d) The presence of single, double and triple bonds in the hydrocarbon chain.
51. The products of the reaction given by the following equation are:

$$CH_3CH_2CH_2COOCH_2CH_2CH_3 + KOH \longrightarrow$$

(a) Potassium propanoate and 1-Butanol
(b) 1-Butanol and 1-Propanol
(c) Potassium butyrate and 1-Propanol
(d) 1-Propanol and Butanoic acid

52. The general structural formula of compounds formed by the reaction of alcohols and carboxylic acids is:
(a) RCOOR'
(b) ROR'
(c) RCOR'
(d) RCHO

53. Which gas is liberated when ethanol reacts with sodium metal?
(a) Carbon dioxide gas
(b) Hydrogen gas
(c) Methane gas
(d) Carbon monoxide

54. The oxidation of primary alcohols in the presence of potassium permanganate yields:
(a) ketones
(b) aldehydes
(c) carboxylic acids
(d) esters

55. Which one of the following alcohols gives a ketone on oxidation?
(a) 1-Pentanol
(b) 2-Methyl-1-butanol
(c) 2,2-Dimethyl-1-propanol
(d) 2-Butanol

56. The correct IUPAC name of the compound $CH_3CH_2CH_2COCH_2CH_3$ is:
(a) 3-Hexanone
(b) Ethylbutanoate
(c) 4-Hexanone
(d) *n*-Propylpropanoate

57. The acid found in rancid butter is:
(a) Methanoic acid
(b) *n*-Butanoic acid
(c) *n*-Propanoic acid
(d) Ethanoic acid

58. Which group of organic compounds is prepared by hydrohalogenation of alkenes?
    (a) Aldehydes
    (b) Alcohols
    (c) Alkyl halides
    (d) Esters
59. Ethylbutanoate is one of the esters that give pineapple its odor and taste. Which alcohol and carboxylic acid can react to form this ester?
    (a) Ethanoic acid and 1-Butanol
    (b) Butanoic acid and 1-Propanol
    (c) Ethanoic acid and Ethyl alcohol
    (d) Butanoic acid and Ethanol
60. Which one of the following is not natural condensation polymer?
    (a) Polyester
    (b) Starch
    (c) Proteins
    (d) Cellulose
61. Which addition polymer is used to coat the surface of cooking utensils?
    (a) Perspex
    (b) Polyethene
    (c) Poly tetrafluoroethylene
    (d) Polypropylene
62. Which one of the following carbohydrate does not yield two monosaccharide units on hydrolysis?
    (a) Sucrose
    (b) Maltose
    (c) Lactose
    (d) Galactose
63. The type of chemicals that are directly sold to the public are:
    (a) Basic chemicals
    (b) Consumer chemicals
    (c) Specialty chemicals
    (d) Fine chemicals
64. Which of the following substances are cause of acid rain?
    (a) Unburnt hydrocarbons and ozone
    (b) Chlorofluorocarbons
    (c) Oxides of sulfur and nitrogen
    (d) Particulates

65. Which one of the following is not the effect of global warming?
    (a) Climate change
    (b) Melting of polar ice
    (c) Rising of ocean water level
    (d) Reducing the global average temperature.
66. Which one of the following is not the application of biotechnology?
    (a) In the production of alcoholic beverages by fermentation.
    (b) In metal extraction by bioleaching.
    (c) In reducing crop yield by changing their genetic make up.
    (d) In manufacturing biofuels to reduce pollution.
67. The extraction of which metal does not involve electrolysis?
    (a) Aluminum
    (b) Iron
    (c) Sodium
    (d) Calcium
68. The mineral ore of which metal needs to be concentrated by froth flotation before its extraction?
    (a) Copper
    (b) Aluminum
    (c) Gold
    (d) Iron
69. The cyanide process is an industrial method for the extraction of:
    (a) Tin
    (b) Aluminum
    (c) Copper
    (d) Gold
70. Down's cell is an apparatus used for the extraction of:
    (a) Aluminum
    (b) Copper
    (c) Sodium
    (d) Tin
71. When the metals sodium, aluminum, iron and calcium are arranged in increasing order of abundance in the earth's crust, the correct sequence is:
    (a) calcium, sodium, aluminum, iron
    (b) sodium, calcium, iron, aluminum
    (c) aluminum, iron, calcium, sodium
    (d) iron, aluminum, calcium, sodium

72. Which one of the following compounds of calcium is incorrectly matched with its use?
    (a) $CaCl_2$ – for drying ammonia gas
    (b) $Ca(OH)_2$ – to remove soil acidity
    (c) $(CaSO_4)_2 . H_2O$ – for plastering walls
    (d) $CaCO_3$ – as flux in iron extraction
73. Copper metal is not used:
    (a) to make electric wire and cable
    (b) to make alloys like bronze and brass
    (c) to produce compounds used as pesticide and fungicide
    (d) as monetary reserve for individuals and nations.
74. Which one of the following non–metallic element does not exhibit allotropy?
    (a) Oxygen
    (b) Sulfur
    (c) Nitrogen
    (d) Carbon
75. Of the following, which one is not a step in Ostwald process of nitric acid production?
    (a) Oxidation of nitrogen by electric arc to produce NO.
    (b) Oxidation of NO to NO_2.
    (c) Catalytic oxidation of ammonia to produce nitric oxide, NO.
    (d) Absorbing NO_2 in water.
76. The non-metallic element extracted industrially by electrolysis is:
    (a) nitrogen
    (b) chlorine
    (c) bromine
    (d) graphite
77. Which oxides react with both acids and bases to form salt and water?
    (a) neutral oxides
    (b) acidic oxides
    (c) basic oxides
    (d) amphoteric oxides
78. The reagent used for the identification of halide ions is:
    (a) barium chloride solution
    (b) lead sulfide
    (c) silver nitrate solution
    (d) lime water

79. The Bosch process is an industrial method for the production of:
    (a) sulfuric acid
    (b) carbon dioxide
    (c) ammonia gas
    (d) halogens
80. Which gaseous substance has a smell of rotten egg?
    (a) hydrogen sulfide
    (b) carbon monoxide
    (c) ammonia
    (d) nitrogen dioxide

Model Test

Answer the following questions

1. The by product of fermentation of sugar is:
    (a) ethanoic acid
    (b) carbon (IV) oxide
    (c) propanol
    (d) propan-1,2,3-triol
2. Which of the following sugar is a product of the condensation of monosaccharide's?
    (a) Galactose
    (b) Glucose
    (c) Maltose
    (d) Fructose
3. The cleansing effect of soap is low in acidic water because of:
    (a) Increase in the *p*H of the soap molecules.
    (b) The formation of unionized fatty acid.
    (c) Anti-biodegradable effect of hydrogen ions.
    (d) The hardness of the acidic water.
4. The following compounds are condensation polymers except:
    (a) Nylon
    (b) Protein
    (c) Polyethene
    (d) Starch

5. What amount of electricity is required to deposit one mole of aluminum from a solution of $AlCl_3$?
   (a) One Faraday
   (b) One ampere
   (c) Three amperes
   (d) Three Faradays
6. Which of the following compounds would react rapidly with bromine?
   (a) Benzene
   (b) Hexene
   (c) Hexane
   (d) Hexanol
7. Alkanols can be manufactured from alkenes by the initial reaction of alkenes with
   (a) Bromine in tetra chloromethane.
   (b) Sodium hydroxide solution.
   (c) Aqueous potassium tetraoxomanganate (VII).
   (d) Concentrated tetraoxosulphate (VI) acid.
8. Which of the following statements about the standard hydrogen electrode is not correct?
   (a) The temperature is kept at 20^oC
   (b) A solution containing 1 mol dm^{-3} of H^+ (aq) ions is used
   (c) A platinum electrode is used
   (d) The hydrogen gas is at a pressure of 1 atmosphere
9. If 60g of M combines with 24g of oxygen, what would the empirical formula of the oxide be? [O = 16.0, M = 120]
   (a) MO
   (b) MO_3
   (c) MO_2
   (d) MO_4
10. The products of the electrolysis of dilute sodium chloride using carbon electrodes are:

	Anode		**Cathode**
(a)	Chlorine	and	Sodium
(b)	Hydrogen	and	Oxygen
(c)	Chlorine	and	Hydrogen
(d)	Oxygen	and	Hydrogen

11. Determine the quantity of electricity used when a current of 0.20 ampere is passed through an electrolytic cell for 60 minutes.
    (a) 720 C
    (b) 360 C
    (c) 120 C
    (d) 12 C
12. Oxo chlorate(I) acid is used as a bleaching agent because it is:
    (a) a weak acid
    (b) a reducing agent
    (c) a strong acid
    (d) an oxidizing agent
13. The IUPAC name for $CH_3CHCH_3CHClCHCH_3CH_2CH_3$ is:
    (a) 3-Chloro-2,4-dimethylhexane.
    (b) 3,5-Dimethyl-4-chlorohexane.
    (c) 4-Chloro-3,5-dimethylhexane.
    (d) 2,4-Dimethyl-3-chlorohexane.
14. A colourless gas with a pungent smell is evolved when dilute hydrochloric acid is added to a sample of a salt. The gas evolved could turn:
    (a) Acidified $K_2Cr_2O_7$ solution colourless.
    (b) $Fe(NO_3)_2$ solution green.
    (c) Acidified $KMnO_4$ solution colourless
    (d) $Pb(NO_3)_2$ paper black.
15. If 5.0 g of marble reacts with 25.0 cm^3 hydrochloric acid, which of the following combinations has the fastest reaction rate?
    (a) Marble chips and 2.0 mol dm^{-3} HCl(aq)
    (b) Marble chips and 2.5 mol dm^{-3} HCl(aq)
    (c) Powdered marble and 2.0 mol dm^{-3} HCl(aq)
    (d) Powdered marble and 2.5 mol dm^{-3} HCl(aq)
16. Increasing the temperature generally:
    (a) increases the solubility of a solid in a liquid but decreases the solubility of a gas in a liquid.
    (b) decreases the solubility of a solid in a liquid but increases the solubility of a gas in a liquid.
    (c) increases the solubility of both a solid and a gas in a liquid.
    (d) decreases the solubility of both a solid and a gas in a liquid.

17. A white precipitate was formed when $BaCl_2(aq)$ was added to an aqueous solution of a salt X.
    (a) CO_3^{2-} ions
    (b) SO_3^{2-} ions
    (c) NO_3^- ions
    (d) SO_4^{2-} ions
18. Before a reaction could take place, there should be:
    (a) ionization of reactant particles.
    (b) breakage of bonds of reactants.
    (c) breakage of bonds of products.
    (d) ionization of product particles.
19. Consider the following reaction equation:

    $$CaO + SiO_2 \longrightarrow CaSiO_3$$

    Silicon(IV) oxide is acting as:
    (a) basic oxide
    (b) reducing agent
    (c) oxidizing agent
    (d) acidic oxide
20. Which of the following acids would form normal salt only?
    (a) Trioxonitrate(V) acid
    (b) Tetraoxosulpahte(VI) acid
    (c) Tetraoxophosphate(V) acid
    (d) Trioxosulphate(IV) acid
21. What is the partial pressure of oxygen at S.T.P. in a gaseous mixture containing 100 cm^3 of oxygen and 900 cm^3 of nitrogen gas?
    (a) 0.9 atm
    (b) 0.1 atm
    (c) 9.0 atm
    (d) 1.0 atm
22. Graphite is used as a dry lubricant due to the presence of:
    (a) mobile electrons
    (b) layered structures
    (c) octahedral structures
    (d) free electrons
23. Which of the following gases is alkaline?
    (a) NH_3
    (b) CO_2

(c) NO_2
(d) N_2O

24. Which of the following statements about an equilibrium system is correct?
    (a) The concentrations of reactants and products can be changed by adding a catalyst.
    (b) The concentrations of reactants must equal that of the products.
    (c) Forward and backward reactions occur at the same rate.
    (d) The concentrations of reactants and products are not affected by a change in temperature.
25. Consider the following reaction equation:

    $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g); \Delta H = -92kJ$

    Increasing the temperature of the reaction would
    (a) shift the equilibrium to the right.
    (b) decrease the yield of ammonia
    (c) decrease the amount of hydrogen.
    (d) increase the yield of ammonia.
26. When air in a syringe is compressed such that there is no change in temperature, the:
    (a) pressure increases
    (b) air liquefies
    (c) intermolecular space increases
    (d) density decreases
27. Which of the following statements about liquids is/are true?
    (i) Liquids maintain their volume at constant temperature.
    (ii) Liquids have fixed shape.
    (iii) Liquids do not diffuse.
    (iv) Change in pressure affects volume of liquids.
    (a) I only
    (b) IV only
    (c) II and III only
    (d) I and IV only
28. A hydrogen chloride gas reacted with oxygen gas to yield water and chlorine gas. The mole ratio of the hydrogen chloride gas to water is:
    (a) 2 : 1
    (b) 1 : 3
    (c) 3 : 1
    (d) 4 : 1

29. What number of moles of oxygen would exert a pressure of 10 atm at 320 K in an 8.2 dm^3 cylinder? [R = 0.082 atm dm^{-3} mol^{-1} K^{-1}]
    (a) 31.25
    (b) 3.13
    (c) 1.52
    (d) 0.32
30. If 50 cm^3 of a saturated solution of KNO_3 at 40°C contained 5.05 g of the salt, its solubility at the same temperature would be [KNO_3 = 101]
    (a) 5.0 mol dm^{-3}
    (b) 2.0 mol dm^{-3}
    (c) 1.5 mol dm^{-3}
    (d) 1.0 mol dm^{-3}
31. Which of the following elements would displace copper from a solution of copper ions?
    (a) Lead
    (b) Gold
    (c) Silver
    (d) Mercury
32. What is the percentage composition of carbon in $Ca(HCO_3)_2$?
    [Ca = 40.0, O = 16.0, C = 12.0, H = 1.0]
    (a) 3.7%
    (b) 7.4%
    (c) 14.8%
    (d) 22.2%
33. Which of the following bond types is intermolecular?
    (a) Hydrogen bond
    (b) Covalent bond
    (c) Ionic bond
    (d) Metallic bond
34. The maximum number of covalent bonds formed by nitrogen is:
    (a) 4
    (b) 3
    (c) 2
    (d) 1
35. The IUPAC name of the compound $CH_3CH(CH)_3CH=CH_2$ is:
    (a) 2-Methylbut-1-ene
    (b) 3-Methylbut-1-ene

(c) 2-Methylbut-2-ene
(d) 3-Methylbut-2-ene

36. Ionization energy increases across the period in the Periodic Table because:
(a) atomic number increases.
(b) mass number decreases.
(c) effective nuclear charge increases.
(d) screening effect decreases

37. Which of the following properties indicate that an element is a metal.
(i) It reacts with oxygen to form an acidic oxide.
(ii) It forms ionic chlorides.
(iii) It has variable oxidation states.
(iv) It displaces hydrogen from dilute HCl.
(a) I and III only
(b) I and II only
(c) I, II, III and IV
(d) II and IV only

38. The electron configuration of carbon atom in its excited state is:
(a) $1s^2 2s^1 2p_x^{\ 1} 2p_y^{\ 1} 2p_z^{\ 1}$
(b) $1s^1 2s^2 2p_x^{\ 1} 2p_y^{\ 1} 2p_z^{\ 1}$
(c) $1s^2 2s^2 2p_x^{\ 2} 2p_y^{\ 0}$
(d) $1s^2 2s^2 2p_x^{\ 1} 2p_y^{\ 1}$

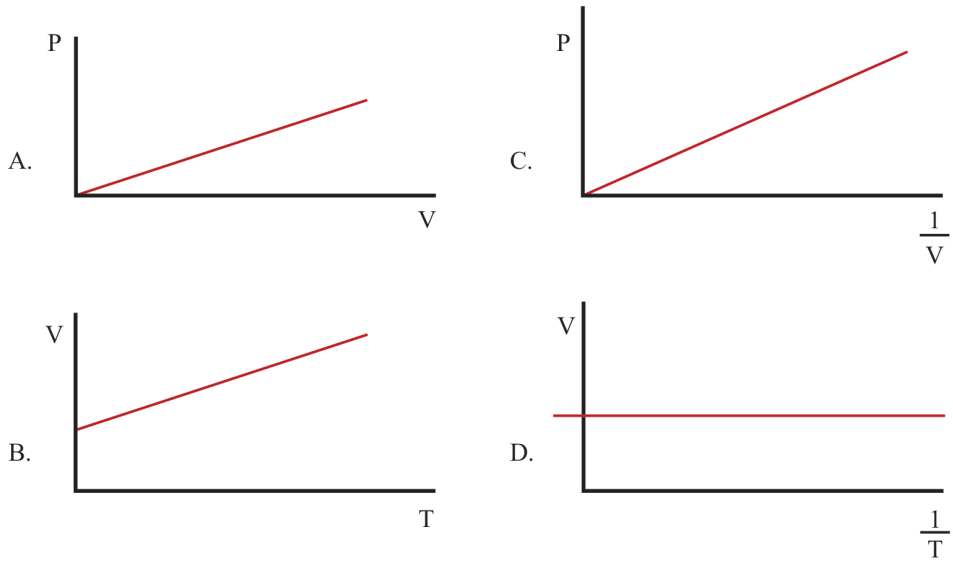
39. An oxide has the following properties:
(i) It is a white powder.
(ii) It reacts with HCl.
(iii) It reacts with NaOH.
(iv) It is insoluble in water.

The oxide is:

(a) alkaline
(b) acidic
(c) amphoteric
(d) neutral

40. Which of the following statements about atoms of a metal is correct?
(a) They are held together by a sea of electron cloud
(b) They are soft
(c) They are held together by covalent bond
(d) They readily accept electrons

41. Which of the following sketches is a graphical representation fo Boyle's law?



42. The atom with the electron configuration $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^4$ is in:
    (a) Period 3, *p*-block
    (b) Period 4, *p*-block
    (c) Period 4, *d*-block
    (d) Period 3, *d*-block
43. Electropositivity of elements across the Periodic Table normally:
    (a) remains constant down the group.
    (b) increases across the period.
    (c) decreases down the group.
    (d) decreases across the period.
44. Consider the following table:

Substance	Melting point /°C	Boiling point /°C
P	-78	-25
Q	-8	40
R	-6	150
S	44	280

Which of the substances is a liquid at room temperature and rapidly evaporates on exposure to air?

(a) P
(b) R

(c) Q
(d) S

45. Which of the following oxides is amphoteric?
(a) Carbon(II) oxide
(b) Lead(II) oxide
(c) Nitrogen(IV) oxide
(d) Calcium oxide

46. Which of the following processes occur during fractional distillation of petroleum?
(a) Evaporation and condensation
(b) Diffusion and evaporation
(c) Diffusion and sublimation
(d) Condensation and diffusion

47. If the molar mass of $X(HCO_3)_2$ is 162 g mol^{-1}. Determine the relative atomic mass of X.

[H = 1.0, C = 12.0, O = 16.0]

(a) 101
(b) 61
(c) 48
(d) 40

48. Charcoal is used in the decolourization of sugar because of its:
(a) absorption property
(b) adsorption property
(c) oxidizing property
(d) amorphous property

49. The first definition of an element was made by:
(a) J. Dalton
(b) A. Lavoisier
(c) J. J. Thompson
(d) R. Boyle

50. Which of the following scientist formulated the law of conservation of mass?
(a) J. Dalton
(b) A. Lavoisier
(c) R. Boyle
(d) J. Proust

Answer two questions only from this section.

1.

(a)

(i) Define functional group.

(ii) Give the structure of the following compound:
2-Methylpropan-1-ol

(b)

(i) Define the term saponification.

(ii) Write a general chemical equation to illustrate saponification.

(c) State two ways of increasing the rate of reaction between dilute hydrochloric acid and magnesium ribbon.

(d) State Avogadro's law.

(e) Outline the procedure for the determination of the pH of a solution using a universal indicator solution.

(f) Mention two applications of electrolysis.

(g) Distinguish between temporary hardness and permanent hardness.

(h) Distinguish between soapy detergents and soapless detergents.

(i) State the reagent and condition necessary for the following conversion:
$CH_3CH_2CH_2OH \longrightarrow CH_3CH_2COOH$

(j) State three differences between a sigma bond and a pi bond.

2.

(a)

(i) What are transition metals?

(ii) Why is it that at high pressure, ideal gases behave as real gases?

(iii) Explain briefly why iodine is partially soluble in polar solvents but readily soluble in non - polar solvents.

(b) Butanol can be produced by fermentation of a sugar solution.

(i) State two conditions necessary for this process;

(ii) If butanol has four isomers, butan-1-ol, butan-2-ol, A and B.

(a) Write down the structures of isomers A and B.

(b) Give the IUPAC name of each of the isomers A and B.

(c) If a piece of copper metal were placed in separate solutions of silver trioxonitrate (V) and zinc trioxonitrate (V):

(i) State which solution would undergo a reaction;

(ii) What type of reaction takes place in the copper metal;

(iii) Write an equation for the reaction in (c) (ii);

(iv) State what visible change would take place in the solution.

(d) Consider the following reaction equation:
$X(OH)_2 + 2HCl \longrightarrow XCl_2 + 2H_2O$
If 25.0 cm^3 of the saturated alkali solution was completely neutralized by 28.5 cm^3 of a 1.5 mol dm^{-3} solution of HCl, calculate the solubility of the alkali in g dm^{-3} given that its molar mass is 150 g mol^{-1}.

3.

(a) How many NO_3^- ions are in 0.10 mol dm^{-3} $Ca(NO_3)_2(aq)$?
$[N_A = 6.02 \times 10^{23}]$

(b) Explain briefly why aqueous solution of Na_2CO_3 is basic while aqueous KCl is neutral.

(c)

(i) Define the term effective collision.
(ii) State three properties that could be used to measure the rate of a chemical reaction.

(d) When ethane gas is compressed, a solid is formed.

(i) Name the process involved in the conversion.
(ii) State two conditions under which the conversion would occur.
(iii) Name the solid formed.
(iv) Give the reason why it is not advisable to allow the solid formed to accumulate in the environment.

(e)

(i) State two postulates of the Bohr's model of the atom.
(ii) State the short comings of the model.
(iii) What is an ideal gas?

4.

(a)

(i) Write the main reactions which take place during the extraction of iron in the blast furnace.
(ii) Which of the reactions stated in (a) (i) can be considered as a neutralization reaction?
(iii) Give a reason for the answer stated in (a) (ii).
(iv) What is the function of $CaCO_3$ in the extraction process?

(b)

(i) State the raw materials used in the production of HNO_3.
(ii) Write a balanced equation for the laboratory production of HNO_3.

(c)

(i) What is destructive distillation of coal?
(ii) State two products of the destructive distillation of coal?
(iii) Give two applications of destructive distillation of coal?

(d)

(i) Name the two main allotropes of sulfur.
(ii) Sate two differences between the allotropes named in (d) (i).
(iii) State what would be observed when sulfur reacts with cold dilute H_2SO_4.

5.

(a)

(i) What is hard water?
(ii) State the two types of hard water.
(iii) After a long time, the inner side of a kettle appears whitish:
(a) What is the cause of this whitish appearance?
(b) How can this appearance be removed?

(b)

(i) In the contact process for the manufacture of tetraoxosulphate (VI) acid, the following reaction occurs:
$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$, $\Delta H = -197\ kJ\ mol^{-1}$
(a) Name the catalyst used in the reaction.
(b) State the optimum temperature for this reaction.
(c) What would be the effect on the yield of SO_3, if a temperature higher than the optimum is used?
(ii) State the precaution that must be taken in the laboratory preparation of a dry sample of sulfur(IV) oxide.
(iii) Give a reason why the precaution stated in (b) (ii) must be taken.
(iv) Write a balanced chemical equation for the preparation of sulfur(IV) oxide.

(c)

(i) State three differences between the bleaching action of chlorine and sulfur(IV) oxide.
(ii) Give a reason why water gas is a better fuel than producer gas.
(iii) Give a reason why a plastic apparatus is not used in the laboratory production of HNO_3.

What is Bullying?

Any unwanted written, verbal, graphic, or physical act by an individual or group toward another person(s) that causes harm or distress.

Types of Bullying

- Physical
- Verbal
- Social
- Emotional
- Cyber

Signs of Bullying

- Headaches
- Depression
- Loss of friends
- School absenteeism
- Academic problems

What You Can Do

PREVENT

- Be a role model for positive communication, healthy relationships, and self-care.
- Reinforce acts of kindness, respect, and inclusion.
- Set policies and rules about bullying.

RECOGNIZE

- Know the definition of bullying and its many forms.
- Talk with and actively listen to the youth who confide in you.
- Watch for warning signs of bullying.

INTERVENE

- If you witness bullying behavior
- Respond quickly and consistently to send the message that it is not acceptable.
- Separate the students involved.
- Meet any immediate medical or mental health needs.
- Stay calm and model respectful behavior.

Source: Teacher's Diary on *Cyber-Crime Awareness* by UNODC, Cybercrime and MoE, Republic of Liberia

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TEXTBOOK MANAGEMENT
Student Textbook Assignment Form

School : _____

District : _____Country: _____

Teacher : _____Subject: _____

Grade : _____

No.	Name of the Student	Name of the Textbook	Barcode Number	Condition of the TB when received	Date Received	Date Returned	Condition of TB when returned	Signature of Student
1								
2								
3								
4								
5								
6								
7								
8								
9								
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11								
12								
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15								