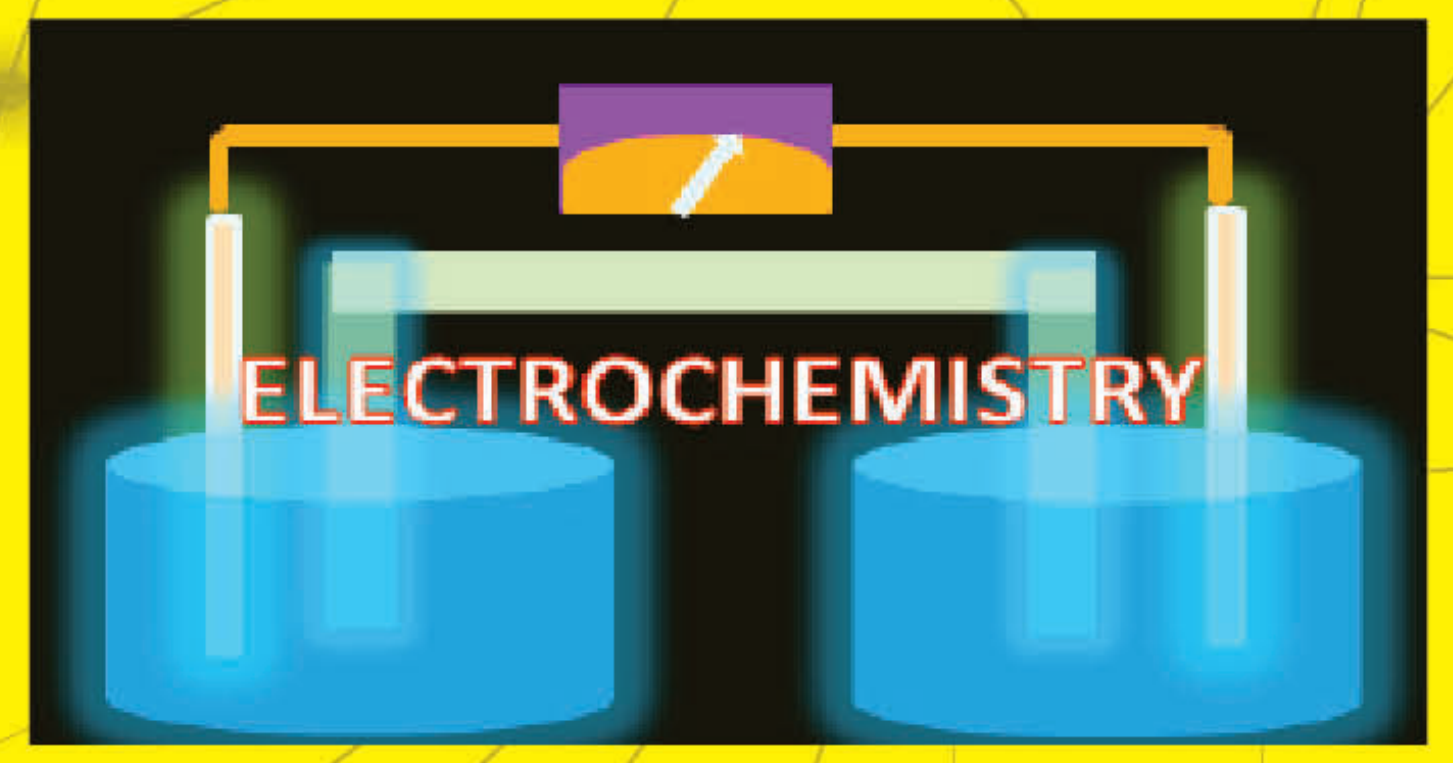
Module - II

ELECTROCHEMISTRY AND SOME IMPORTANT SUBSTANCES (METALS, NONMETALS, AND HYDROCARBONS)

CHEMISTRY
GRADE 10



Federal Democratic Republic of Ethiopia
Ministry of Education

CHEMISTRY
GRADE 10

ELECTROCHEMISTRY AND SOME IMPORTANT SUBSTANCES
(METALS, NONMETALS, AND HYDROCARBONS)

Module - II

ELECTROCHEMISTRY AND SOME IMPORTANT SUBSTANCES
(METALS, NONMETALS, AND HYDROCARBONS)

CHEMISTRY
GRADE 10

ISBN: XXXXXXXXX

Federal Democratic Republic of Ethiopia
Ministry of Education

PRICE: ETB XX.XX

CHEMISTRY

MODULE - II
GRADE 10

Electrochemistry and Some Important Substances (Metals, Nonmetals, and Hydrocarbons)

Writers:
Alemayehu Paulos (Ph.D.)
Adelew Estifanos (Ph.D.)

Editors:
Anteneh Wasyhun (Ph.D.) (Curriculum Edditor)
Kenenisa Beresa (M.A.) (Language Editor)

Illustrator:
Abinet Tilahun (M.Sc.)
Designer:
Konno B. Hirbaye (M.Sc.)

Evaluators:
Nega Gichile (B.Sc., M.A.) (Evaluator)
Sefiw Melesse (M.Sc.) (Evaluator)
Tolessa Mergo (B.Sc., M.Sc.) (Evaluator)

Federal Democratic Republic of Ethiopia
Ministry of Education

Hawassa University

First Published 2023 by the Federal Democratic Republic of Ethiopia, Ministry of Education, under the General Education Quality Improvement Program for Equity (GEQIP-E) supported by the World Bank, UK's Department for International Development/DFID-now merged with the Foreign, Common wealth and Development Office/FCDO, Finland Ministry for Foreign Affairs, the Royal Norwegian Embassy, United Nations Children's Fund/UNICEF), the Global Partnership for Education (GPE), and Danish Ministry of Foreign Affairs, through a Multi Donor Trust Fund.

The Ministry of Education wishes to thank the many individuals, groups and other bodies involved – directly or indirectly – in publishing this Textbook. Special thanks are due to Hawassa University for their huge contribution in the development of this textbook in collaboration with Addis Ababa University, Bahir Dar University, Jimma University and Samara University.

Photo Credit:

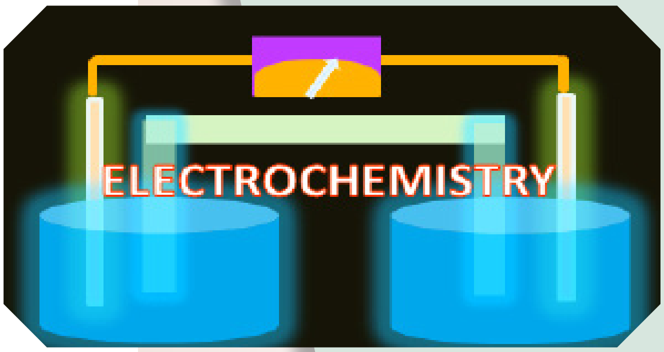
Printed by:
PRINTING
P.O.Box:
ETHIOPIA

Under Ministry of Education Contract no.:

ISBN: 978-999944-2-046-9

MODULE CONTENTS

UNIT 4



ENERGY CHANGES AND ELECTROCHEMISTRY

Module Introduction

- This Part II of the Chemistry Grade 10 Distance Learning Module has three units. As this is a continuation of the first module, which already had three units, we continue with Unit 4 and go through Unit 5 and unit 6. The first unit of this module that is Unit 4, deals with energy changes involved in chemical reactions and electrochemistry, where you will learn about exothermic and endothermic reactions, examples of each, and energy diagrams, and the importance of chemical reactions. Then, you will study electrochemistry-a branch of chemistry that deals with redox reactions taking place in electrochemical cells and the energy changes involved. Our focus will be on galvanic cells where spontaneous redox reactions are used to generate electrical energy. We will consider the different types of galvanic cells, namely primary, and secondary cells. In higher grades,you will learn the third type of galvanic cells called fuel cells. In the unit, we will briefly see the other type of the electrochemical cells known as electrolytic cells through a discussion of the electrolysis of fused salts because details of this will be part of your future study. The second unit (Unit 5) of this module deals with metals and nonmetals, where you will study some important metals and nonmetals, their extraction, use, and production. The third unit (Unit 6) deals with a very important class of organic compounds called hydrocarbons. We will see the classification, nomenclature, sources, physical and chemical properties, and isomerism of these substances.

- I hope you'll develop a better understanding of key chemical concepts in energy changes and electrochemistry, important metals and nonmetals, and get an impression of a very interesting field of study called organic chemistry through your experiences with hydrocarbons in this module. Your learning will be supported throughout the units by the extensive use of practical examples and solved problems. In addition, there are activities and self-test exercises that are supposed to help you assess your progress.

- Dear learner, welcome to the Grade 10 Chemistry Lesson on Energy Changes and Electrochemistry! You have already studied in Unit 1 about the different types of chemical reactions and their characteristics. One of these characteristics is that chemical reactions almost always involve energy changes.

? Why do you think we should be interested in the energy changes involved in chemical reactions? Do you know the different forms of energy and their use?

You are familiar with a hand battery. You get light energy. But how does the battery generate light energy? All sorts of vehicles including automobiles, trucks, etc use fuel to run. Do you know the type of energy change that occurs when the vehicles run? What about their batteries? How do they work? Don't worry we will answer these questions and similar ones as we proceed through this unit!

The Required Study Time (10 Hours)

You should complete this unit in two weeks. If you schedule 2 hours a day, this will cost you a total of 10 hours.

Unit Learning Strategies

Dear student, you can adapt to different learning strategies depending on the circumstances. We kindly advise you to take a few minutes to read and understand the content in each section. It is a wise strategy to associate what you learn with your daily experiences. This helps you stabilize your memory of the learned material. Be assisted with examples. Frequently check your progress with the help of the activities and self-test exercises provided under each section. Be assisted with the internet, especially video lessons. You can also find a friend attending a similar program, arrange a meeting, and hold joint discussion on topics that you find difficult at first. We assume that you can find schools in your area. Feel free to contact the school's chemistry teachers. They will help you. Similarly students of grades 10 and above can also help you enrich your understanding of the subject matter. Hiring a tutor is another alternative that you can think of if deemed necessary. Please be sure that you understand the contents under the current section very well before you proceed to the next one. Sketch your own study timetable and try to respect it.

Unit Contents

Unit Outcomes

At the end of this unit, you should be able to:

- describe energy changes in chemical reactions;
- describe how a chemical reaction produces electric current and how electricity brings about a chemical reaction in electrochemical cells;
- distinguish the difference between metallic conduction and electrolytic conduction;
- develop skills in writing the oxidation half-reaction, reduction half-reaction and cell reaction for the electrolysis of molten electrolytes that occur in electrolytic cells;
- describe the three types of Voltaic cells;
- explain the difference between electrolytic cells and Voltaic cells and
- demonstrate scientific inquiry skills: observing, classifying, comparing and contrasting, inferring, predicting, communicating, measuring, asking questions, interpreting data, drawing conclusion, applying concepts, relating cause and effect and problem-solving.

Section 4.1: Introduction

- In this section you will learn about the definitions and energy exchange between the surrounding and the system. You will also understand how one form of energy is converted into another without being destroyed or created.

- At the end of this section, you should be able to describe energy changes in chemical reactions.

- Dear learner, I hope you are familiar with the use of heat energy. You use it to cook your food. But how is the heat energy generated? Well, you know that you should burn fossil fuel or charcoal to get that heat energy. This means when the fuel burns, it is the combustion reaction of carbon in oxygen represented by the chemical equation

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

that results in the release of energy in the form of heat and light. During this process, the chemical energy contained in fossil fuels is converted into heat and light energy. Similarly, natural gas (principally methane, which has the formula CH_4) bums in oxygen.

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

gives not only the gaseous products carbon dioxide and water, but also energy in the form of heat and light.

Similarly plants use the energy from the sun to produce food. This process called photosynthesis also involves a chemical reaction-a combination reaction between carbon dioxide and water.

$$6CO_2(g) + 6H_2O \xrightarrow{\text{Sunlight}} \underset{\text{Glucose}}{C_6H_{12}O_6} + 6O_2$$

I hope you understood the importance of chemical reactions as a source of energy. To study the energy change, (ΔE), involved in chemical reactions like the combustion reaction we have just cited, scientists conceptually divide the universe into two parts: the system (the part being studied) and the surrounding (everything else).

Universe = System + Surrounding

A system is part of the universe that is being studied. Surrounding is anything other than the system in the universe. Each particle in a system under investigation, such as a reaction mixture in a test tube, has potential energy and kinetic energy, and the sum of all these energies is the internal energy, E, of the system.

The internal energy of a system is the sum of potential energy and kinetic energies of the components of the system.

$$(\text{Internal Energy})_{\text{system}} = (\text{potential energy} + \text{kinetic energy})_{\text{system}}$$

Potential energy is stored energy. It is stored in chemical bonds. Kinetic energy is the energy due to motion. It causes work to be done through movement. When the reactants in a chemical system change into products, the system's internal energy is changed. This change, ΔE, is the difference between the internal energy after the change (E_{final}) and before the change (E_{initial}):

$$E = E_{\text{final}} - E_{\text{initial}} = E_{\text{products}} - E_{\text{reactants}}$$

Where Δ (Greek delta) means "change (or difference) in" and refers to the final state minus the initial state. Thus, ΔE is the final quantity of energy in the system minus the initial quantity.

Note that the total energy of the universe remains constant. During photosynthesis, for instance, solar energy is converted into chemical energy stored in bonds in starch and O_2; when you digest starch, this chemical energy is converted into the muscular (mechanical) energy needed to run or walk, etc. Thus, energy changes form but does not simply appear or disappear—energy cannot be created or destroyed. Put another way, energy is conserved: the total energy of the system plus the surroundings remains constant.

During a chemical reaction, when the system loses a certain amount of energy, the surrounding area gains the same amount of energy. This means that energy is simply being exchanged between the two components of the universe keeping the total energy of the universe constant (***Figure 4.1***).

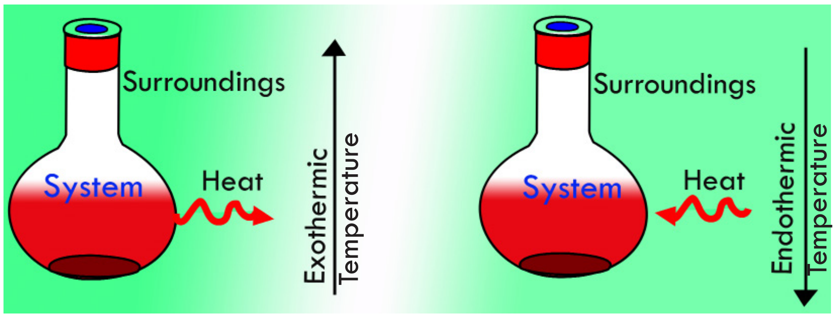


Figure 4.1 Energy exchange between the system and its surrounding.

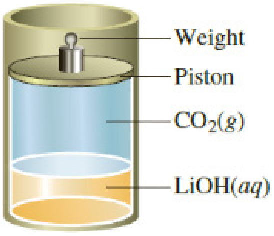
Energy transferred from a system to its surroundings or vice versa appears in two forms: heat and work. For instance, the various chemicals that makeup gasoline contain a large amount of chemical (potential) energy that is released when the gasoline is burned in a controlled way in the engine of the car. The release of that energy does two things: some of the potential energy is transformed into work, which is used to move a car; at the same time, some of the potential energy is converted to heat, which makes the car's engine very hot. Therefore, the energy changes in a system occur as either heat (q) or work (w), or some combination of both.

$$E = q + w$$

Dear learner, let's develop your understanding of this topic through examples.

Example 4.1

In a closed breathing systems, such as in spaceships, it is necessary to remove carbon dioxide exhaled during breathing from the air as well as replenish oxygen. One way to remove exhaled carbon dioxide is to circulate the air through a solution of LiOH with which CO_2 reacts:



$$2LiOH(aq) + CO_2(g) \rightarrow Li_2CO_3(s) + H_2O(l)$$

Imagine a setup in which a piston and weight (the surroundings) enclose a cylinder containing CO_2 gas above a solution of LiOH (the system) as shown above.
As CO_2 reacts with LiOH, the gas volume decreases, and the piston and weight move downward.

When 1.0 mol of CO_2 reacts, 89.1 kJ of heat evolves, and the piston and weight do 2.5 kJ of work on the system. The change in internal energy is (choose one):

A. + 91.6 kJ B. – 91.6 kJ C. + 86.6 kJ D. – 86.6 kJ

Given	Required	Solution
Q = - 89.1 kJ because heat is evolved		
W = 2.5 because the work is done on the system	ΔE?	ΔE = q + w
		= - 89.1 kJ + 2.5 kJ
		= - 86.6 kJ
		The correct answer is D

Dear student, what did you notice in the above example? If you have noticed that during the reaction chemical energy (energy stored in the chemicals in the form of potential energy) is converted into heat energy. That is great! In addition, the chemical reaction caused a decrease in the amount of gases or pressure associated with it, allowing mechanical work to be done on the system.

Section 4.2: Exothermic and Endothermic Chemical Reactions

- In this section you will learn about the definitions of exothermic and endothermic reactions and their corresponding energy diagrams. You will also conduct an experiment to further your understanding of how to measure energy changes of in chemical reactions.

At the end of this section, you should be able to

- Define endothermic reaction.
- Describe endothermic reaction.
- Define exothermic reaction.
- Describe exothermic reaction.
- Elucidate endothermic and exothermic reactions using diagrams.
- Do simple experiments to demonstrate exothermic and endothermic reactions.

☞ All of the combustion reactions mentioned in the previous section release energy in the form of heat. Such reactions are described as being exothermic (from the Greek exo meaning outside and therme meaning heat). One of the examples cited earlier is the combustion of coke in oxygen, which results in the release of a considerable amount of energy. Similarly, although on a much more modest scale, when NaOH dissolves in water, the test-tube becomes warm. In other words, the process results in a temperature rise. This observation indicates that the dissolving process for NaOH is also exothermic; that is, it is accompanied by the release of energy, which heats up the solution.

$$NaOH(s) \rightarrow Na^+(aq) + OH^-(aq)$$

The other is the reaction between calcium chloride and water:

$$CaCl_2(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + 2HCl(g) \ + heat$$

In this case too, heat is released during the reaction, elevating the temperature of the reaction mixture, and thus the reaction flask becomes hot. But, when potassium nitrate, KNO_3, dissolves in water, the mixture gets colder. This process can be represented by the following equation:

$$KNO_3(s) + Heat \xrightarrow{H_2O} K^+\ (aq) + NO_3^-(aq)$$

Reactions like this are described as being endothermic (from the Greek endo meaning within).

To study whether the energy is released or absorbed during a chemical reaction, we need to keep the temperature and pressure constant. Thus, if a reaction takes place at constant temperature and pressure, the heat transferred is called the enthalpy of the reaction, and this is denoted by the symbol ΔH:

$$H = H_{Products} - H_{reactants}$$

For an exothermic reaction: ΔH is negative, $\Delta H < 0$.
For an endothermic reaction: ΔH is positive, $\Delta H > 0$.
The relative energies of reactants and products in exothermic and endothermic reactions can be represented as shown schematically in ***Figure 4.2 a*** and ***b***, respectively.

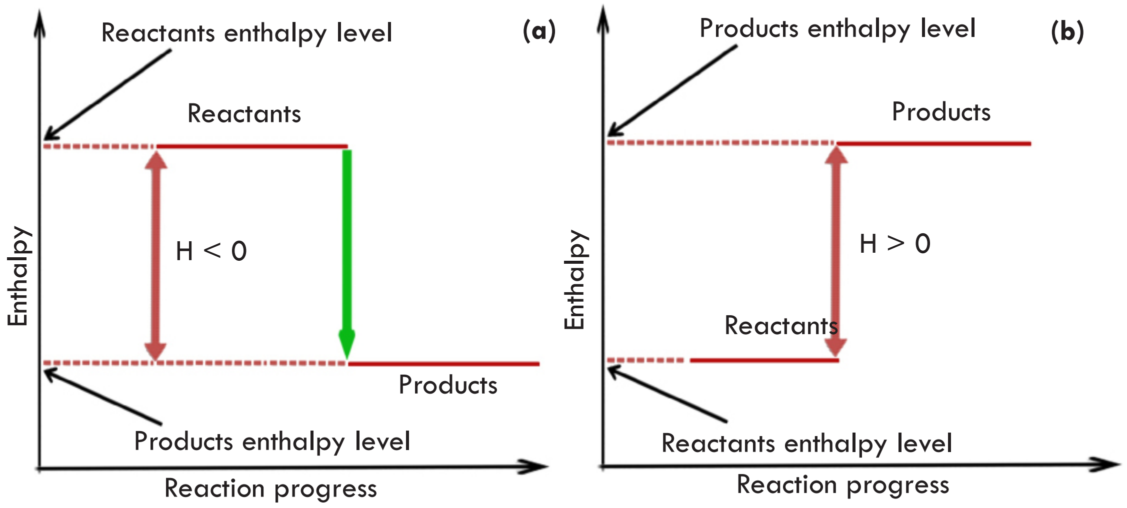


Figure 4.2 Enthalpy diagram for (a) exothermic reactions and (b) endothermic reactions.

The device used to measure the heat released (or absorbed) by a chemical reaction is called calorimeter. To find the energy change during chemical reaction, we measure the change in temperature and determine the quantity of heat released or absorbed using the following relation:

$$q \quad \Delta T \text{ or } \qquad q = \text{constant} \times \Delta T \qquad \text{or} \qquad q/\Delta T = \text{constant}$$

The proportionality constant in the above equation is called heat capacity. Every object has its own heat capacity. The heat capacity of a substance is defined as the quantity of heat required to change its temperature by 1 K.

$$\text{Heat capacity} = q/\Delta T$$

The unit of heat capacity is Joule per Kelvin (J/K). Heat capacity is related to a substance's ability to retain heat and the rate at which it will heat up or cool down. For example, a substance with a low heat capacity, such as iron, will heat and cool quickly, while a substance with a high heat capacity, such as water, heats and cools slowly.

A related property is specific heat capacity (c). The specific heat capacity (c) of a substance is defined as the quantity of heat required to change the temperature of 1 gram of the object by 1 K.

$$\text{Specific heat capacity } (c) = (\text{Heat capacity})/\text{mass} = q/(\text{mass} \times \Delta T)$$

If we know c of the object being heated (or cooled), we can measure the mass and the temperature change and calculate the heat absorbed (or released):

$$q = c \times \text{mass} \times \Delta T$$

Notice that metals have relatively low values of c and water has a very high value: for instance, it takes over 30 times as much energy to increase the temperature of a gram of water by 1 K as it does a gram of gold. This is one of the properties that make water unique and responsible for its use as a coolant in car radiators and industries

Experiment 4.1

Energy Changes in Chemical Reactions

Objective: To explore the energy changes involved in the reaction between acetic acid and baking soda.

Materials needed: Plastic cup or beaker, vinegar (acetic acid), baking soda ($NaHCO_3$), spatula/teaspoon, thermometer.

Procedure:

Pour about 10 mL of vinegar into a small plastic cup. Then, place a thermometer into the vinegar. Record the initial temperature (T_i).

While the thermometer is in the cup, add about ½ teaspoon of baking soda to the cup. Watch the thermometer for any change in temperature. After it has stopped changing, record the final temperature (T_f).

1. Based on your observations of the baking soda and vinegar reaction, is the reaction exothermic or endothermic?
2. Use energy level diagram to visualize the energy changes
3. Repeat the above steps using calcium chloride instead of vinegar. Briefly, dissolve 1/2 a spoonful of calcium chloride in 20 mL water in a test tube. Record your observation. In a second test tube, dissolve equal amount of baking soda and record your observation. Allow both solutions to cool to equal (room) temperature and record this temperature as Ti. Mix the two solutions in a plastic cup/beaker and record the final temperature.
4. Discuss the endothermic and exothermic processes observed in the above procedure.
5. Write the reaction equation and use energy level diagram to visualize the energy changes during reaction of calcium chloride and baking soda.

We have completed our discussion of the energy changes in chemical reactions. Based on energy changes, we classified reactions as endothermic and exothermic. We also studied how to represent these reactions using energy diagrams. Now take some time to perform the following activity and answer the self-test exercise. You may refer to the following sources that the author used to prepare this module.

Resources

- The current Ethiopian Grade 10 Chemistry Textbook for face-to-face modality.
- Silberberg, Martin S. Principles of General Chemistry-3rd ed. McGraw-Hill. 2013.
- Chang, R., Overby, J. General Chemistry-The Essential Concepts. 6th ed. McGraw-Hill. 2013.
- Ebbing, D. D., Gammon, S. D. General Chemistry Eleventh Edition, CENGAGE Learning 2015.

Activity 4.1

1. You have learnt in this section that reactions that cause the surrounding to heat up are called heat-releasing reactions and the process is exothermic. Reactions that take up energy from the surrounding such as the reaction flask are called heat absorbing and the process is endothermic. Based on this information, discuss whether energy (in the form of heat) is released or absorbed during

a. the baking of bread (consider the heat of the stove before and after the cold dough is loaded)

b. cooking food

c. burning wood, and then classify each of them as exothermic or endothermic. What other processes can you cite from your daily life experience that either release heat or absorb heat?

2. The major component of dynamite is nitroglycerin, a very unstable material, mixed with diatomaceous earth. What type of energy change occurs when dynamite explodes?

3. Is photosynthesis an endothermic or exothermic reaction? Write the balanced equation and draw an energy diagram indicating all the necessary information. Repeat this activity for respiration.

4. Please contact people working in energy sector offices around your area to help you:

a. Describe the energy sources of our country, Ethiopia. Compare their relative importance to the country's development. Which one is the principal source? Which one is the most important source that is underutilized? What are the different forms of energy contained in each of these sources?

b. Discuss the relevance of hydroelectric dams such as the GERD (the Grand Ethiopian Renaissance Dam) to the country's development vis-à-vis climate change. What energy changes are involved?

5. Discuss how hand batteries generate electrical energy and how light bulbs convert it into light.

Self-Test Exercise 4.1

1. Where does the energy released during chemical reaction come from?
2. How is the energy that you get from food stored in your body? How is it supplied to the cellular processes in your body when needed?
3. Explain the energy changes involved when:
   a. quicklime or calcium oxide (CaO) reacts with water to form slaked lime [$Ca(OH)_2$].

   $$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2\ (aq)$$

   b. limestone ($CaCO_3$) decomposes to give quicklime (CaO).
   c. Nitroglycerine (the major component of dynamite) decomposes

   $$4C_3H_5\ (NO_3)_3(l) \rightarrow 12CO_2(g) + 10H_2O(g) + O_2\ (g) + 6N_2\ (g)$$

Is it exothermic or endothermic? Explain! Draw an enthalpy diagram for each of these three reactions.

4. On a hot summer day the water in a lake stays cool even though the air above it heats quickly, and the water stays warm at night after the air has cooled. Can you explain this?
5. Have you encountered an earthen stove called "*Injera Mitad*" that takes longer a time to feel hot? Explain why. Which stove stays warm for a longer time after the heat source is disconnected the one that heats up quickly or slowly?
6. What property of the substance is responsible for the observations in Q1 and Q5?

4.2.1 Importance of Chemical Changes

- In this section you will appreciate the importance of chemical changes as a source of energy and a means to produce new useful substances.

At the end of this section, you should be able to discuss the importance of chemical changes in the production of new substances and energy.

- Chemical reactions are the most important types of events in the universe. It's through chemical reactions that plants grow, produce fruit, and become compost for new plants. It's because of chemical reactions that human beings (and all other animals) reproduce, digest, grow, hear, and think. All chemical reactions involve chemical changes. Chemical changes are also involved during digestion and respiration. You get energy from respiration. You get food because of a chemical change called photosynthesis. Therefore, the two principal advantages of chemical changes are production energy and useful substances.

Self-Test Exercise 4.2

1. Discuss the importance of chemical changes in your life. Consider, for instance, the oxidation of glucose in your body cells. The photosynthesis and combustion reactions, the digestion, etc. Do you think life is possible without chemical reactions or chemical changes?
2. Can you mention some pharmaceuticals and their uses? How are they made?
3. What two major uses of chemical reactions or changes can you suggest from the above discussion?

Section 4.3: Energy Changes in Electrochemistry

At the end of this section, you should be able to

- Describe electrochemistry.
- Define electrical conductivity.
- Explain metallic conductivity.
- Explain electrolytic conductivity.
- Differentiate between metallic conduction and electrolytic conduction.

- Electrochemistry is a field of chemistry that deals with the interconversion of electrical energy and chemical energy. It is concerned with the use of electricity to cause chemical reactions (changes) to happen or to generat electricity from chemical reactions. Thus, electrical energy and chemical energy are inter-convertible.

4.3.1 Electrical Conductivity

Student, can you explain why metals conduct electricity but nonmetals do not? Do you know any non-metals that conduct electricity? Electrical conductivity is the ability of a substance to transmit electricity. The materials that allow the passage of electricity through them are called electrical conductors. Electricity is constituted by the movement of charged particles or charge carriers. Electrons carry a negative charge whereas ions may carry positive (cations) or negative (anions) charges. Thus, only materials that have mobile charge carriers can conduct electricity. Depending on the nature of the particles responsible for the flow of electric charges through conductors, electrical conductivity can be classified as metallic conductivity or electrolytic conductivity.

a) Metallic conductivity

Electrical conductivity in metals is a result of the movement of electrically charged particles called electrons. The atoms of metal elements are characterized by the presence of valence electrons; which are electrons in the outer shell of an atom that are free to move about. It is these "free electrons" that allow metals to conduct an electric current. Because valence electrons are free to move, they can travel through the metallic lattice that forms the physical structure of a metal. Silver is the best electrical conductor.

A metallic lattice can be described as an atmosphere of positive ions in a sea of mobile electrons (***Figure 4.3***). The electrons entering the metal displace (repel) the freely moving electrons at the point of entry. The displaced electrons occupy new positions by pushing neighboring electrons ahead. This will continue until electrons are forced out of the wire at the opposite end. The charge carriers in metallic conduction are electrons. Hence, metallic conductivity is also called electronic conductivity.

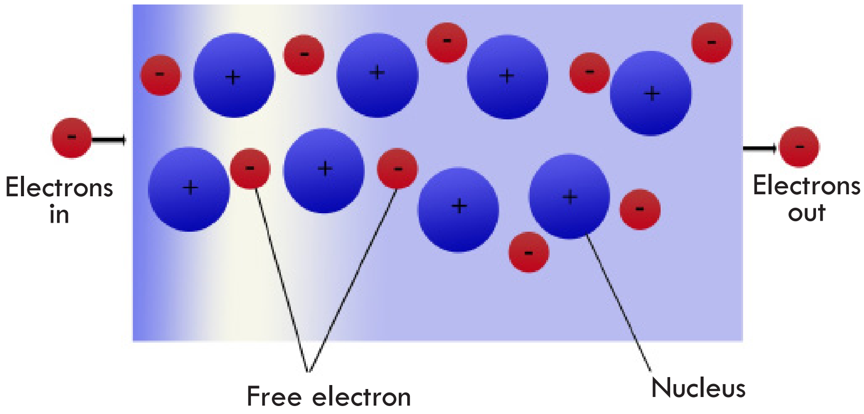


Figure 4.3 Electrical conductivity in metals.

Non-metals are generally non-conductors of electricity because they do not have freely moving electrons. Graphite is a form of carbon in which the carbon atoms are bonded in a trigonal planar fashion to the three other carbon atoms to form interconnected hexagonal rings, as shown in ***Figure 4.4***. Electrons move freely through the hexagonal layers, making graphite a good conductor of electricity.

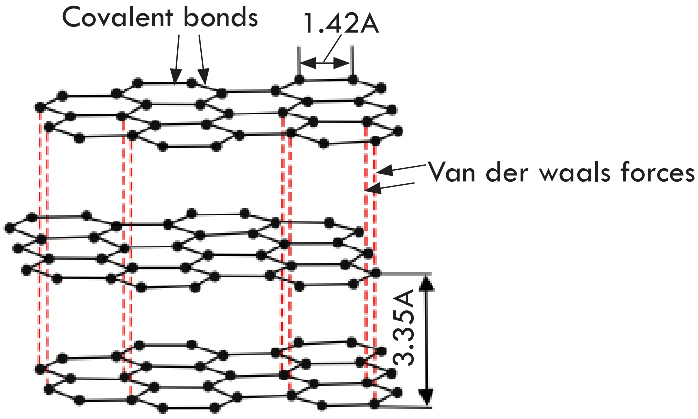


Figure 4.4 Structure of graphite.

b) Electrolytic conductivity

Electrolytes are substances that transmit electricity in a molten state or in an aqueous solution. Unlike metallic conductivity, the conductivity of electrolytic solutions depends on the type and concentration of ions in solution. Based on their degree of ionization or the extent to which they produce anions and cations, electrolytes can be classified as strong electrolytes or weak electrolytes. Recall from Unit 2 that many ionic compounds such as NaCl dissociate completely in water and are therefore called strong electrolytes.

$$NaCl\ (aq) \rightarrow Na^{+}\ (aq) + Cl^{-}\ (aq)$$

When electrical potential is applied through an electrolyte solution, the positive ions (cations) move in one direction and the negative ions (anions) move in the opposite direction. This movement of ions through the electrolyte, caused by the application of electricity, is called electrolytic conductivity. Hence, the charge carriers in electrolytic conductivity are ions (anions and cations). That is electrolytic conductors are also called **ionic conductors**.

Depending on the ability to exhibit electrolytic conductivity, all solutes that dissolve in water fall into one of two categories: electrolytes or nonelectrolytes.

An electrolyte is a substance that, when dissolved in water, results in a solution that can conduct electricity. To conduct a current, a substance must contain mobile ions. All ionic compounds are electrolytes. When ionic compounds dissolve, they dissociate (break apart) into ions, which are then able to conduct a current. Thus, we can represent sodium chloride dissolving in water as

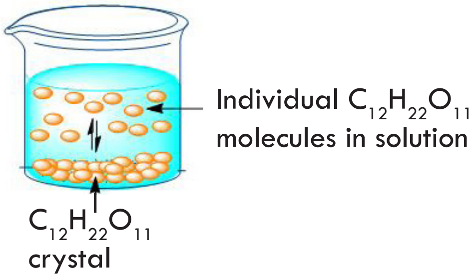
$$NaCl(s) \xrightarrow{H_2O} Na^+(aq) + Cl^-(aq)$$

What this equation says is that the sodium chloride that enters the aqueous solution ends up as Na^+ and Cl^- ions. Thus, Na^+ and Cl^- are responsible for the electrical conductivity of the NaCl solution.

Even insoluble ionic compounds, such as $CaCO_3$, are considered electrolytes because they can conduct a current in the molten (melted) state. Some polar covalent compounds, such as acetic acid (CH_3COOH), that can, at least partially, dissociate into ions when dissolved in water are also classified as electrolytes.

A nonelectrolyte is a substance that does not conduct electric current in either aqueous solution or in the molten state. Most polar covalent compounds, such as table sugar ($C_{12}H_{22}O_{11}$), and all nonpolar covalent compounds are good examples of nonelectrolytes. When these compounds dissolve in water, they do not produce ions. An equation can still be written that simply shows the solute going into the solution without dissociating into ions. For example, the process of dissolving sucrose in water can be written as follows:

$$C_{12}H_{22}O_{11}(s) \rightarrow C_{12}H_{22}O_{11}(aq)$$



Strong and Weak Electrolytes

A strong electrolyte is a substance that, when dissolved in water, dissociates completely into its ions. All ionic compounds are strong electrolytes. NaCl is a good example. A weak electrolyte is a substance that, when dissolved in water, dissociates partially into its ions. For example, acetic acid $(CH_3COOH)^-$ the compound in vinegar, and nitrous acid (HNO_2) only partially ionize into respective ions (H^+ and CH_3COO^- or H^+ and NO^{2-}) when dissolved in water.

$HNO_2(aq) \rightleftharpoons H^+(aq) + NO_2^-(aq)$

$CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$

Aqueous nitrous acid is composed of only about 5% ions and 95% intact (undissociated) nitrous acid molecules. Thus, the solutions of acetic acid and nitrous acid poorly conduct electricity because of the low concentration of ions in the solution. Table 4.1shows some strong and weak electrolytes.

Table 4.1: Classification of Solutes in Aqueous Solutions.

Strong Electrolyte	Weak Electrolyte	Nonelectrolyte
HCl	CH_3COOH	$(NH_2)_2CO$ (urea)
HNO_3	HF	CH_3OH (methanol)
$HClO_4$	HNO_2	C_2H_5OH (ethanol)
H_2SO_4	NH_3	$C_6H_{12}O_6$ (glucose)
NaOH	H_2O	$C_{12}H_{22}O_{11}$ (sucrose)
$Ba(OH)_2$		
Ionic compounds		

Difference between metallic conduction and electrolytic conduction

Metallic Conduction	**Electrolytic Conduction**
Conduction through metals is due to the movement of electrons.	Conduction through electrolytes is due to the movement of ions.
No change in the chemical properties of the conductors is observed.	It may cause chemical decomposition of the electrolytes.
It does not involve any transfer of matter.	It involves the transfer of matter as ions.
The resistance of metals is due to obstacles of vibrating kernels of metal atoms.	The resistance of electrolytic solutions is due to factors like concentration inter-ionic attractions, the viscosity of solvent etc.
It decreases with the increase in temperature.	It increases with the increase in temperature.

Note that metallic conduction is a physical process, but electrolytic conduction is accompanied by chemical changes that occur on the surface of the electrodes.

Experiment 4.1

Conductivity of Materials

Objectives: To test the conductivity of substances and classify them as strong, weak or non-conductors of electricity.

Apparatus: Copper wire, light bulb, power supply (DC) or dry cells, scotch tape, distilled water, 1M NaCl solution, 1 M HCl, 1 M acetic acid solution, 1 M sugar solution, pencil graphite, wood, magnesium ribbon and an iron nail.

Procedure:

1. Arrange the conductivity apparatus as shown in ***Figure 4.5***.

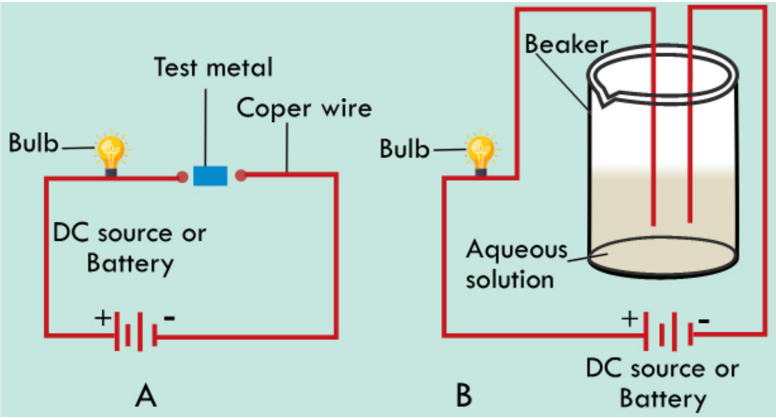


Figure 4.5 Conductivity apparatus for (A) metals and (B) electrolytic solution

2. Pour some distilled water in the beaker (as illustrated in *Figure 4.5B*), dip the electrodes into the water and turn the switch on. Set-up the experiments to test the conductivity of pencil graphite, magnesium ribbon, wood or an iron nail as illustrated in *Figure 4.5A*.
3. Repeat the experiment with separate solutions of table salt, copper sulphate, hydrochloric acid, sodium hydroxide, acetic acid, ammonia solution, molten lead bromide and sugar solution. (use 1.0 M solutions of each).

Observations and Analysis:

a. Does the bulb glow when the switch is turned on?
b. Solutions of which substances make the bulb glow and not glow, when you turn on the switch?
c. Solutions of which substances make the bulb to glow with a: i) bright light? ii) dim light?
d. Classify the substances used in this experiment as strong conductors, weak conductors and non-conductors by completing the table below:

Strong Conductors	Weak Conductors	Non-conductors

e. Which substances in the experiment are used as: i strong electrolytes ii weak electrolytes

Repeat the experiment with lemon juice, and orange juice and answer the questions. Note that if the solution contains ions, current flows through the circuit and the light bulb glows. The brightness of the bulb increases with current strength, which increases with the number of ions in the solution. Strong electrolytes dissociate completely and produce more ions in solutions brighter light than weak electrolytes that dissociate slightly.

f. In your experiment using set-up 4.5 A, what observations did you make? In which case did the bulb glow and in which case did not? Pencil graphite, magnesium ribbon, wood, or iron nail?

Write a laboratory report on what you have observed and submit to your teacher.

Experiment 4.2

The Distinction Between Electrolyte and Nonelectrolyte Solutions

Objective: To distinguish between electrolyte and nonelectrolyte solutions

Chemicals: Water, Table salt

Apparatus: power source, wires, beaker (or water glass) and light bulb

Procedure

1. Construct the light bulb experiment as shown in ***Figure 4.6***.
2. Fill the glass with water as shown in the Figure. Write your observation
3. Add a tea spoonful of fine NaCl in the water and let it dissolve. Make sure the circuit is complete. Write your observation.

Caution: Bare wires are a hazard! Skin will conduct an electric current and will cause a shock. Do not touch the bare part of the wires when the light-bulb apparatus is plugged in.

Question

In which case does the light bulb glow? With just water or salt dissolved in it?

Explain your observations. Try the same experiment using table sugar (sucrose) instead of salt. Apply the concept to test whether the drinking water in your locality is salty or potable. Note that the brightness of the light bulb depends on the concentration of the salt.

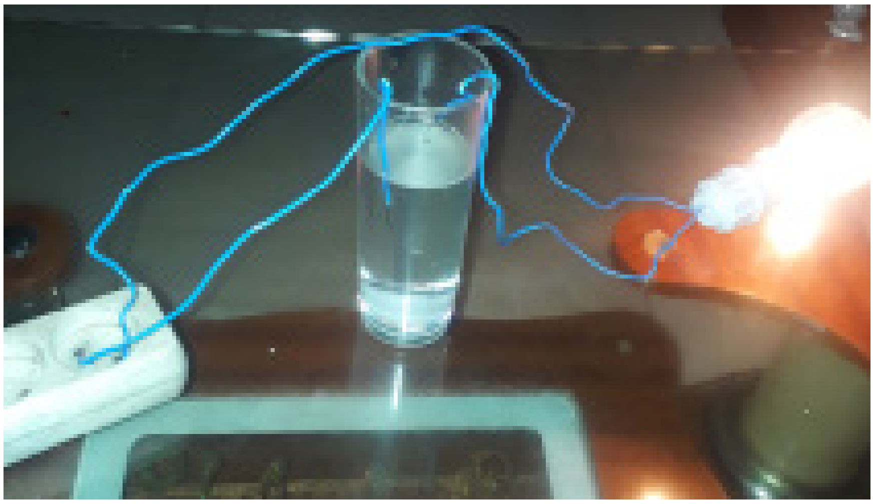


Figure 4.6 Setup for electrolytic conductivity test.

Resources

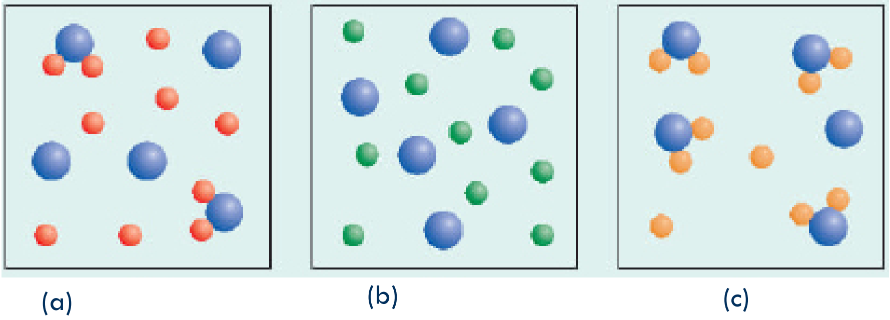
The current Ethiopian Grade 10 Chemistry Textbook for face-to-face modality.

Silberberg, Martin S. Principles of General Chemistry-3rd ed. McGraw-Hill. 2013.

Chang, R., Overby, J. General Chemistry-The Essential Concepts. 6th ed. McGraw-Hill. 2013.

Self-Test Exercise 4.3

1. Na and Ca metals conduct electricity in the solid state, but NaCl and $CaCl_2$ conduct electricity only when they are dissolved in water or when they are in the molten form, not in the solid state. Why?
2. Why are solutions of strong electrolytes better conductors of electricity than solutions of weak electrolytes?
3. Which of the following substances is capable of conducting electricity? Give a reason for your answer.
   a. Iron
   b. Sulphur
   c. Solid sodium chloride
   d. molten calcium chloride
4. Classify each of the following as electrolytes or nonelectrolytes.
   a. air
   b. pure water
   c. saline solution
   d. lemon water
   e. table salt
   f. table sugar
5. Classify each of the following as weak or strong electrolyte
   a. acetic acid
   b. lemon water
   c. sulphuric acid
   d. table salt
   e. ammonia solution
6. The diagrams below show three compounds (a) AB_2, (b) AC_2, and (c) AD_2 dissolved in water. Which is the strongest electrolyte, and which is the weakest? (For simplicity, water molecules are not shown.)



Section 4.4: Electrochemical Cells

- So far we have discussed that substances need mobile electrons and ions as charge carriers to conduct electricity. Metals and graphite conduct electricity because of mobile electrons while electrolytic solutions conduct electricity due to the movement of ions in solution. In addition, you have studied in unit 1 about redox reactions that involve the transfer of electrons. Oxidation reaction produces electrons whereas reduction reactions gain electrons. If you connect the two reactions with a conductive wire you can produce a system where the electron generated by the oxidation reaction move through the wire to the reduction reaction center. The system we have just described is an electrochemical cell. The following section will help you understand electrochemical cells- the definitions, type, and importance in your daily lives.

Section Learning Outcomes

At the end of this section, you should be able to describe the importance of electrochemical cells in daily life (Votic cells and car batteries).

☞ An electrochemical cell is a system that incorporates a redox reaction to produce or use electrical energy. It consists of two or more electrodes that are dipped into an electrolyte (see ***Figures 4.7 and 4.10***) in which a chemical reaction either uses or generates an electric current, and the electronic circuitry for controlling and measuring the current and the potential. Electrodes are strips of metal or graphite that allow electrons to leave or enter the electrolytes. They can be chemically active or inert. Active electrodes directly take part in reactions. Examples include zinc and magnesium. Inert electrodes do not directly take part in chemical reactions. They only serve to transfer electrons. Examples include platinum and graphite.

Depending on the purpose or the types of reactions taking place, electrochemical cells are divided into two groups. These are galvanic (voltaic) cells and electrolytic cells.

4.4.1 Galvanic (Voltaic) Cells

What is a galvanic cell?

A galvanic cell or voltaic cell is an electrochemical cell in which chemical energy contained in reactants is converted into electrical energy via a spontaneous redox reaction. The galvanic cell or voltaic cell was so named after the Italian scientists Luigi Galvani and Alessandro Volta, who constructed early versions of the device.

Examples include the cells we use in our hand batteries (dry cells), flashlight batteries, wristwatches, cameras, and car batteries. The redox reactions between the chemicals in these cells are responsible for the generation of electricity. The reaction proceeds on its own without any external influence. This type of chemical reaction is called a spontaneous redox reaction. Therefore, Galvanic cells are electrochemical cells in which spontaneous redox reactions generate electricity. Galvanic cells are classified into **primary cells, secondary cells, and fuel cells**. Here, we shall be concerned with the primary and secondary cells only. Fuel cells will be discussed in Grade 11. The chemical reactions that take place in both primary and secondary cells generate electrical energy. So in these cells, chemical energy is converted into electric energy when the battery is in use.

Primary Cells (Battery Cells)

Primary cells or also known as battery cells are galvanic cells that are not rechargeable. This is because once the chemicals in the cells that serve as reactants are completely used up, it is not possible to recover them by charging the cells. In other words, the reactions in primary cells are irreversible. Examples of primary cells include Daniell's cell and zinc-carbon (Leclanche) dry cells. The common feature of all galvanic cells is that they contain two electrodes in contact with an electrolyte. The electrolyte in a galvanic cell can be in the form of a solution (Daniell cell) or a paste (Leclanche cell). The cells containing electrolytes in the form of solution are called **wet cells**, and those containing electrolytes in the form of paste are called dry cells.

An example of a wet primary cell is the Daniell cell. It consists of a zinc strip placed in $ZnSO_4$ solution in one compartment and a copper strip placed in copper sulphate, $CuSO_4$, solution in another compartment (***Figure 4.7***).

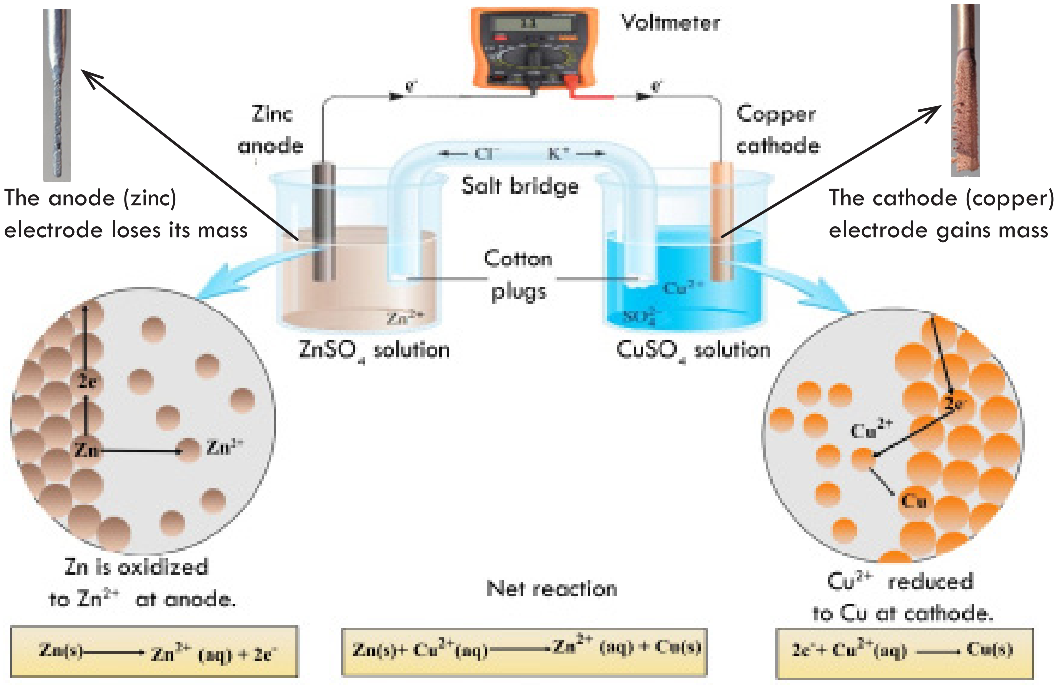


Figure 4.7 The Daniell Cell.

Each compartment is called a half-cell, and the reactions occurring in each compartment are called half-cell reactions. The solutions in the two compartments are linked by a salt bridge. The salt bridge consists of a delivery tube filled with warm mixture of conc. KCl solution and agar solution, which is then allowed to cool so that it sets in the form of a gel. In the anode compartment, the zinc atoms from the zinc electrode lose two electrons each and become zinc ions, Zn^{2+}. The ions enter the solution, and the electrons remain on the electrode and flow through the external wire to the copper electrode (see anode half reaction below). This situation causes the zinc electrode to be negative and the solution to have an overall positive charge. In the process the anode (zinc) electrode loses its mass. That is why the anode of the galvanic cell is sometimes called sacrificial electrode. On the other hand, in the compartment containing the copper electrode, copper ions, Cu^{2+}, from the solution move to the cathode and gain two electrons each to become copper atoms and deposit on the surface of the copper electrode (see cathode half-reaction below). This condition causes the electrode to be positive and the solution to have a negative charge. In addition, the cathode continues to grow in mass as more and more copper deposits on it. The electron flows from anode to cathode in the external conductor.

The half-cell reactions and the cell reactions in Daniell cells are represented as

Anode reaction: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e-$
Cathode reaction: $Cu^{2+}(aq) + 2e- \rightarrow Cu(s)$
Overall (cell) reaction: $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

Due to the oxidation-reduction reaction in the cell, the Daniell cell generates electricity. What is the purpose of the salt bridge in ***Figure 4.7***? From the preceding discussion, it is clear that the solution in which the zinc electrode is placed has an overall positive charge while the solution in the copper compartment has a negative charge. Unless the two solutions are neutral, the cell cannot produce electricity. Thus, the purpose of the salt bridge is to maintain electrical neutrality between the two solutions.

Although wet cells like the Daniell cell can serve as a source of electricity, they are not portable since they contain solutions. Due to this practical problem of using wet cells, dry cells were developed. In a dry cell, a moist electrolyte paste is used instead of solutions. This cell was invented by Georges Leclanche, a French chemist.

We commonly use Leclanche cells as convenient, portable sources of energy. Flashlights and radios are examples of devices that are often powered by the zinc–carbon, or Leclanché, dry cell (***Figure 4.8***). This voltaic cell has a zinc can as the anode, a graphite rod in the center, surrounded by a paste of manganese dioxide, ammonium and zinc chlorides, and carbon black, as the cathode. It produces electricity as a result of a spontaneous redox reactions:

Anode reaction: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e-$

Cathode reaction: $2NH_4^+(aq) + 2MnO_2(s) + 2e \rightarrow Mn_2O_3(s) + H_2O(l) + 2NH_3(aq)$

Overall (cell) reaction:

$$Zn(s) + 2NH_4^+(aq) + 2MnO_2(s) \rightarrow Zn^{2+}(aq) + Mn_2O_3(s) + H_2O(l) + 2NH_3(aq)$$

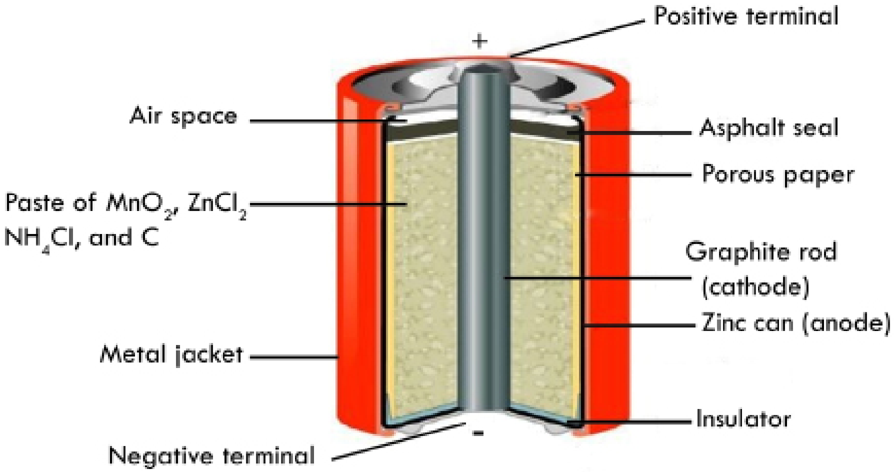


Figure 4.8 Zinc-carbon dry cell (Leclanche cell).

A buildup of ammonia gas around the cathode may disrupt the current. However, this is prevented by the reaction between Zn^{2+} and NH_3 to form a complex ion, $[Zn(NH_3)_2]^{2+}$ which crystallizes as a chloride salt through reaction with chloride (spectator ion).

$$Zn^{2+}(aq) + 2NH_3(aq) + 2Cl^-(aq) \rightarrow Zn(NH_3)2Cl_2(s)$$

Therefore, the overall reaction occurring in a Leclanche cell is often written as:

$$Zn(s) + 2NH_4Cl(aq) + 2MnO_2(s) \rightarrow Zn(NH_3)2Cl_2(s) + Mn_2O_3(s) + H_2O(l)$$

The voltage of this dry cell is initially about 1.5 V, but it decreases as the current is drawn off. The voltage also deteriorates rapidly in cold weather. There are other examples of dry cells, such as the alkaline dry cell, silver oxide cell, and copper oxide cell which are left for interested students to read.

b. Secondary (Rechargeable) Cells

Unlike primary cells, secondary cells are rechargeable. The electrode reactions are reversible, and the original reactants can be regenerated. This can be achieved by passing a direct current through the cell. The process is called charging or recharging. A secondary cell needs to be recharged when it stops producing electricity. A lead storage battery is an example of a secondary cell. A lead storage battery is the common automobile battery that usually delivers either 6 or 12 volts, depending on the number of cells used in its construction. The inside of this voltaic cell consists of electrodes made of lead alloy grids; one electrode is packed with a spongy lead to form the anode, and the other electrode is packed with lead (IV) oxide to form the cathode (see ***Figure 4.9***). Both are bathed in an aqueous solution of 35% sulfuric acid, H_2SO_4. A single lead-storage cell delivers 2 volts. Therefore, a 12 V battery contains six cells connected in series (***Figure 4.9***).

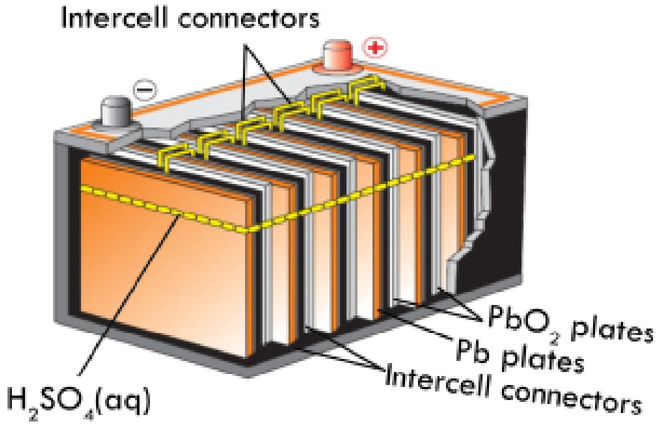


Figure 4.9 A Lead - Storage Battery. Each cell delivers about 2 V, and a battery consisting of six cells in series gives about 12 V

When a lead-storage battery is in operation (on discharge), the following reactions occur at the electrodes:

Anode reaction: $Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e-$

Cathode reaction: $PbO_2(s) + 4H^+(aq) + SO_4^{2-}(aq) + 2e- \rightarrow PbSO_4(s) + 2H_2O(l)$

Overall (cell) reaction: $Pb(s) + PbO_2(s) + 4H^+(aq) + 2SO_4^{2-}(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$

From the electrode reactions it can be noticed that $PbSO_4$ is produced at both electrodes. Lead-storage battery, as a secondary cell, is rechargeable when it runs down. The reaction that takes place on recharging a lead storage battery is given by the following equation.

$$2PbSO_4(s) + 2H_2O(l) \rightarrow Pb(s) + PbO_2(s) + 2H_2SO_4(aq)$$

Note: The electrode that served as an anode during discharging (use) is forced to behave as a cathode during recharging. Consequently, the direction of the electron flow that was from left (Pb = anode) to the right (PbO_2 = cathode) is changed to right (PbO_2 = anode) to left (Pb = cathode). Note that oxidation always takes place at the anode and reduction at the cathode. The direction of electron flow is always from anode to cathode.

Dear learner, we have completed the discussion of electrochemical cells- Voltaic cells. In this section, we mentioned three types of voltaic cells: primary, secondary, and fuel cells. But we focused our discussion on only one primary and one secondary cells. In order to substantiate your understanding about the two types of voltaic cells, we recommend the following project. Please make a self-managed plan. Perform the following two projects. You are expected to submit the report to your tutor.

Project 4.1

Constructing Simple Galvanic Cells

Objectives: To construct a simple galvanic cell.

Direction: Construct a simple voltaic cell using locally available materials.

Write a project report and submit it to your tutor. Take recordings (photos or videos) to demonstrate the functioning of the developed cell. Your report should describe the basic features of the developed cell including identification of electrodes as anodes and cathod, the electrolytes, and the equations for the redox reactions involved. The half-reactions and where (on the electrode) they occur. Compare the performance (light intensity) of your cell with the commercially available cells.

Project 4.2

1. Do you know how car batteries are maintained? Your teacher will arrange a visit to the nearby car battery maintenance center. Before the trip, prepare the following questions for the interview.
2. Why do car battery fail?
3. What are the components of the car battery?
4. How are they assembled into a self-contained device?
5. What is the advantage of a car battery over other types of batteries such as dry cells?
6. Each dry cell can generate 1.5 V. If we assemble eight of them in series, we can generate 12.0 V. So, why can't we use this option?
7. How the health or the degree of discharge is tested?
8. How is the battery recharged?

After getting answers for the above questions, and reaching conclusion after discussion in a group, write a report about what you have learnt during your visit and present it to the class.

Self-Test Exercise 4.5

A voltaic cell is constructed from a half-cell in which a cadmium rod is dipped into a solution of cadmium nitrate, $Cd(NO_3)_2$, and another half-cell in which a silver rod is dipped into a solution of silver nitrate, $AgNO_3$. A salt bridge connectes the two half-cells. The silver ion is reduced during the operation of the voltaic cell.

a. Sketch the cell.

b. Label the anode and cathode, showing the corresponding half-reactions at these electrodes.

c. Indicate the electron flow in the external circuit (with a lightbulb) and the signs of the electrodes.

Section 4.5: Electrolysis

- In this section you will learn about the use of electrolytic cells to produce useful substances. Electrolytic cells, unlike galvanic cells, convert electrical energy into chemical energy. We will consider the definitions, the electrochemical cell for electrolysis, and the half-reactions as well as cell reactions considering some examples of electrolysis.

At the end of this subsection, you should be able to

- Define the term electrolysis.
- Define the terms electrode, anode, cathode, electrolyte, anion, and cation.
- Describe electrolytic cell.
- Draw labelled diagram of an electrolytic cell.
- Define the terms' half-reaction and cell reaction.
- Write the oxidation half-reaction, reduction half reaction and cell reaction for the electrolysis of molten or fused electrolytes.
- Perform an activity to show electrolysis of molten electrolytes.

In contrast to spontaneous redox reactions, which result in the conversion of chemical energy into electrical energy, electrolysis is a process by which electrical energy is used to drive an otherwise nonspontaneous reaction. Electrolysis stands for "electro" which means electricity and "lysis" which means to separate or break. So in terms, electrolysis would mean "breakdown via electricity". An electrochemical cell in which electrolysis occurs is called an electrolytic cell (***Figure 4.10***). It has two components: electrodes (anode and cathode) and an electrolyte.

In an electrolytic cell, the electrode connected to the positive terminal of the source (e.g., battery) is positively charged and is called the anode. It is the electrode through which electrons leave the cell. The electrode connected to the negative terminal of the source is negatively charged and is called the cathode. It is the electrode through which electrons enter the cell (see ***Figure 4.10***).

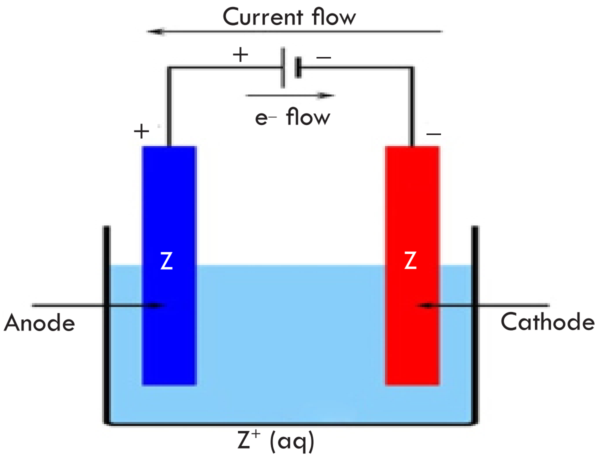


Figure 4.10 A sketch of an electrolytic cell.

During electrolysis, the ions of the electrolyte migrate to the electrodes of the opposite charge. The positive ions are attracted to the cathode and are called cations. Since the cathode has excess electrons, the cations will discharge by gaining electrons. This process of gaining electrons is called reduction. The negative ions are attracted by the positive electrode (anode) and are called anions. These ions are discharged by losing electrons (getting oxidized) at the anode. This process of losing electrons is called oxidation. Thus, the cathode is the electrode at which reduction occurs and the anode is the electrode at which oxidation takes place.

4.5.1 Electrolysis of Molten (Fused) Electrolytes

Ionic solids can melt at elevated temperatures. NaCl, for instance, melts at 801°C. The process is called melting or fusion. When ionic solids melt, they dissociate into positive and negative ions that are free to move. To understand the chemical reactions that occur during the electrolysis of molten (fused) electrolytes, consider the electrolysis of molten NaCl. ***Figure 4.11*** shows a simple electrolytic cell. Wires from a battery are connected to electrodes that are dipped into molten sodium chloride. At the electrode connected to the negative pole of the battery, globules of sodium metal form; chlorine gas evolves from the other electrode. The half-reactions are

Cathode: $Na^+(l) + e^- \rightarrow Na(l)$

Anode: $Cl^- (l) \rightarrow 1/2Cl_2(g) + e^-$

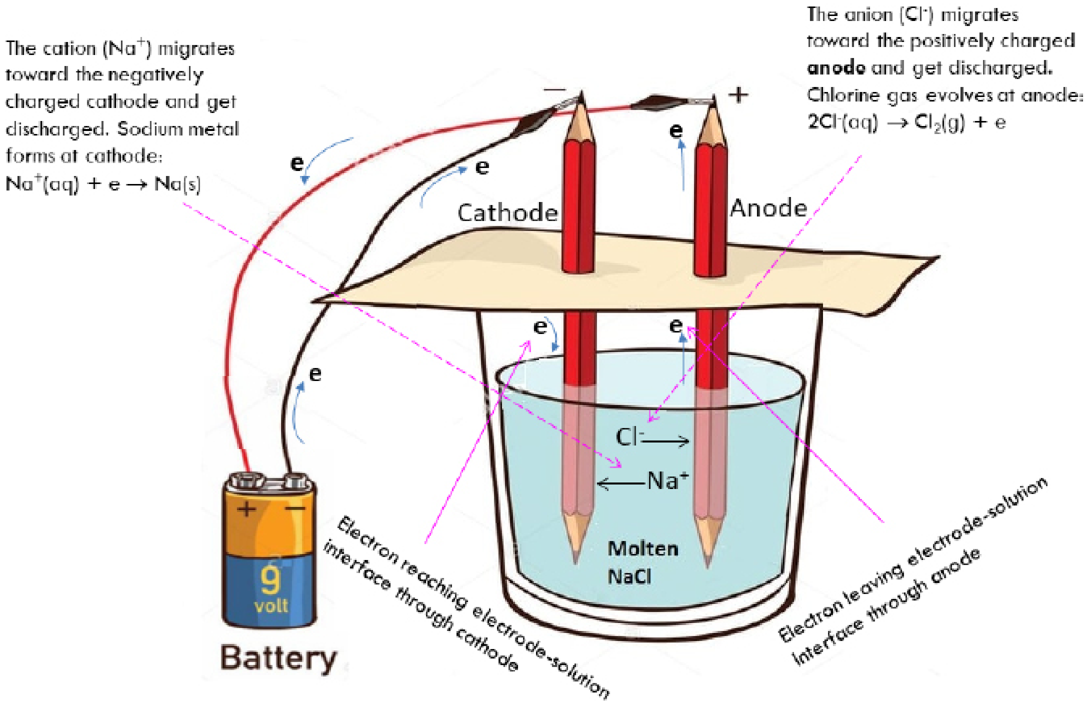


Figure 4.11 Electrolysis of molten sodium chloride. Sodium metal is produced commercially in this way.

The reduction of Na^+ to Na occurs at the cathode, and the oxidation of Cl^- to Cl_2 occurs at the anode (note the labeling of electrodes in ***Figure 4.11***. You obtain the cell reaction by adding the half-reactions.

$$Na^+(l) + e^- \rightarrow Na(l)$$
$$Cl^-(l) \rightarrow 1/2Cl_2(g) + e^-$$

$$Na^+(l) + Cl^-(l) \rightarrow Na(l) + \tfrac{1}{2}Cl_2(g)$$

As you can see from the cell reaction, the electrolysis of molten NaCl is used commercially to obtain sodium metal from sodium chloride. The electrolysis of a molten salt or ionic compound produces several reactive metals. Lithium, magnesium, and calcium metals are all obtained by the electrolysis of the chlorides.

Experiment 4.3

Electrolysis of Molten (Fused) Lead Bromide

Objectives: To observe substances produced at the electrodes during electrolysis.

Materials required: Stand and clamp, two graphite electrodes, wires, switch, light bulb, test tube (bigger in size), Bunsen burner, lead bromide crystals (melting point: 373°C).

Precaution: Bromine causes very severe burn on the skin.

Procedure:

1. Assemble the materials as shown in ***Figure 4.12***.
2. Place small amount of lead bromide crystals in a beaker. Insert the two electrodes, as shown in ***Figure 4.12***, until they are in contact with the lead bromide crystals. Then turn on the switch. Does the bulb glow?
3. Heat the lead bromide in a beaker gently, using a Bunsen burner. When the lead bromide melts, turn on the switch.

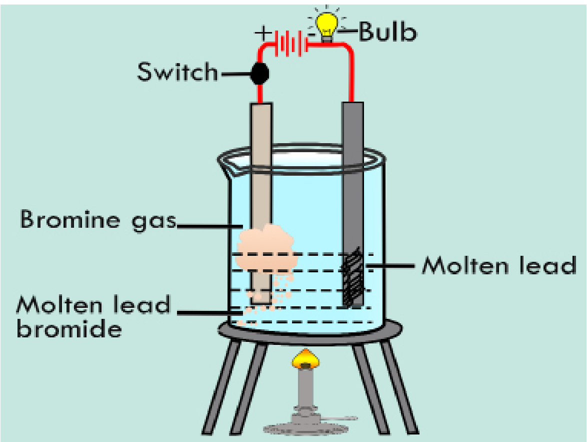


Figure 4.12 Electrolysis of Fused Lead Bromide.

Observations and Analysis:

1. Does the bulb glow? If yes, what is the reason?
2. Write the dissociation reaction for $PbBr_2$.
3. Identify the ions which migrate to the respective electrodes
4. Write the products formed at each electrode.
5. Identify the half reactions as oxidation and reduction.
6. Write the cell reaction

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

Now, it is your turn to do some calculations and exercises.

Resources

1. The current Ethiopian Grade 10 Chemistry Textbook for face-to-face modality.
2. Silberberg, Martin S. Principles of General Chemistry-3rd ed. McGraw-Hill. 2013.
3. Chang, R., Overby, J. General Chemistry-The Essential Concepts. 6th ed. McGraw-Hill. 2013.

Self-Test Exercise 4.5

1. A lead-storage buttery is an example of ____
   a. an electrolytic cell called a secondary cell
   b. galvanic cell called the secondary cell
   c. rechargeable electrolytic cell called a secondary cell
   d. only b and c
2. How do you know if an electrode is a cathode or an anode in voltaic cells and electrolytic cells?
3. Can you suggest why positive and negative ions are named cations and anions respectively?
4. Distinguish between voltaic cells and electrolytic cells.
5. During the electrolysis of fused $PbBr_2$,
   a. Which ions are responsible for the conduction of electricity through the molten salt?
   b. What half-cell reactions occur at the anode and cathode?
6. Write the half-reactions for the electrolysis of the following molten compounds: a. KCl; b. KOH.
7. Is the polarity of the electrodes in galvanic cells similar to that of the electrodes in electrolytic cells? Explain your answer.

Unit Summary

All chemical reactions accompany energy changes. There are many forms of energy and they are all interconvertible. The internal energy of a substance is the sum of its potential energy and kinetic energy. Potential energy is stored energy. Potential energy is stored in chemical bonds and as intermolecular forces. Chemical energy is a form of potential energy. Energy change occurs when energy transfer takes place between the system and the surrounding. Energy transfer takes place in the form of heat, or work, or both.

Any chemical reaction that gives off heat to the surroundings is called an exothermic reaction; any chemical reaction that absorbs heat from the surroundings is called an endothermic reaction.

Enthalpy is a measure of the energy change in a system of reactants and products.

Enthalpy change is calculated as the enthalpy of products minus the enthalpy of reactants.

Enthalpy change is positive for endothermic reactions and negative for exothermic reactions.

Like any other reaction, redox reactions also involve energy changes.

The energy change in redox reactions is dealt with in electrochemistry.

Electrochemistry is a field of chemistry that studies how chemical reactions produce electricity and how electricity is used to bring about chemical reactions in electrochemical cells.

Electrical conductivity is the ability of substances to conduct electricity.

Metallic conductivity is the flow of electricity through metals, and the conduction of electricity through metals is due to the presence of freely moving (delocalized) valence electrons.

Electrolytes are substances that conduct electricity in solution or a molten state.

The conduction of electricity through electrolytes is due to the movement of anions and cations towards electrodes of opposite charge, and the charge carriers in electrolytic conduction are ions. Cations carry a positive charge whereas anions carry a negative charge. Electrochemical cells include galvanic (voltaic) cells and electrolytic cells. Galvanic cells convert chemical energy into electrical energy. Electrolytic cells convert electrical energy into chemical energy. Electrolysis is a process in which electricity is used to bring about an oxidation-reduction reaction in an electrolytic cell and produces useful substances.

Electrolysis is also the process of decomposing of an electrolyte using electrical energy.

Electrodes are either metal strips or graphite rods.

Primary cells are voltaic cells that are not rechargeable, and the reactions taking place in them are irreversible.

Secondary cells are voltaic cells that are rechargeable since the reactions taking place in them are reversible.

Unlike electrolytic cells, the anode is negative and the cathode is positive in galvanic/voltaic cells.

In voltaic cells, the polarity (charge) of the electrodes is determined by the redox reactions.

In electrolytic cells the polarity of the electrodes is determined by the external power source.

An anode is the electrode attached to the positive terminal of a direct current source in electrolytic cell, at which oxidation (loss of electrons) by anions occurs, and electrons leave the cell.

A cathode is the electrode attached to the negative terminal of a DC source in electrolytic cell, the negative electrode at which reduction of cations occurs and electrons enter the cell.

Oxidation always takes place at anode and accompanied by reduction at cathode.

During electrolysis, anions move to the anode and cations move to the cathode.

The reaction taking place at each electrode (cathode or anode) is said to be a half-cell reaction.

Cell reaction is the reaction that takes place in the entire cell and obtained by adding half reactions.

Checklist 4.1

The following checklists are provided to you as a guide to check what you have learned in this unit. Check you understanding by putting a "✓" mark if you can remember what is presented in relation to the terms. If you don't remember, please go back to the corresponding section and make a quick review. I can ...

SN	Competencies	No
1	describe energy changes in chemical reactions.	
2	describe how the internal energy of a system changes in relation to the energy absorbed or given off and the work done by or on the system.	
3	define endothermic reactions, give examples, and represent the using energy diagrams.	
4	define exothermic reactions, give examples, and represent it using energy diagrams.	
5	describe the importance of chemical changes/reactions.	
6	describe how a chemical reaction produces an electric current in galvanic cells and how electricity brings about a chemical reaction in electrolytic cells.	
7	distinguish the difference between metallic conduction and electrolytic conduction.	
8	write the oxidation half-reaction, reduction half-reaction and cell reaction for the electrolysis of molten electrolytes that occur in electrolytic cells.	
9	describe the three types of Voltaic cells-more importantly the two ones primary and secondary cells; the nature of the reaction, the outcome of the reaction, electrodes at which oxidation and reduction takes place, the direction of electron flow, and the polarity of the electrodes.	
10	explain the difference between electrolytic cells and voltaic cells.	

Self-Assessment Exercises

Part I: Choose the correct answer from the suggested options

1. The energy released during chemical reactions comes from
   a. The bond being formed
   b. The bond being broken
   c. The heat supplied from the surrounding
   d. All
2. Which of the following is not correct about voltaic cells?
   a. The anode is negative
   b. The cathode is positive
   c. Oxidation takes place at the cathode
   d. Redox reactions produce electricity in the cell
3. Which one of the following is used to produce useful compounds?

a. Voltaic cells
c. Daniel's cell
b. Electrolytic cells
d. Batteries

4. Electrolysis is not used for the:
   a. Purification of metals
   c. Electroplating of metals
   b. Production of metals
   d. Production of electricity
5. Which substance is not used in the Leclanche cell?
   a. H_2SO_4
   c. MnO_2
   b. NH_4Cl
   d. powdered carbon
6. Which one of the following is correct about automobile batteries?
   a. The electrodes are graphite electrodes
   b. Each cell in the battery delivers 1.5 volts
   c. The electrolyte is aqueous H_2SO_4 solution
   d. Lead (IV) oxide is used as an anode
7. Which of the following occurs during electrolysis of the molten binary salt of a metal:
   a. The metal will deposit on the cathode
   b. Reduction will take place at the anode
   c. Oxidation will take place at the cathode
   d. No current will flow through the molten salt
8. Two copper electrodes dipped in copper sulphate solution are connected to a12 volt battery. The electrode connected to the end of the battery marked with a "-" is:
   a. anion
   c. anode
   b. cathode
   d. cation
9. The charge carriers in electrolytic conduction are:
   a. anions only
   c. cations and anions
   b. cations only
   d. delocalized electrons
10. During the electrolysis of fused lead bromide, the anode half reaction involves:
    a. oxidation of lead atoms to ions
    b. reduction of bromine atoms to give bromide ions
    c. reduction of lead ions to form free metal
    d. oxidation of bromide ions to elemental bromine
11. Voltaic cells and electrolytic cells are similar in that:
    a. The anode is positive and cathode is negative in both types of cells
    b. Oxidation half-reaction occurs at the cathode in both types of cells
    c. Both types of cells contain two electrodes in contact with electrolytes
    d. Reduction half-reaction occurs at the anode in both types of cells
12. Four different solutions of equal volume (1L) were prepared by dissolving one mole of each of the following substances. The conduction of electricity is least in the solution containing:
    a. HCl
    c. CH_3COOH
    b. HNO_3
    d. KCl
13. Which of the following is a wet voltaic cell:
    a. Leclanche cell
    b. cells used in mobile telephones

c. lead-storage cell

Part II: Give short answers to each of the following questions

14. Under what condition is the heat of a reaction equal to the enthalpy change of the same reaction?
15. Describe at least two exothermic processes and two endothermic processes.
16. Decomposition reactions are usually endothermic, whereas combination reactions are usually exothermic. Give a qualitative explanation for these trends.
17. Draw an enthalpy diagram for a general exothermic reaction; label the axis, reactants, products, and ΔH with its sign.
18. Draw an enthalpy diagram for a general endothermic reaction; label the axis, reactants, products, and ΔH with its sign.
19. Consider these changes.
    a. $Hg(l) \rightarrow Hg(g)$
    b. $3O_2(g) \rightarrow 2O_3(g)$
    c. $CuSO_4.5H_2O(s) \rightarrow CuSO_4(s) + 5H_2O(g)$
    d. $H_2(g) + F_2(g) \rightarrow 2HF(g)$

At constant pressure, which of the reactions is exothermic and which is endothermic?

20. Why are ionic compounds like NaCl, KCl, $CaCl_2$, $PbBr_2$, etc. non-conductors in the solid state but conductors in aqueous solutions?
21. Describe the basic features of a galvanic cell. Why are the two components of the cell separated from each other?
22. Explain the differences between a primary galvanic cell-one that is not rechargeable-and a storage cell (for example, the lead storage battery), which is rechargeable.
23. During the electrolysis of fused $CaCl_2$,
    a. Which ions are responsible for the conduction of electricity through the molten salt?
    b. Which ion migrates towards the anode?
    c. Which ion migrates towards the cathode?
    d. What half-cell reactions occur at the anode and cathode?

Assignment for Submission

Part I. Multiple Choice Questions

Direction: Choose The Best Answer and write the letter of Your Choice on a Separate Answer Sheet to be submitted to Your Tutor

1. Which of the following is true about Galvanic and Electrolytic cells?
    a. Electrolysis takes place in electrolytic cells
    b. electrolytic cells produce electrical energy whereas Galvanic cells produce useful products by
    c. consuming electrical energy
    d. Oxidation takes place at cathode and reduction takes place at anode in both cases
    e. The direction of electron flow is from cathode to anode in both cases
2. The difference between primary and secondary cells is that

a. the reactions is reversible in secondary cells but irreversible in primary cells
b. Secondary cells are 'use and throw' whereas primary cells can be reused
c. Primary cells are Galvanic cells whereas secondary cells are electrolytic cells
d. The polarity of anode and cathode is different in primary and secondary cells

3. During electrolysis of molten NaCl
   a. oxygen is evolved at anode
   b. chlorine is liberated at anode
   c. sodium metal is deposited at anode
   d. hydrogen is liberated at cathode
4. A substance which when dissolved in water exists only as ions is called________
   a. electrolyte
   b. Strong electrolyte
   c. Weak electrolyte
   d. transparent
5. A substance which when dissolved in water exists as some ions and molecules is called____
   a. Electrolyte
   b. Strong electrolyte
   c. Weak electrolyte
   d. transparent
6. Which of the following events does not occur during electrolysis of brine?
   a. oxygen gas is evolved at anode
   b. hydrogen gas is evolved at cathode
   c. the electrolyte gradually changes from a solution of NaCl to a solution of NaOH
   d. chlorine gas is liberated at anode
7. What happens if molten Lead Bromide ($PbBr_2$) is electrolyzed?
   a. At anode, brown fumes of bromide gas are given off
   b. At anode, molten lead can be seen
   c. At cathode, brown fumes can be seen
   d. At cathode, lead bromide can be seen
8. Which one of the following is not conductor of electricity in solid state?
   a. Metals
   b. Graphite
   c. Table Salt
   d. Metallic Alloys
9. Which of the following is not correct about voltaic cells?
   a. the anode is negative
   b. the cathode is positive
   c. oxidation takes place at the cathode
   d. redox reactions produce electricity in the cell
10. Which substance is not used in the Leclanche cell?
    a. H_2SO_4
    b. NH_4Cl
    c. MnO_2
    d. powdered carbon
11. Which one of the following is correct about automobile batteries?
    a. the electrodes are graphite electrodes
    b. each cell in the battery delivers 1.5 volts
    c. the electrolyte is aqueous H_2SO_4 solution
    d. lead (IV) oxide is used as anode
12. Which of the following occurs during electrolysis of the molten binary salt of a metal:

a. the metal will deposit on the cathode
b. reduction will take place at the anode
c. oxidation will take place at the cathode
d. no current will flow through the molten salt

13. Voltaic cells and electrolytic cells are similar in that:
    a. the anode is positive and cathode is negative in both types of cells
    b. oxidation half-reaction occurs at the cathode in both types of cells
    c. both types of cells contain two electrodes in contact with electrolytes
    d. reduction half-reaction occurs at the anode in both types of cells
14. The charge-carriers in electrolytic conduction are:
    a. anions only
    b. cations only
    c. cations and anions
    d. delocalized electrons
15. Which of the following is a wet voltaic cell:
    a. Leclanche cell
    b. cells used in mobile telephones
    c. lead-storage cell
    d. Dry cells

Part II. Essay Type Question

16. Write all the ions present in the aqueous solutions of the following:
    a. Caustic potash
    b. Acetic acid
    c. Magnesium sulphate
    d. Formic acid
    e. Phosphoric acid
    f. Ammonium chloride
17. Explain the following
    a. A solution of table sugar does not conduct electricity, but a solution of acetic acid is weak electrolyte
    b. Sodium chloride conducts electricity in molten or aqueous state but not in solid state
18. By giving four examples in each case, define or explain the terms
    a. strong electrrolyte
    b. weak electrolyte
19. Classify each of the following as electrolytes or nonelectrolytes:
    a. air
    b. pure water
    c. saline solution
    d. lemon water
    e. sulphuric acid
    f. nitric acid
    g. ammonia solution
20. Describe at least two exothermic processes and two endothermic processes and draw energy diagrams.

Answer Key to Self Test Exercises

Answer Key to Activity 4.1

1.

Energy is transferred from the stove to the dough. Therefore energy is absorbed during the baking of bread. It is endothermic

Energy is released during the burning of wood. It is exothermic

Further processes include respiration and photosynthesis. During respiration heat is released. During photosynthesis heat is absorbed.

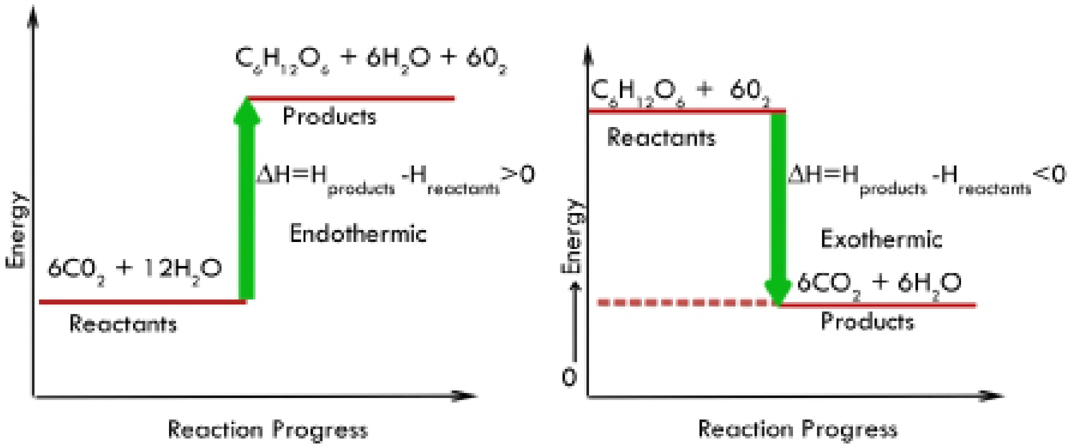
2. Chemical energy is converted to heat energy.
3. Photosynthesis is an endothermic reaction.

$$6CO_2(g) + 6H_2O \xrightarrow{\text{Sunlight}} \underset{\text{Glucose}}{C_6H_{12}O_6} + 6O_2$$

Respiration is an exothermic reaction.

$$C_6H_{12}O_6 \quad + \quad 6O_2 \qquad 6CO_2 \quad + \quad 6H_2O \quad + \text{ Energy}$$

The corresponding energy diagrams as follows:



4. Write about your experiences from your visit to energy sector offices
5. See the section on galvanic cells.

Self-Test Exercise 4.1

1. Bond formation.
2. In the form of ATP. When it is hydrolyzed.
3.

(a) exothermic (combination reactions involve only bond formation which releases energy)

(b) endothermic

(c) exothermic (see your module for sample enthalpy diagrams)

4. It is due to the high specific heat capacity of water. This means water heats up slowly and stays warm for longer.
5. This is because of the low specific heat capacity of the material the stove is made of. So, a stove that heats slowly will stay warm for a longer time.
6. Specific heat capacity

Self-Test Exercise 4.2

1. National developments as well as life processes all require chemical changes.
2. Ask a dealer in a pharmacy near your locality
3. Production of energy and the synthesis of useful substances such as pharmaceuticals.

Self-Test Exercise 4.3

1. Na and Ca metals conduct electricity in a solid state, but NaCl and $CaCl_2$ conduct

electricity only when they are dissolved in water or when they are in the molten form, but not in the solid state? Why? Because conduction requires the movement of charged particles. In metals, valence electrons are free to move even in a solid state and conduct electricity. In salt, however, the ions are intact and not able to move in solid- state. They become free and moveable in solution, or in molten state and conduct electricity.

2. Because conductivity is proportional to the amount of charge -carrying groups-ions or electrons. Strong electrolytes produce more ions than weak electrolytes, and are better conductors than weak electrolytes which dissociate to a limited extent.

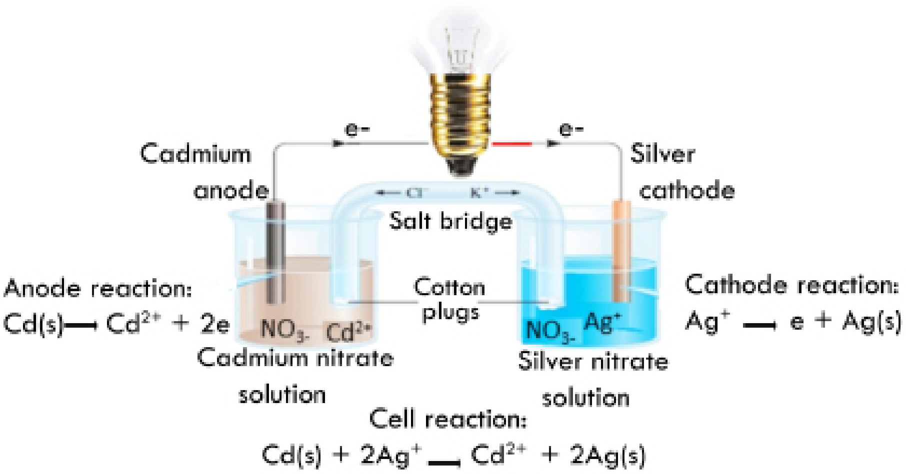
3. Answer a and d.

Self-Test Exercise 4.4

1. a. Air, nonelectrolyte b. pure water, nonelectrolyte
c. Saline solution, electrolyte d. lemon water, weak electrolyte
e. sulphuric acid, electrolyte f. nitric acid, electrolyte
g. ammonia solution, weak electrolyte

2. case ‘b’ demonstrates strong electrolyte because the compound is completely dissociated. Case ‘c’ demonstrates the weakest.

Self-Test Exercise 4.5 (See figure below for questions in a-c)



Self-Test Exercise 2.6

1.C

2.

	Voltaic Cell	Electrolytic cell
Anode	Negative	Positive (connected to positive terminal of battery)
Cathode	Positive	Negative (connected to negative terminal of battery)

3. The names anion and cation are given to negative and positive ions due to their movement towards the anode and cathode, respectively.

4.

Voltaic cell	Electrolytic cell
The reaction is spontaneous	The reaction is nonspontaneous
Chemical reaction generates electricity	Electrical energy brings about chemical change
Converts chemical energy to electrical energy	Convert electrical energy to chemical energy
Anode is negative	Anode is positive
Cathode is positive	Cathode is negative

4. a) The Pb^{2+} and $Br-$ ions

b) Anode: $2Br- \rightarrow Br_2 + 2e$ (Br_2 liberated at the anode)

Cathode: $Pb^{2+} + 2e \rightarrow Pb$ (deposited at the cathode)

Cell reaction: $PbBr_2(l) \rightarrow Pb(s) + Br_2(g)$

5. a.

Anode: $2Cl- \rightarrow Cl_2 + 2e$ (Cl_2 liberated at the anode)

Cathode: $2K+ + 2e \rightarrow 2K$ (deposited at the cathode)

Cell reaction: $2KCl \rightarrow Cl_2 + 2K$

b)

Anode: $4OH- \rightarrow O_2 + 2H_2O + 4e-$

Cathode: $4K+ + 4e- \rightarrow 4K$;

Cell reaction: $4KOH \rightarrow 4K + O_2 + 2H_2O$

6. No, see the corresponding section in your module

Answers to the Review Exercise

Part I

1.	A	4.	D	7.	A	10.	D	13.	C
2.	C	5.	A	8.	B	11.	C		
3.	B	6.	C	9.	C	12.	C		

Part II

14. Under constant pressure
15. see your module.
16. Decomposition reactions involve bond breaking which requires energy whereas combination reactions involve bond formation which releases energy
17. see your module.
18. see your module.
19. Consider these changes.
    a. $Hg(l) \rightarrow Hg(g)$ endothermic
    b. $3O_2(g) \rightarrow 2O_3(g)$ endothermic
    c. $CuSO_4 .5H_2O(s) \rightarrow CuSO_4(s) + 5H_2O(g)$ endothermic
    d. $H_2(g) + F_2(g) \rightarrow 2HF(g)$ exothermic
20. see your module.
20. see your module.
20. see your module.
21. During electrolysis of fused $CaCl_2$,
    a. Ca^{2+} and Cl^- ions

b. Cl^-

c. Ca^{2+}

d. Anode: $2Cl^- \rightarrow Cl_2 + 2e$

Cathode: $Ca^{2+} + 2e- \rightarrow Ca$

UNIT 5

METALS AND NONMETALS

Unit Contents

Section 5.1: Metals

5.1.1: General properties and extraction of metals and alloys

5.1.2: Production of aluminum, iron and copper

Section 5.2: Nonmetals

5.2.1: General Properties of Nonmetals and Common Uses of Some Nonmetallic Compounds

5. 2.2: Production of Nitrogen, Phosphorous, Oxygen, Sulphur and Chlorine

Feed Back to Activities

Answer Key to Selftest Exercises

References

Introduction

- Dear learner, Unit 5 is about metals and nonmetals. Metals and nonmetals are two types of substances that may be distinguished by their physical and chemical characteristics.

? What are the sources of metals and nonmetals?

Dear learner, metals and nonmetals are natural resources. Natural resources are resources that exist without any actions of humankind such as sunlight, land, fossil fuels (crude oil, coal, and natural gas), crops, water and air. Natural resources can be classified as renewable and non-renewable. Renewable resources are resources that can be replenished (replaced) by natural processes. Examples are water, air and plant materials (biomass). Non-renewable resources are resources that are found in a fixed amount in nature and cannot be replenished. Fossil fuels, nuclear energy, and metallic and nonmetallic minerals are examples of non-renewable resources. Metallic minerals are minerals that contain one or more metallic elements. Non-metallic minerals are those that do not contain metals. Metallic minerals occur in rare, naturally formed concentrations known as mineral deposits.

The principal source of metallic and nonmetallic minerals is the planet Earth. The majority of metals and non-metals are extracted from their minerals. Minerals such as iron haematite (Fe_2O_3) or aluminum bauxite ($Al_2O_3.2H_2O$), sulphides such as zinc blende (ZnS), or carbonates such as malachite ($Cu(OH)_2.CuCO_3$) are examples of metallic minerals. Diamond, gravel, and mica are examples of nonmetallic minerals. Metals and non-metals can also be found in seawater. Some non-metallic elements, such as oxygen and nitrogen, are found in the atmosphere. In this unit you will learn about the general properties and extraction of metals and nonmetals, alloys, and the production and uses of some metals and nonmetals.

Objectives

Upon completion of this unit, you will be able to

- Describe the general properties of metals and nonmetals.
- Describe the extraction, chemical properties and uses of aluminium, iron, copper, nitrogen, phosphorus, oxygen, sulphur, and chlorine.

- Demonstrate scientific inquiry skills: observing, classifying, communicating, and asking questions, applying concepts and problem solving.

Section 5.1: Metals

- Metals are elements (except hydrogen) that form positive ions by losing electrons during chemical reactions. Approximately three-quarters of all known chemical elements are metals.

Objectives

Upon completion of this section, you will be able to

- Describe the source of metals and non-metals.
- Explain the natural occurrence of metals and nonmetals.
- Explain the nature of alloys.
- Discuss the general properties and extraction of metals.
- Explain occurrence and extraction of Aluminum, Iron and Copper.
- Describe the applications of Aluminum, Iron and Copper.

5.1.1. General Properties and Extraction of Metals and Alloys

- Dear learner, metals have common and specific properties. In this section, you will study the common or general properties as well as the extraction of metals. The specific properties and extraction of some metals will be discussed in Section 5.2. This topic will also briefly touch on the definition and characteristics of alloys.

Properties and Extraction of Metals

About 80 % of the known elements are metals. These metals have some common properties. What are the properties of metals ?

A. Some physical properties of metals

They have a shining appearance (lustrous) and can be polished. Gold is shining yellow and copper is brown. Iron, aluminum, zinc and silver are lustrous grey or silvery.

They are malleable, (can be beaten into thin sheets). Aluminum foils, which are used to wrap cigarettes, medicines, etc., and gold and silver ornaments of different designs are due to the malleability of these metals.

They are ductile, i.e. they can be drawn into wires. For example copper, gold, iron and silver are ductile.

They are hard and have tensile strength except for lithium, potassium, and sodium.

They generally have a high density except lithium, potassium, sodium.

They are usually sonorous-produce metallic sound when struck (e.g. school bell)

B. Chemical properties of metals

Metals possess positive valency and have a tendency to lose electrons.

$$M(g) \rightarrow M^{n+}(g) + ne^-$$

They have 1, 2, or 3 valence electrons.

They are oxidized by losing electrons and act as reducing agents

They mostly form basic oxides and some amphoteric oxides (refer to Unit 3)

They form chlorides that are true salts and electrovalent.

They form hydrides which are ionic, unstable and reactive.

They usually replace hydrogen from dilute non-oxidizing acids like HCl and H_2SO_4. Exceptions are copper, silver and gold.

C. Reactivity series of metals

If we take solutions of different metals and place other metals in these solutions, we can compare the reactivity of the metals with respect to each other.

The arrangement of metals in decreasing order of their activity is known as the **activity or reactivity series**. The most active metal is at the top and the least active metal is at the bottom of the reactivity series.

Hydrogen, a nonmetal, has been included in the series only for the comparison of the activity of the metals. The metals above hydrogen like potassium, sodium, calcium and magnesium in the reactivity series liberate hydrogen gas when treated with dilute acids. The metals below hydrogen in the reactivity series like copper, silver, and gold do not liberate hydrogen when treated with dilute acids. A less reactive metal (low in the reactivity series) can be displaced from its compound or from its salt solution by a more reactive metal (high in the reactivity series)(see ***Figure 5.1***). Thus, potassium can displace all the metals from their salt solution.

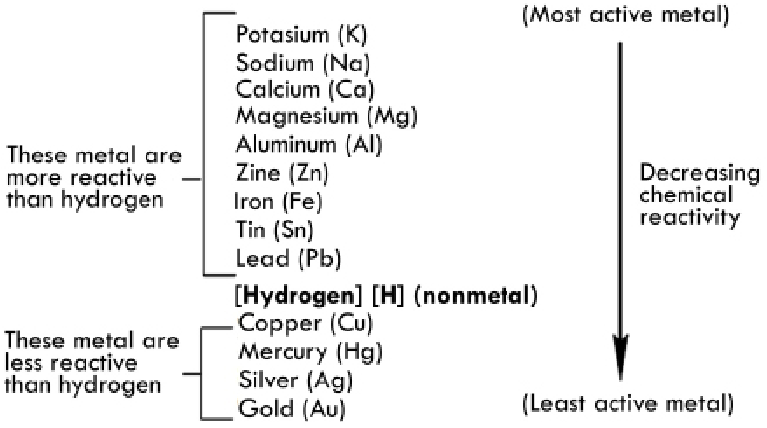


Figure 5.1 Reactivity series of metals.

Metals at the top of the reactivity series are **strong reducing agents**. Metals at the bottom in the reactivity series are weak reducing agents. Hence, potassium is the strongest reducing agent whereas gold is the weakest reducing agent in the above reactivity series.

D. Natural occurrence and extraction of metals

The noble metals Ag, Au, Bi, Cu, Pd, Pt exist in nature in thier uncombined or free state. More active metals like alkali and alkaline earth metals never exist in an uncombined state. They always exist in compounds. Active metals may exist in the form of carbonates, halides, oxides, phosphates, silicates, sulphides and sulphates.

The constituents of the earth's crust that contain these metals or their compounds are known as minerals. For example, sodium exists as the mineral halite (NaCl), potasium as sylvite (KCl), magnesium as magnesite ($MgCO_3$), calcium as limestone ($CaCO_3$).

In some places, minerals contain a high percentage of particular metals and the metal can be profitably extracted from them, such minerals are called ores. An ore taken from the earth contains a lot of impurities in the form of sand and other undesirable materials called gangue. In fact, metals exist in these ores in the form of compounds. The science and technology of extracting metals from their ores and compounding alloys is called metallurgy.

The three principal steps in the extraction of a metal from its ore are (1) preparation (concentration) of the ore, for example, oil floatation, magnetic separation, and (2) production of the metal, for example, roasting, calcination, and (3) purification of the metal (last step), example: chemical reduction, electrolytic reduction, as shown in ***Figure 5.2***.

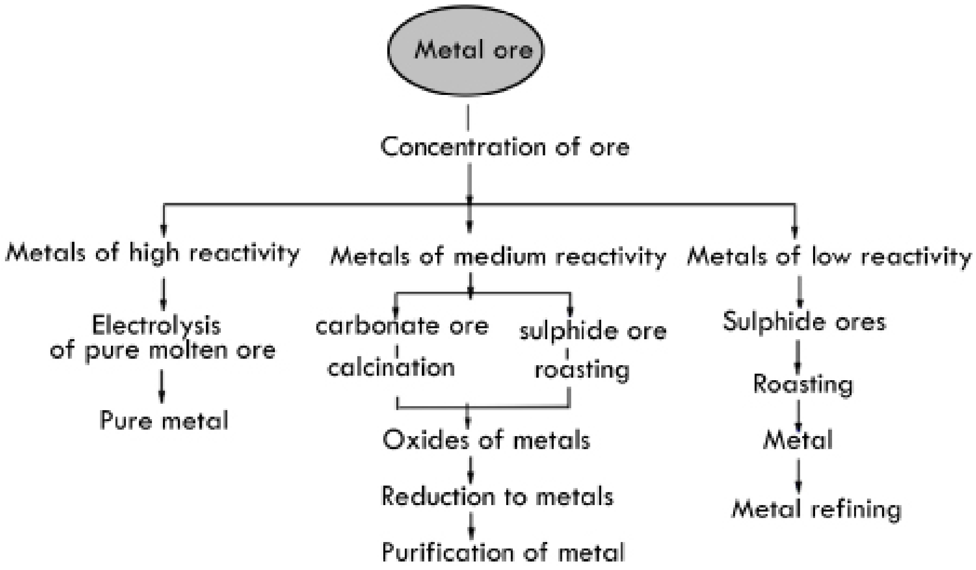


Figure 5.2 General metallurgical processes of metals.

The most active metals such as K, Na, Ca, and Mg are extracted from their compounds only by electrolysis because there is no economic reducing agent that can reduce them from their compounds. It is only by using electricity (electrolysis) that these metals are extracted or reduced.

Alloys are mixtures of two or more metals or metals and nonmetals when molten and do not separate when solidified.

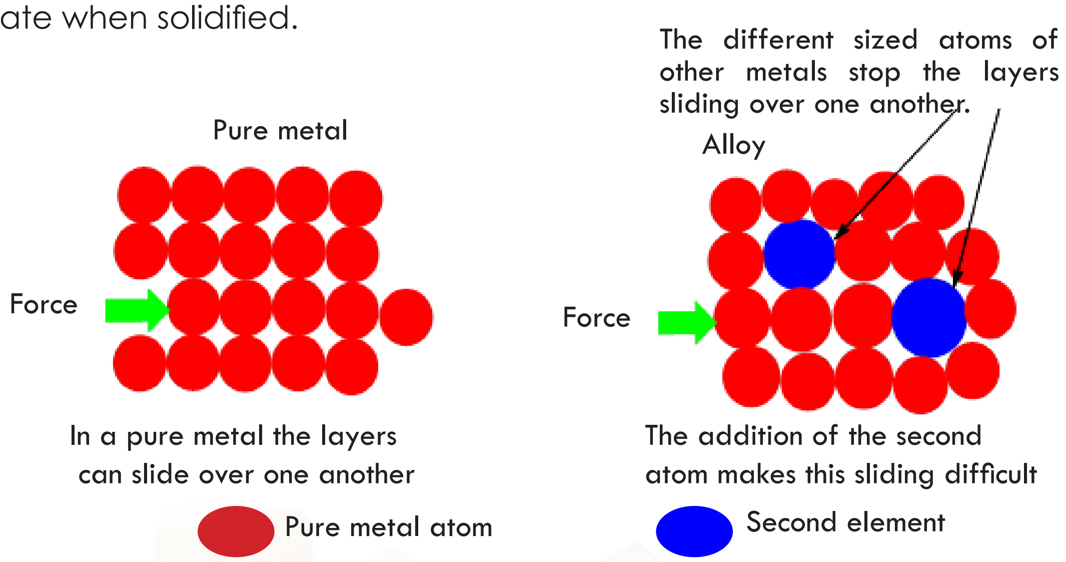


Figure 5.3. Arrangement of metal atoms in pure metal and an alloy.

The constituent elements are melted together and then allowed to cool to form a solid material called an alloy ***Figure 5.3***.

Alloying metals increases their hardness and strength, modifies their colors and melting points, decreases their electrical conductivity, and increases their resistance to corrosion. For example, amalgam is an alloy of mercury and another metal. Gun metal is an alloy of copper (87 %), tin (10 %) and zinc (3 %).

Solder is called fuse metal. Its composition is 67 % tin and 33 % lead. It melts at 183 ^{0}C which is lower than the melting points of tin (Sn melts at 232 ^{0}C). Solder is used to join wires and electrical resistances, etc.

Gold alloys: Gold is a very soft metal and is therefore hardened by alloying it with copper and silver. The quantity of gold in an alloy is called its gold content. The gold content of the alloy is expressed either in carats or as a mass percent. A carat is equal to the mass unit of gold in 24 mass units of the alloy. Thus, 24-carats represents pure gold. It doesn't contain any other metal. 22-carat gold contains 22 parts of pure gold by mass in 24-carats of the alloy.

Nowadays 22-carat gold is used to make jewelry. 18-carat contains 18 parts of pure gold by mass in 24 parts of alloy. Thus, the mass percent of gold in different types of alloys can be calculated as follows:

Mass % of gold in 24 carat gold = 24 x100/24 = 100.00 (pure gold, no Cu or Ag)
Mass % of gold in 22 carat gold = 22 x100/24 = 91.67 (alloy, 8.33 % Cu or Ag)

5.1.2. Production of Aluminum, Iron and Copper

In this section, you are going to study the extraction of three metals: aluminum, copper, and iron. In the periodic table, **Aluminum** is a metal of Group 13, and copper and iron are transition metals. In general, metals are extracted from their ore, which is a naturally occurring substance. Aluminum is extracted electrolytically, which involves the passing of electricity through an ionic substance in a solvent in the presence of two rods called electrodes. During the process, the metal gets deposited on one of the electrodes. Copper is extracted by the self-reduction method. Iron is extracted by the carbon reduction method from its ores.

A. Aluminum

Occurrence and extraction

Aluminum is the most abundant metal in the earth's crust and the third most abundant element after oxygen and silicon. Approximately eight percent of the earth's crust is aluminum. In terms of consumption, it is the second most important metal after iron. Aluminum does not occur in uncombined or free metal state in nature. Its main mineral is bauxite ($Al_2O_3.2H_2O$). Other minerals containing aluminum are orthoclase ($KAlSi_3O_8$), cryolite (Na_3AlF_6), corundum (Al_2O_3), beryl ($Be_3Al_2Si_6O_8$) and china clay ($Al_2Si_2O_7.2H_2O$).

Industrially, aluminum is extracted from bauxite, $Al_2O_3 \cdot 2H_2O$, mainly by the Hall–Héroult process or simply the Hall process. In this process, the bauxite must be purified first because it is often contaminated by silicon dioxide (SiO_2), iron oxide, and titanium (IV) oxide. To separate the pure Al_2O_3 from the bauxite, the powdered ore is first heated with a sodium hydroxide solution to convert the silica to soluble silicate.

$$\underset{\text{Insoluble}}{SiO_2\ (s)} + 2NaOH\ (aq) \rightarrow \underset{\text{soluble}}{Na_2SiO_3\ (aq)} + H_2O\ (l)$$

At the same time aluminum oxide is converted to soluble sodium aluminate.

$$\underset{\text{Insoluble}}{Al_2O_3\ (s)} + 2NaOH\ (aq) \rightarrow \underset{\text{soluble}}{NaAlO_2\ (aq)} + H_2O\ (l)$$

Impurities like iron oxides and titanium (IV) oxide remain unaffected by the base and are filtered off. Why are they not affected?

Then the solution is treated with acid to precipitate aluminium hydroxide.

$$AlO^{2-}\ (aq) + H_3O^+\ (aq) \rightarrow Al(OH)_3\ (s)$$

Aluminum hydroxide is collected by filtration, washed, dried, and then heated strongly in a furnace to get Al_2O_3.

$$2Al(OH)_3\ (s) \xrightarrow{\text{Heat}} Al_2O_3\ (s) + 3H_2O\ (g)$$

Pure aluminum oxide is mixed with some cryolite, Na_3AlF_6, and then melted. Cryolite is added to Al_2O_3 to reduce its melting point from 2045°C to 1000°C. The molten cryolite also provides a good conducting medium for the electrolysis process. The molten mixture is then electrolyzed to obtain pure aluminum. The electrolytic cell, in which the molten mass is electrolyzed, contains graphite electrodes as both anode and cathode (See ***Figure 5.4***).

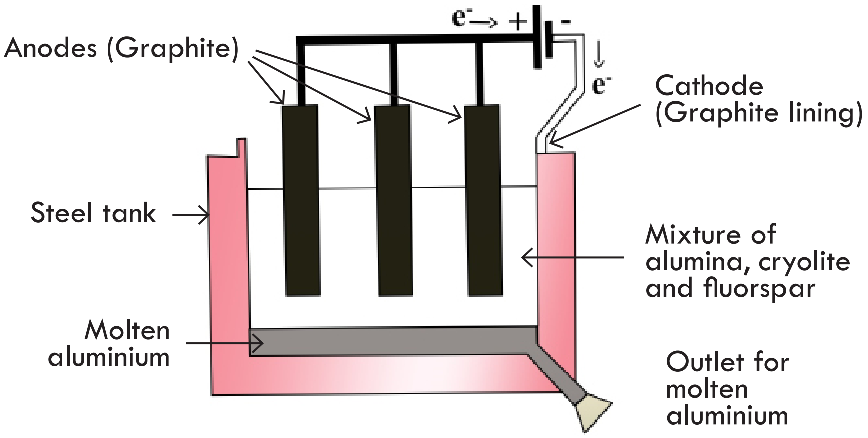


Figure 5.4. Electrolytic reduction of aluminum based the Hall's process.

Al_2O_3 is converted to Al, by electrolysis. The reactions at the graphite (carbon) electrodes are:

Anode reaction: $3C(s)\ (\text{graphite electrode}) + 6O^{2-} \rightarrow 3CO_2(g) + 12e$

Cathode reaction: $\underline{4Al^{3+}(l) + 12e \rightarrow 4Al(l)}$

Over all reaction: $4Al^{3+}(l) + 6O^{2-}(l) + 3C(s) \rightarrow 4Al(l) + 3CO_2(g)$

Or $2Al_2O_3(l) + 3C(s) \rightarrow 4Al(l) + 3CO_2(g)$

Note that under the prevailing conditions in the electrolytic cell, the anode (graphite electrode) will gradually oxidize to carbon dioxide and must be replaced regularly. Molten aluminum is siphoned or drawn from the bottom of the electrolytic cell. We do not use reducing agents for the reduction of aluminum from aluminum oxide; why do you think?

Physical Properties: Aluminum is a soft silvery-white and light metal with a density of 2.7 g/cm^3. It melts at 660 °C. It can be shaped into wires, rolled, pressed or cast into different shapes. It is a good conductor of heat and electricity.

Chemical Properties: Aluminum is a reactive metal, even though its reactions are not vigorous in comparison with those of sodium, potassium, calcium and other metals of groups IA and IIA. It undergoes the following reactions:

i. Reaction with Oxygen

Aluminum has affinity for oxygen and reacts with atmospheric oxygen to form a thin film of aluminum oxide on its surface.

$$4Al\ (s) + 3O_2\ (g) \rightarrow 2Al_2O_3\ (s)$$

This thin film of oxide inhibits further reactions with oxygen. The thin film can be removed by rubbing with mercury or mercury (II) chloride solution. What type of oxide is Al_2O_3?

ii. Aluminum burns in Nitrogen gas to form Aluminum Nitride.

$$2Al\ (s) + N_2\ (g) \rightarrow 2AlN\ (s)$$

iii. Reaction with dilute acids

Aluminum reacts with dilute acids like HCl and H2SO4, forming salts and liberating hydrogen gas.

$$2Al\ (s) + 3H_2SO_4\ (aq) \rightarrow Al_2(SO_4)_3\ (aq) + 3H_2\ (g)$$
$$2Al\ (s) + 6HCl\ (aq) \rightarrow 2AlCl_3\ (s) + 3H_2\ (g)$$

Aluminum does not react with dilute or concentrated HNO_3 due to the formation of a protective oxide layer on its surface. Therefore, materials made of Al may be used to transport HNO_3.

iv. Aluminum burns in chlorine gas to form aluminum chloride

$$2Al\ (s) + 3Cl_2\ (g) \rightarrow 2AlCl_3\ (s)$$

v. Aluminum reacts with sodium hydroxide solutions

$$2Al\ (s) + 2NaOH\ (aq) + 6H_2O\ (l) \rightarrow 2NaAl(OH)_4\ (aq) + 3H_2\ (g)$$

Uses of Aluminum

Aluminum is a lightweight metal and resistant to corrosion, which is why it is used to make light alloys, such as duralumin (a mixture of Al, Cu, and Mg). Aluminum alloy is widely used in the transportation industry to make airplanes, ships, and automobiles. Due to its high thermal conductivity and corrosion resistance, it is used to make household cookware. It is also used in the manufacture of door and window frames and building roofs, as a packaging material in the food industry, and for power transmission lines. Al is also used in the thermite welding process.

Thermite Welding

Thermite welding is useful in welding rails, propeller shaft and other steel parts of machinery that are difficult to repair by any other method. The process is explained as follows: Aluminum is more reactive than iron; therefore, it displaces iron from iron oxide. In the thermite welding process, powdered aluminum when mixed with iron (III) oxide and ignited, produces a temperature of about 3000°C. This temperature is quite sufficient for welding metals. The reaction in this process is as follows:

$2Al\ (s) +$	$Fe_2O_3\ (s)$	$\rightarrow$	$2Fe\ (l) +$	$Al_2O_3\ (s)$
Aluminum	Iron oxide		Iron	Aluminum oxide

The mixture of powdered aluminum and iron oxide is called thermite. Similar reactions are used to insulate other metals such as Chromium:

$$Al(s)\ +\ Cr_2O_3\ \rightarrow\ 2\ Cr\ (l)\ +\ Al_2O_3\ (s)$$

B. Iron

Iron is the second-most abundant metal in the earth's crust after aluminum, and the fourth-most abundant element. It accounts for about 4.7% of the weight of the earth's crust. It has never been found as a free metal in nature. It exists only in the form of compounds in nature, such as oxides, carbonates and sulphides. The chief ores of iron are hematite (Fe_2O_3), limonite ($Fe_2O_3.H_2O$), magnetite (Fe_3O_4), and siderite ($FeCO_3$). It is also found in the form of iron pyrites (FeS_2) which is commonly called fool's gold.

Iron is generally extracted from hematite (Fe_2O_3), magnetite (Fe_3O_4) and siderite ($FeCO_3$).

Producing pig iron (impure iron)

The extraction of iron from its ores is carried out in a blast furnace (***Figure 5.5***). The raw materials for the extraction of iron are iron ore, coke, limestone and hot air. The furnace is charged with a mixture of iron ore, limestone and coke at the top and a blast of hot air is blown at the bottom. The coke burns to form carbon dioxide and the temperature approaches 2000°C near the bottom. As the carbon dioxide rises, the coke reduces it to carbon monoxide. The carbon monoxide then reduces the iron oxide to iron metal.

The reactions taking place in the blast furnace can be summarized as follows:

i. Oxidation of coke to carbon dioxide: $C\ (s) + O_2\ (g) \rightarrow CO_2\ (g) + \text{Heat}$

ii. Reduction of carbon dioxide to carbon monoxide: $CO_2\ (g) + C\ (s) \rightarrow 2CO\ (g)$

iii. Reduction of iron oxides to metallic iron by carbon monoxide:

$$3Fe_2O_3\ (s) + CO\ (g) \rightarrow 2Fe_3O_4\ (s) + CO_2(g)$$
$$Fe_3O_4\ (s) + CO\ (g) \rightarrow 3FeO\ (s) + CO_2\ (g)$$
$$FeO\ (s) + CO\ (g) \rightarrow Fe\ (l) + CO_2(g)$$

iv. Decomposition of the limestone by heat in the blast furnace serves as a flux to remove impurities: $CaCO_3\ (s) \rightarrow CaO\ (s) + CO_2\ (g)$

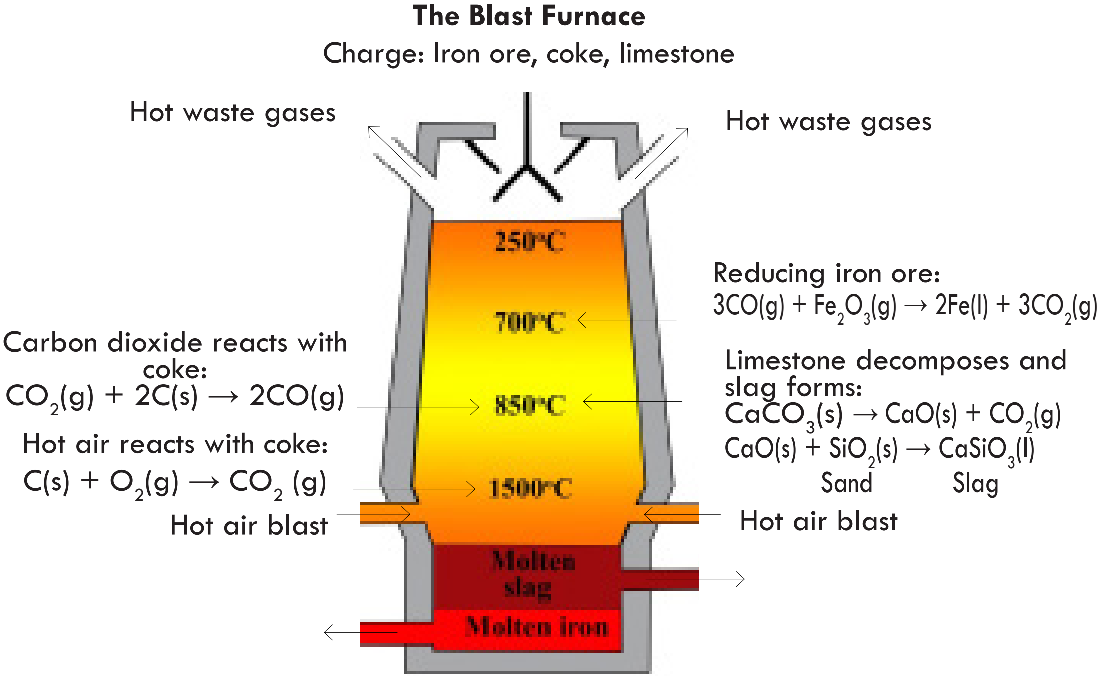


Figure 5.5 Production of pig iron from iron ore in the blast furnace.

v. Calcium oxide (CaO) removes impurities like sand or silica (SiO_2) to form calcium silicate which is a glass-like material called slag.

CaO	+	SiO_2	→	$CaSiO_3$
Lime	+	sand		calcium silicate
(Flux)		(Impurity)		(Slag)

The molten slag is lighter than the molten metal. Therefore, it floats over the molten metal and thus the two can be easily separated. The slag is used mostly for the manufacture of cement.

The iron obtained directly from the blast furnace is called pig iron. It is impure and contains about 2 % silicon, up to 1% phosphorus and manganese, and traces of sulphur. These impurities make pig iron brittle. Pig iron, also known as crude iron, is an intermediate product of the iron industry in the production of steel. When pig iron is re-melted with scrap iron and cast into moulds, it forms cast iron. Pig iron contains at least 92% Fe and has a very high carbon content, typically 3.5 - 4.5%. Along with silica and other constituents of dross, which makes it very brittle and not useful directly as a material except for limited applications.

The purest form of commercial iron is called wrought iron. It is obtained by removing most of the impurities from pig iron. Metal factories manufacture wrought iron by heating impure iron with hematite and limestone in a furnace. This increases the purity of the iron to 99.5%. Wrought iron is a tough, malleable and ductile form of iron.

Steelmaking from pig iron (purification of pig iron)

The relatively high carbon content of the iron recovered from the blast furnace (pig iron) makes it very hard and brittle. The conversion of pig iron to steel is essentially a purification process in which impurities are eliminated through oxidation. This purification process is carried out in a furnace at high temperatures. Three distinctive techniques are used to convert pig iron into steel. These are the Bessemer converter, the Open-hearth Furnace and the Basic Oxygen Process.

i. The Bessemer converter: In the process of converting pig iron to steel, molten pig iron from the blast furnace is transferred to a cylindrical vessel containing a refractory lining of $MgCO_3$ and $CaCO_3$ (see ***Figure 5.6 a***). A blast of hot air is blown through the molten metal from a set of small holes at the bottom of the vessel. The oxygen passing through the molten metal converts silicon, phosphorus and sulphur to their oxides, which then react with the lining to form a slag. The carbon in the pig iron is also oxidized to carbon monoxide, so its concentration is also reduced. The conversion of the pig iron to steel by this process requires only 15 minutes. However, the reaction is difficult to control and the quality of the steel produced can be quite variable.

ii. The Open-hearth Furnace: It has a large, shallow hearth, which is usually lined with a basic oxide refractory (MgO and CaO)(***Figure 5.6 b***). The furnace is charged with a mixture of pig iron, Fe_2O_3, scrap iron and limestone. A blast of hot air and burning fuel is directed over the surface of the charge to maintain it in the molten state. Impurities in the pig iron are oxidized by Fe_2O_3 and air. Carbon dioxide, and sulphur dioxide formed by the oxidation of the carbon and sulphur, respectively, in the pig iron bubble out of the mixture as waste gases.

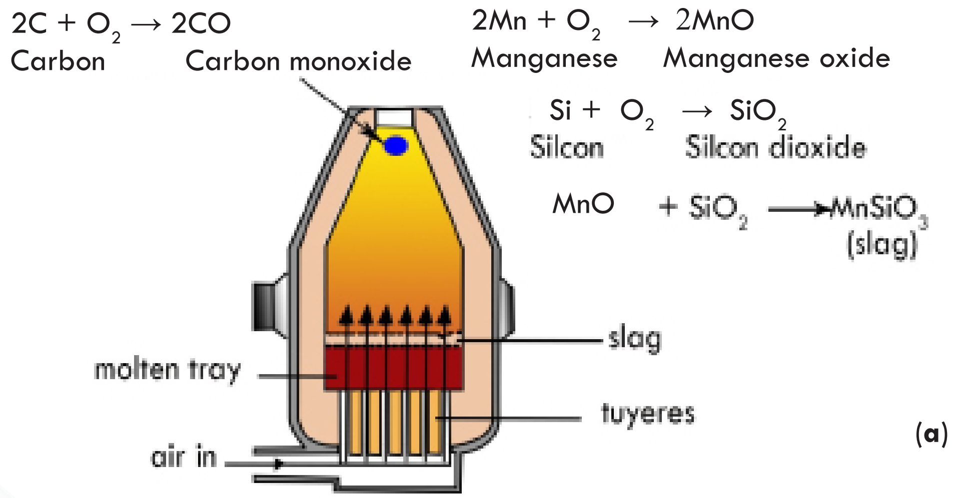
The SiO_2 and other acidic oxides like P_4O_{10} combine with CaO (from limestone) and the refractory lining to form a slag.
The impurities in pig iron are oxidized in the following way:

$$C + O_2 \rightarrow CO_2$$
$$S + O_2 \rightarrow SO_2$$
$$12P + 10Fe_2O_3 \rightarrow 3P_4O_{10} + 20Fe$$
$$3Si + 2Fe_2O_3 \rightarrow 3SiO_2 + 4Fe$$

Calcium oxide, formed by the decomposition of limestone, reacts with oxides of silicon and phosphorus to form slag.

$$P_4O_{10} + 6CaO \rightarrow 2Ca_3(PO_4)_2$$
$$SiO_2 + CaO \rightarrow CaSiO_3$$

Impurities manganese and silicon form respective oxides and removed as slag.



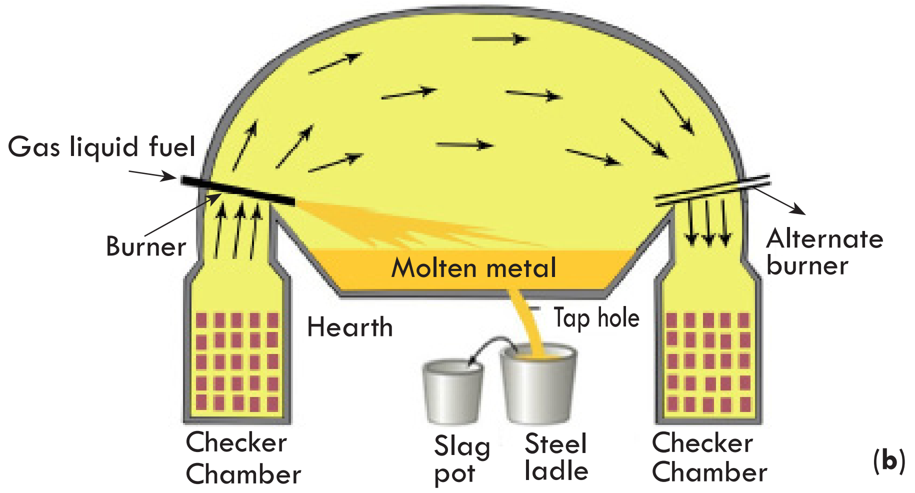


Figure 5.6 Bessemer converter (a) and Open-hearth furnace (b)

This entire process takes 8 to 10 hours to complete and the quality of the steel is much more easily controlled. A calculated amount of various elements can be added to the steel to form steel alloys with the desired properties.

iii. Basic Oxygen Process: This newer procedure has largely replaced the open hearth, because of its high speed. It involves forcing a mixture of powdered calcium oxide, CaO, and oxygen gas directly into the surface of the molten pig iron. The oxygen reacts exothermically with carbon, sulphur, silicon, phosphorus and impurity metals. Carbon and sulphur are oxidized to CO_2 and SO_2, respectively, and are released as exhaust gases. The oxides of silicon (SiO_2), phosphorus, (P_4O_{10}) and impurity metals combine with lime (CaO), forming slag *Figure 5.7*. The charge in the converter is maintained in the molten state by the energy released in these oxidation reactions. The converter is tilted to remove the slag. After a second blow of oxygen, the converter is tilted once again and the molten steel is poured out. This process takes only about 20 to 25 minutes.

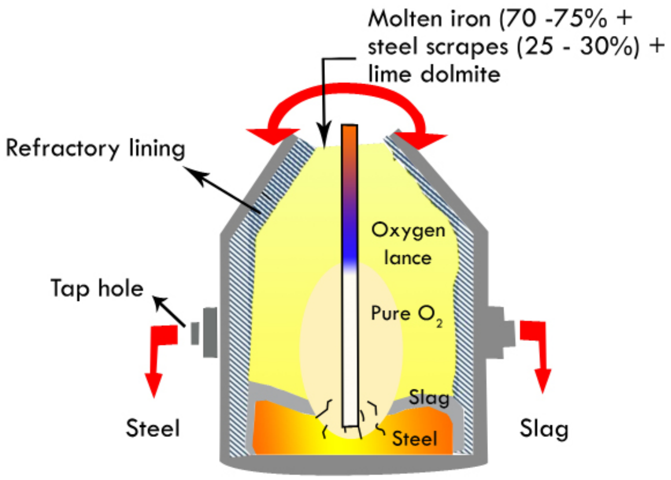


Figure 5.7. The basic oxygen converter

Tempering of steel is a process by which steel is conditioned to a desired hardness by heating and a controlled rate of cooling. Some of the carbon in steel is present as a compound called cementite (Fe_3C). It reduces the hardness of steel. Cementite can be removed by tempering which is difficult to remove by the above methods.

Physical Properties of Iron

Do you remember the physical properties of iron? Can you mention some of them? Iron is a gray lustrous, malleable and ductile metal. It is a good conductor of heat and electricity. It has a high melting point (1580°C) and a high density (7.87 g/cm^3). It is a ferromagnetic metal, which means it can be permanently magnetized.

Chemical Properties of Iron

? Have you ever noticed the formation of a thin reddish film on the surface of an iron object? Do you know the chemical nature of this thin film? From your observations, what do you conclude about the reactivity of iron?

Iron is a reactive metal. Its reactivity is very slow compared to group IA and IIA metals. Iron rusts in the presence of air and moisture to form hydrated iron (III) oxide.

$$4Fe(s) + 3O_2(g) \longrightarrow 2Fe_2O_3.xH_2O(s)(rust)$$

Iron reacts with dilute acids, like HCl and H_2SO_4, forming iron (II) salts and liberating hydrogen gas

$$Fe\ (s) + 2HCl\ (aq) \rightarrow FeCl_2\ (aq) + H_2\ (g)$$
$$Fe\ (s) + H_2SO_4\ (aq) \rightarrow FeSO_4\ (aq) + H_2\ (g)$$

Like other transition metals, iron also exhibits different oxidation states. It commonly exists as ferrous (Fe^{2+}) and ferric (Fe^{3+}) ions. Iron (II) and iron (III) compounds are coloured. Aqueous solutions of iron (II) compounds are pale-green and solutions of iron (III) compounds are yellowish brown.

Aqueous solutions of some iron (II) compounds are rapidly oxidized to the corresponding iron (III) compounds. For example, iron (II) hydroxide, $Fe(OH)_2$, on exposure to air, oxidizes to iron (III) hydroxide.

$$4Fe(OH)_2\ (s) + O_2\ (g) + 2H_2O\ (l) \rightarrow 4Fe(OH)_3\ (s)$$

Heated iron reacts with hydrogen chloride gas, forming iron (II) chloride and hydrogen gas.

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

Heated iron reacts with chlorine and sulphur to form chloride and sulphide, respectively

$$2Fe\ (s) + 3Cl_2\ (g) \rightarrow 2FeCl_3\ (s)$$
$$Fe\ (s) + S\ (s) \rightarrow FeS\ (s)$$

Iron has the ability to displace less active metals from solutions of their salts. For example, when a piece of iron is placed in a solution of $CuSO_4$, it is oxidized to Fe^{2+} and a reddish-brown deposit of copper metal forms on the surface of the iron.

$$Fe\ (s) + Cu^{2+}\ (aq) \rightarrow Fe^{2+}\ (aq) + Cu\ (s)$$

Uses of Iron

Iron is the most widely used metal and takes the first place in worldwide consumption. It is used as a structural metal in the construction of buildings and bridges. In the form of pig iron, it is used to make domestic boilers, hot-water radiators, railings, water pipes, castings, and moldings. As wrought iron, it is used in making nails, sheets, horseshoes, ornamental gates, doorknockers, farm machinery etc. Iron is also used in the manufacture of alloys such as carbon steels and alloy steels.

Table 5.1 Types and uses of carbon steels.

Type	% of carbon	Use
Mild steel	Up to 0.2	Making screws, motors, car batteries, railway lines, ships, nuts and bolts
Medium steel	0.3 - 0.6	Making springs and chains
High carbon steel	0.6 - 1.5	Making drill bits, knives, hammers and chisels
Stainless steel	Fe = 73, C =1, Cr = 18, Ni = 8	For making knife blades, kitchen pots, pans, food machinery, automobile parts, and laundry machines

Alloy Steel: contains iron and a relatively higher percentage of other metals. For example, stainless steel contains chromium (14–18%) and nickel (7–9%). Tool steels include tungsten steel and manganese steel. These metals give the alloy hardness, toughness and heat resistance. They are used in rock drills, cutting edges and parts of machinery that are subjected to heavy wear.

C. Copper

Copper is occasionally found as native copper. However, it is found mainly in compounds such as sulphides, oxides and carbonates. The most important sulphide ores are chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS) and bornite (Cu_5FeS_4). The principal oxide ores are cuprite (Cu_2O) and tenorite (CuO). In the carbonate form, it exists as malachite ($CuCO_3.Cu(OH)_2$).

Copper is principally extracted from chalcopyrite. Since the amount of copper in the ore is very small, the crushed and ground sulphide ore is first concentrated by froth flotation. This treatment changes the concentration of the ore from 2 % copper to as high as 30% copper. The concentrated ore is then roasted with a limited supply of air (oxygen).

$$2CuFeS_2\,(s) + 4O_2\,(g) \rightarrow Cu_2S\,(s) + 2FeO(s) + 3SO_2\,(g)$$

The roasted mixture is melted by adding limestone and sand to form a molten slag that removes many of the impurities. FeO present in the roasted mixture can also be removed as slag in the form of iron silicate ($FeSiO_3$), and silica in the form of calcium silicate ($CaSiO_3$).

$$CaCO_3\,(s) + SiO_2\,(s) \rightarrow CaSiO_3\,(l) + CO_2\,(g)$$
$$FeO\,(s) + SiO_2\,(s) \rightarrow FeSiO_3\,(l)$$

The Cu_2S obtained by roasting chalcopyrite is then reduced by heating it with a limited supply of oxygen.

$$Cu_2S\,(s) + O_2\,(g) \rightarrow 2Cu\,(l) + SO_2\,(g)$$

The copper produced by the above process is called blister copper and it has 98.5 – 99.5 % purity. Blister copper contains iron, silver, gold and sometimes zinc as impurities. So it is refined further by electrolysis as shown in ***Figure 5.8***.

Electrolytic refining of copper

The main parts of the electrolytic cell are:

Anode: A thick block of impure copper
Cathode: A thin strip of pure copper
Electrolyte: An aqueous solution of copper sulphate.

A small quantity of dilute sulphuric acid is also added to the salt solution to prevent hydrolysis. When electric current is passed, the copper of the anode is oxidized to Cu^{2+} ions. The Cu^{2+} ions pass into solution.

$$Cu \text{ (impure metal)} \rightarrow Cu^{2+}(aq) + 2e \qquad \text{oxidation at anode}$$

At the same time an equal number of Cu^{2+} ions of the solution move towards cathode where they are reduced and deposited as metallic copper.

$$Cu^{2+}(aq) + 2e \rightarrow Cu \text{ (metal)} \qquad \text{reduction at cathode}$$

The processes of oxidation at the anode and reduction at the cathode continue as long as the current is passed. Thus, the cathode becomes thicker and the anode becomes thinner. Pure copper deposited at the cathode is removed and used. Copper obtained by electrolytic refining is 99.99% pure.

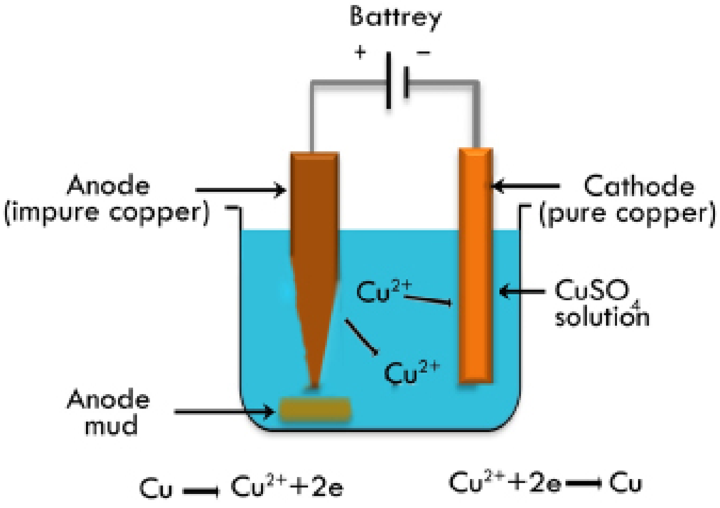


Figure 5.8 Electrolytic refining or purification of copper.

Physical Properties of Copper

Copper is a soft, ductile, malleable, reddish-brown metal with a density of 8.96 g/cm^3. It is second to silver in electrical conductivity. It melts at 1086°C and boils at 2310°C.

Chemical Properties of Copper

Copper is a less reactive metal which is why it is found in its native state. Although it is not very reactive, it undergoes the following reactions:

Powdered copper, when heated in air forms a black powder of copper (II) oxide, CuO.

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

Copper does not react with dilute acids like HCl and H_2SO_4. It cannot displace hydrogen from acids. However, it can be oxidized by oxidizing acids such as dilute and concentrated nitric acid and hot concentrated sulphuric acid, H_2SO_4.

$$3Cu(s) + 8HNO_3\ (aq) \xrightarrow{\text{dilute}} 3Cu(NO)_3)_2\ (aq) + 2NO\ (g) + 4H_2O\ (l)$$

$$Cu(s) + 8HNO_3\ (aq) \xrightarrow{\text{concentrated}} Cu(NO)_3)_2\ (aq) + 2NO_2\ (g) + 2H_2O\ (l)$$

$$Cu(s) + 2H_2SO_4\ (aq) \xrightarrow{\text{Hot and concentrated}} CuSO_4(aq) + SO_2\ (g) + 2H_2O\ (l)$$

Copper corrodes in moist air over a long period of time as a result of oxidation caused by a mixture of water, oxygen and carbon dioxide. It turns green due to the formation of verdigris: a basic copper carbonate ($CuCO_3.Cu(OH)_2$) or $Cu_2(OH)_2CO_3$.

$$2Cu\ (s) + H_2O\ (l) + O_2\ (g) + CO_2\ (g) \rightarrow CuCO_3.Cu(OH)_2$$

Basic copper carbonate is responsible for the green layer that forms on the surface of copper and bronze objects. This layer adheres to the surface and protects the metal from further corrosion. Copper is a transition metal and exhibits different oxidation states. It exists as cuprous (Cu^+) and cupric (Cu^{2+}) ions. Compounds containing copper in the +2 oxidation state are stable. Cu^{1+} is unstable and cannot exist in an aqueous solution since it reduces and oxidizes (disproportionates) itself as follows:

$$2Cu^+\ (aq) \rightarrow Cu^{2+}\ (aq) + Cu\ (s)$$

Soluble compounds containing Cu^+, such as CuCl, CuI and CuBr, are all colourless solids. The most stable oxidation state of copper is +2. Aqueous solutions of many copper (II) compounds are blue; thus, copper forms coloured compounds in the oxidation state of +2. For example, hydrated copper sulphate, $CuSO_4.5H_2O$, consists of blue crystals, and its aqueous solution is also blue.

Uses of Copper

Copper is used to manufacture alloys. For example, bronze is an alloy of copper and tin, and it is used to make coins, medals, bells, machinery parts, etc. Brass is an alloy of copper and zinc, and it is used for hardware tops, terminals and pipes. Copper is widely used in the electrical industry in the form of electric wires, cables etc. Copper compounds, such as copper chloride, copper carbonate and copper hydroxide, are used as pesticides

Checklist - 5.1

The following checklists are provided to you as a guide to check what you have learned in this unit. Check you understanding by putting a "✓" mark if you can remember what is presented in relation to the terms. If you don't remember, please go back to the corresponding section and make a quick review. I can ...

SN	Competencies	Check
1	describe the source of metals and non-metals.	
2	explain the natural occurrence of metals and nonmetals.	
3	explain the nature of alloys.	
4	discuss the general properties and extraction of metals.	
5	explain occurrence and extraction of Aluminum, Iron and Copper?.	
6	describe the applications of Aluminum, Iron and Copper.	

Self-Test Exercise 5.1

I. Answer the following questions correctly.

1. Classify the following as naturally available and made by humans: water, sunlight, land, minerals, statues, concrete, plastics, and buildings, fossil fuels (crude oil, coal, and natural gas)
2. Categorize the following as renewable and nonrenewable resources: rocks, metal ores, soil, wood, air, water, crops, fossil fuels, and biofuels
3. Describe the occurrence and extraction of the following metals: aluminium, iron, and copper.
4. Which of the three metals, Al, Fe and Cu is produced by electrochemical reduction?
5. Explain how Al, Fe and Cu behave in dry air, moisture and acidic solutions.
6. Why is limestone used in steel?
7. Discuss the main areas of applications of Al, Fe and Cu in the home and industry.
8. The kitchen utensils used for cooking foods are made of metals like aluminum, iron, copper or alloys of some metals. Give a reason.
9. Why are wires employed in electrical appliances made of copper and/or aluminum?

II. Give an example of a metal for each of the following questions.

10. a. A metal which is liquid at room temperature. Is there any metal that exists in the gaseous state at room temperature?
    b. A metal that is the best conductor of heat
    c. A metal that is the poorest conductor of heat
    d. A metal that can be cut with a knife
11. What is activity or reactivity series. Compare the reactivity series of alkali metals.
12. Where are metals found ? How are metals exracted from their ores?
13. What is the advantage of alloying metals?

Section 5.2: Nonmetals

5.2.1. General Properties of Nonmetals and Common Uses of Some Nonmetallic Compounds

Nonmetals have opposite characteristics to that of metals.

Objectives

Upon completion of this section, you will be able to

- Discuss the general properties and extraction of nonmetals.
- Explain occurrence and extraction of nitrogen, phosphorous, oxygen, sulphur and chlorine.
- Describe the applications of nitrogen, phosphorous, oxygen, sulphur and chlorine.

A. Physical properties

Nonmetals have the following characterstics.

Occurs in solids, liquids, and gases states.
Non-lustrous
Nonmalleable and non-ductile
Varying hardness and have low density
Low melting and boiling points
do not show any metallic luster.
are soft in comparison to metals
are non-sonorous
Poor conductors of heat and electricity

B. Chemical properties of non-metals

Nonmetals react with oxygen on heating or burning to form their oxides
Do not displace hydrogen in reactions with dilute acids
React with oxygen to form acidic or neutral oxides
Combine with hydrogen to form stable hydrides
Do not react with water
Electronegative i.e for negative ions by gaining electrons
Oxidizing agents

5.2.2. Production of Nitrogen, Phosphorous, Oxygen, Sulphur and Chlorine

A. Nitrogen

Occurrence and Production

Nitrogen occurs in nature in its elemental form. It also exists in the form of compounds. In its elemental state, it exists as a diatomic molecule, N_2, in atmospheric air. It constitutes about 80% of the volume of the atmosphere. In the form of compounds, it exists as sodium nitrate (Chile saltpeter, $NaNO_3$) and potassium nitrate (KNO_3) also called saltpetre. It is also found in the DNA molecules and proteins of all living things.

In the industrial production of nitrogen, the first step is to remove impurities like dust and other particles from the air. The air is then compressed under high pressure and low temperature to remove carbon dioxide and water vapor since they solidify at a relatively high temperature compared to nitrogen and oxygen. As the temperature continues to decrease, the air containing mainly nitrogen and oxygen condenses to form a pale-blue liquid. Nitrogen is thus separated on an industrial scale by fractional distillation of liquid air. When liquid air is fractionally distilled, nitrogen is collected and stored in steel cylinders under pressure.

The second fraction consists of argon, which distills off the mixture at –186°C, leaving behind a blue liquid of oxygen that boils at –183°C. In the laboratory, nitrogen is prepared by warming an aqueous solution containing ammonium chloride and sodium nitrite

$$NH_4Cl\ (aq) + NaNO_2\ (aq) \rightarrow NaCl\ (aq) + N_2\ (g) + 2H_2O\ (l)$$

Physical Properties of Nitrogen

Nitrogen is a colorless, odorless and tasteless gas. It is inert under ordinary conditions, and that is why it is found in atmospheric air as N_2. The inertness of nitrogen at low temperatures is directly related to the strength of the triple bond, which requires high energy to break.

Chemical Properties of Nitrogen

Though nitrogen is inert at low temperatures, it reacts with metals of groups IA and IIA as well as oxygen at higher temperatures. When heated with reactive metals like lithium, calcium and magnesium, it forms compounds known as nitrides.

$$6Li\ (s) + N_2\ (g) \rightarrow 2Li_3N\ (s)$$
$$3Ca\ (s) + N_2\ (g) \rightarrow Ca_3N_2\ (s)$$
$$3Mg\ (s) + N_2\ (g) \rightarrow Mg_3N_2\ (s)$$

Nitrogen combines with oxygen at elevated temperatures or under an electric arc to form oxides.

$$N_2\ (g) + O_2\ (g) \rightarrow 2NO\ (g)$$
$$N_2\ (g) + 2O_2\ (g) \rightarrow 2NO_2\ (g)$$

Nitric oxide, also called nitrogen monoxide, NO, is a colorless and reactive gas. It forms nitrogen dioxide (NO_2), a reddish brown gas, when it comes into contact with oxygen. This reddish-brown gas dimerizes at low temperatures to give a colorless gas of dinitrogen tetraoxide, N_2O_4.

$$2NO_2\ (g) \rightarrow N_2O4\ (g)$$

Nitrogen also forms oxides, like dinitrogen monoxide, N_2O, (commonly called laughing gas), dinitrogen trioxide (N_2O_3) and dinitrogen pentoxide (N_2O_5). Nitrogen reacts directly with hydrogen in the Haber process to form ammonia. In this process, a mixture of N_2 and H_2 gas, at a pressure of 200 - 300 atm and a temperature of 400 - 600°C, is passed over a catalyst of finely divided iron.

$$N_2(g) + 3H_2(g) \xrightleftharpoons[400\text{-}600^0C]{Fe/200\ -\ 300atm} 2NH_3(g)$$

This method produces ammonia that is primarily used in the manufacture of fertilizers. Nitrogen is also used for the production of nitric acid (HNO_3).

Uses of Nitrogen

Nitrogen is used in food packaging to prevent oxidation, and to create an inert atmosphere in the production of semiconductors. Liquid nitrogen is used as a refrigerant to preserve bulls' semen and blood. Its major use is in the production of ammonia.

B. Phosphorus

Occurrence and Extraction

Does phosphorus exist in its pure form (elemental state), as does nitrogen? If not, why? Phosphorus is a relatively abundant element, ranking 12th in the earth's crust. It exists naturally only in the combined state, such as in rock phosphate, $Ca_3(PO_4)_2$, fluoroapatite, $Ca_{10}(PO_4)_6F_2$ or $3Ca_3(PO_4)_2.CaF_2$. It is also found in teeth, bones and DNA.

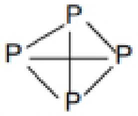
? What is allotropy? What are the two common allotropes of phosphorus?

Allotropes are different forms of the same element with the same physical state but different physical properties. This is due to the difference in the arrangement of atoms. The two common allotropic forms of phosphorus are white phosphorus and red phosphorus.

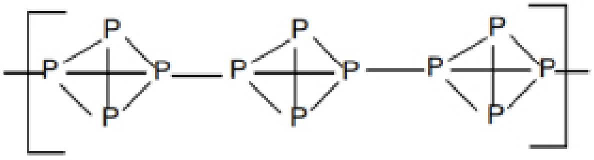
Physical Properties of Phosphorus

White phosphorus is a very poisonous, white waxy-looking substance that melts at 44.1°C and boils at 287°C. Its density is 1.8 g/cm^3. It consists of individual tetra-atomic (P_4) molecules and is an unstable form of phosphorus

Red phosphorus is denser (2.16 g/cm^3) and is much less reactive than white phosphorus at normal temperatures. It consists of P_4 molecules linked together to form a polymer (large molecule) as shown below.



The white phosphorus molecule



The arrangement of atoms in red phosphorus

Industrially, white phosphorus is manufactured by heating a mixture of crushed rock phosphate, $Ca_3(PO_4)_2$, silica, SiO_2, and coke in an electric furnace. The reaction in the furnace is:

$$2Ca_3(PO_4)_2\ (s) + 6SiO_2\ (s) + 10C\ (s) \rightarrow 6CaSiO_3(l) + P_4(g) + 10CO\ (g)$$

The vaporized phosphorus (P_4) is condensed, collected and stored under water. Red phosphorus is prepared by heating white phosphorus in sunlight for several days. White phosphorus is stored under water because it spontaneously ignites (bursts into flames) in the presence of oxygen. Red phosphorus is much less reactive than white phosphorus and does not need to be stored under water. Although red phosphorous is insoluble in water, it is very soluble in carbon disulphide. Solutions of P_4 in CS_2 are reasonably stable. As soon as CS_2 evaporates, however, the phosphorous bursts into flame.

Chemical Properties of Phosphorus

Phosphorus exhibits the following common chemical reactions. Phosphorus reacts with limited and excess supplies of oxygen to form tetraphosphorus hexoxide (P_4O_6) and tetraphosphorus decoxide (P_4O_{10}) respectively

$$P_4\ (s) + 3O_2\ (g) \rightarrow P_4O_6(s)$$
$$P_4\ (s) + 5O_2\ (g) \rightarrow P_4O_{10}(s)$$

P_4O_6 and P_4O_{10} dissolve in water to form phosphorous acid, H_3PO_3, an orthophsophoric acid, H_3PO_4 respectively.

$$P_4O_6\ (s) + 6H_2O\ (l) \rightarrow 4H_3PO_3\ (aq)$$
$$P_4O_{10}\ (s) + 6H_2O\ (l) \rightarrow 4H_3PO_4\ (aq)$$

Phosphorus also reacts with limited and excess supplies of chlorine to form phosphorus (III) chloride (PCl_3) and phosphorus (V) chloride (PCl_5) respectively

$$P_4\ (s) + 6Cl_2\ (g) \rightarrow 4PCl_3\ (s)$$

$$P_4\ (s) + 10Cl_2\ (g) \rightarrow 4PCl_5\ (s)$$

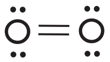
Uses of Phosphorus

Red phosphorous is used to make matches. Most of the white phosphorous produced is used to make phosphoric acid or other phosphorous compounds. Phosphorous is also used in making fireworks, smoke bombs, rat poisons, and tracer bullets. Phosphorous is essential for plant growth. Large quantities of phosphorous compounds are converted into acids and salts to be used as fertilizers, in baking powder and in the chemical industries.

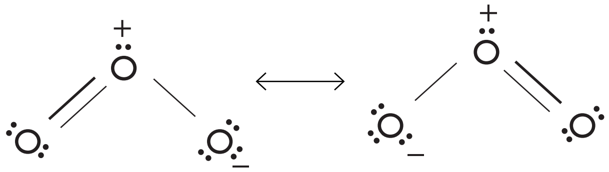
C. Oxygen

Occurrence and Production

Oxygen is the most abundant element on Earth. It constitutes about 46.6% weight of the earth's crust in the form of compounds such as oxides, silicates, carbonates, phosphates etc. It exists in nature in its elemental state in atmospheric air constituting about 20% by volume. Oxygen is manufactured industrially by the fractional distillation of liquid air in a way similar to that of nitrogen. Oxygen has two allotropic forms: diatomic (O_2) and triatomic (O_3), ozone.



Structure of O_2 molecule



Resonance structures of O_3 molecule

Ozone is naturally produced in the stratosphere by a two- step reactive process. In the first step, solar ultraviolet radiation (sunlight) breaks apart an oxygen molecule to form two separate oxygen atoms. In the overall process, three oxygen molecules plus sunlight react to form two ozone molecules according to the equation:

$$3O_2 \xrightarrow{\text{UV - light}} 2O_3$$

The occurrence of this process in the upper atmosphere removes radiation that would be harmful to life on the surface of the Earth.

Physical Properties

Oxygen is a colorless, odorless, and tasteless gas. It changes from a gas to a liquid at a temperature of -182.96°C. The liquid formed has a slightly bluish color to it. Liquid oxygen can then be solidified or frozen at a temperature of -218.4°C. The density of oxygen is 1.429 grams per liter. By comparison, it is denser than air. The density of air is about 1.29 grams per liter

Chemical Properties of Oxygen

Oxygen is relatively reactive and combines directly with most elements to form oxides. Oxygen combines with metal to form metal oxides (*basic oxides*). For example,

$$2Mg\ (s) + O_2\ (g) \rightarrow MgO\ (s)$$
$$2Ca\ (s) + O_2\ (s) \rightarrow 2CaO\ (s)$$

Oxygen combines with non-metals to form acidic oxides, for example:

$S_8 (s) + 8O_2 (g) \rightarrow 8SO_2 (g)$

$P_4 (s) + 5O_2 (g) \rightarrow P_4O_{10} (g)$

Oxygen supports combustion and is necessary for the burning of substances like charcoal, hydrocarbon fuel, etc.

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

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

D. Sulphur

Occurrence and Extraction

Sulphur is found in nature and in the form of compounds such as galena (PbS), pyrites (FeS_2) (fool's gold), cinnabar (HgS), sphalerite (ZnS), gypsum ($CaSO_4.2H_2O$), barite ($BaSO_4$), and hydrogen sulphide (H_2S) in natural gas and crude oil.

Sulphur is extracted from underground deposits of elemental sulphur by the Frasch process (***Figure 5.9***). In this process, three concentric pipes are sent down to the sulphur deposit.

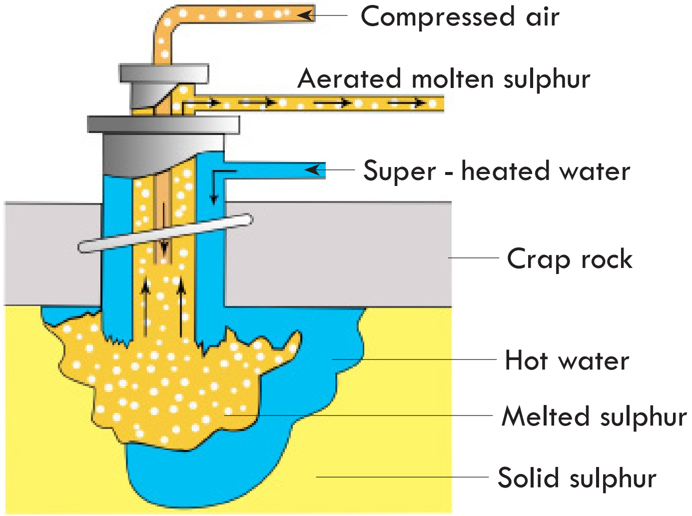


Figure 5.9 Frasch process- extraction of sulphur.

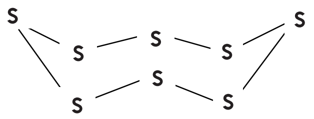
Superheated water at about 170°C is pumped through the outermost pipes. Hot air is compressed in the innermost tube. A froth of sulphur, air and water comes out to the surface of the earth forced by hot compressed air in the middle tube. The molten sulphur is then cooled and solidified.

Uses of Sulphur

Nearly one-half of the sulphur needed by chemical industries is obtained as a waste product of other industrial processes. For example, sulphur can be obtained in the form of hydrogen sulphide (H_2S) from natural gas and during the purification of crude oil. It can also be obtained in the form of sulphur dioxide from the roasting of sulphide ores during the manufacture of metals. The use of sulphur obtained from waste products of other industries reduces the demand for the element from natural deposits. This also reduces the pollution of the atmospher and the formation of acid rain.

Allotropic Forms of Sulphur

Sulphur exhibits allotropy. The two most important allotropes of sulphur are rhombic and monoclinic sulphur. Rhombic sulphur is the most stable form of sulphur consisting of S_8 molecules.



Crown shape of S_8 molecules

Rhombic Sulphur (α-sulphur): rhombic sulphur is crystalline in nature and has an octahedral shape. On heating the solution of roll sulphur in CS_2, we get rhombic sulphur. It is yellow with a melting point of 385.8K and a specific gravity of 2.06. Rhombic sulphur cannot be dissolved in water but can be dissolved in benzene, ether, alcohol, etc. Rhombic sulphur is the most stable form of sulphur consisting of S_8 molecules.

Monoclinic Sulphur (β-sulphur): β-Sulphur is a yellow solid with a monoclinic crystal form and is less dense than α-sulphur. Like the α- form it contains puckered S_8 rings and only differs from it in the way the rings are packed in the crystal. It is unusual because it is only stable above 95.3 °C; below this temperature it converts to α-sulphur.

Physical Properties of Sulphur

Pure sulphur is a tasteless, odourless, brittle solid that is pale yellow in colour, a poor conductor of electricity, and insoluble in water

Chemical Properties of Sulphur

Sulphur is relatively stable and unreactive at room temperature. However, it reacts with metals and non-metals when heated.

Sulphur combines with metals when heated to form sulphides.

$$8Fe\ (s) + S_8\ (s) \rightarrow 8FeS\ (s)$$

Sulphur burns with oxygen to form oxides.

$$S_8\ (s) + 8O_2\ (g) \rightarrow 8SO_2\ (g)$$

Sulphur is the raw material for the production of sulphuric acid (H_2SO_4) by the Contact Process. This process of sulphuric acid production involves the following steps

Step 1: Sulphur is first oxidized to produce sulphur dioxide:

$$S_8\ (s) + 8O_2\ (g) \rightarrow 8SO_2\ (g)$$

Step 2: Sulphur dioxide is converted to sulphur trioxide at high temperatures in the presence of a catalyst:

$$2SO_2\ (g) + O_2 \rightarrow 2SO_3\ (g)$$

Step 3: Sulphur trioxide is absorbed into concentrated sulphuric acid to produce oleum ($H_2S_2O_7$).

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

Step 4: The oleum is then diluted with water to produce the desired concentration of sulphuric acid. Commercially used concentrated sulphuric acid is 98% H_2SO_4.

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

E. Chlorine

Occurrence and Extraction

Chlorine belongs to group VIIA, known as the halogens. It is the most abundant element among the halogens. It is found in nature only in the form of compounds. Chlorine is found in nature chiefly in the form of chlorides of sodium, potassium, calcium and magnesium. Sodium chloride is the chief source of chlorine, and it is obtained from seawater or as deposits of rock salt. Commercially, chlorine is manufactured by the electrolysis of a concentrated aqueous solution of sodium chloride. During electrolysis of the concentrated solution, chlorine is formed at the anode and the reduction of water occurs at the cathode, producing hydrogen gas and hydroxide ions (OH^-). The electrode and the overall cell reactions are as follows:

Oxidation at anode: $2Cl^- (aq) \rightarrow Cl_2 (g) + 2e^-$

Reduction at cathode: $2H_2O (l) + 2e^- \rightarrow H_2 (g) + 2OH^- (aq)$

Cell reaction: $2NaCl (aq) + 2H_2O (l) \rightarrow 2NaOH (aq) + Cl_2 (g) + H_2 (g)$

Although NaOH forms at the cathode compartment and Cl_2 at the anode, the two substances must be kept apart from one another. This is because, if they come into contact with each other, they can react according to the following equation.

$$NaOH (aq) + Cl_2 (g) \rightarrow NaOCl (aq) + HCl (aq)$$

? What is the oxidation number of chlorine in NaOCl?

Physical Properties of Chlorine

Some of its physical properties include the following:

Chlorine is a greenish-yellow gas at room temperature.

It melts at –102°C and boils at –34°C.

It is fairly soluble in water.

It is extremely poisonous, causing inflammation of the lungs and mucous membranes if inhaled, even in very small amounts. It is fatal if inhaled in higher amounts.

Chemical Properties of Chlorine

Chlorine is a highly reactive non-metal. It reacts directly with almost all elements except the noble gases, carbon and nitrogen. It is a powerful oxidizing agent and oxidizes most of the elements with which it reacts. The following are the main reactions of chlorine. Chlorine reacts with heated metals to form chloride salts.

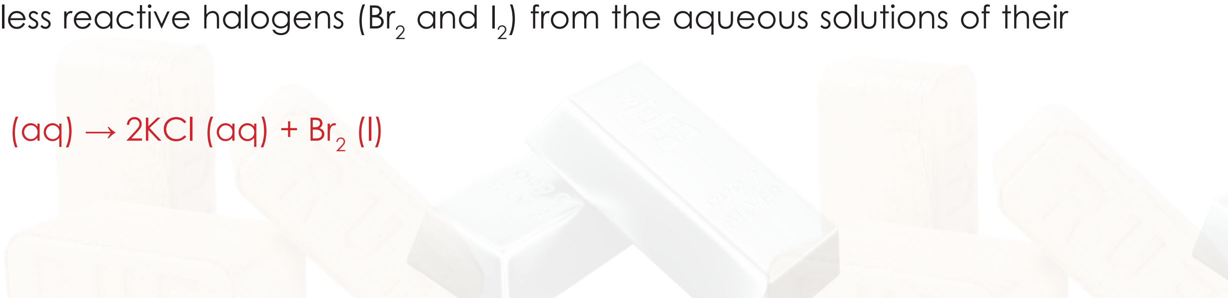
$$2Fe (s) + 3Cl_2 (g) \rightarrow 2FeCl_3 (s)$$
$$2Al (s) + 3Cl_2 (g) \rightarrow 2AlCl_3 (s)$$

Chlorine reacts smoothly with hydrogen in the presence of charcoal as a catalyst at room temperature to form hydrogen chloride.

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

Chlorine displaces less reactive halogens (Br_2 and I_2) from the aqueous solutions of their compounds.

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



$$Cl_2\ (g) + 2KI\ (aq) \rightarrow 2KCl\ (aq) + I_2\ (aq)$$

Can bromine displace chlorine in a chemical reaction?

Chlorine dissolves in water and reacts with it, forming an acidic solution containing hydrochloric acid (HCl) and hypochlorous acid (HOCl).

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

This type of reaction is called a disproportionation reaction, where chlorine is itself reduced and oxidized.

Uses of Chlorine

Chlorine is commercially used as a bleaching agent and disinfectant (it kills germs). As elemental chlorine or chlorine water, it is strong enough to oxidize dyes and bleach coloured materials. For example, it can be used to remove yellow or brown colors from wood pulp, paper, and cotton.

Checklist - 5.2

The following checklists are provided to you as a guide to check what you have learned in this unit. Check you understanding by putting a "✓" mark if you can remember what is presented in relation to the terms. If you don't remember, please go back to the corresponding section and make a quick review. I can ...

SN	Competencies	Check
1	discuss the general properties and extraction of nonmetals.	
2	explain occurrence and extraction of nitrogen, phosphorous, oxygen, sulphur and chlorine.	
3	describe the applications of nitrogen, phosphorous, oxygen, sulphur and chlorine.	

Self-Test Exercise 5.2

I. Answer the following questions appropriately

1. What are the main natural sources of N, P, O, S, and Cl?
2. Describe the main processes involved in the production (extraction) of N, P, O, S and Cl.
3. How do N, P, and S behave when heated in the air?
4. Write an equation for the reaction of chlorine with water.
5. Describe and discuss the common uses of CO_2, Na_2CO_3, NH_3, HNO_3, H_3PO_4, $Ca_3(PO_4)$, SO_2, and H_2SO_4

II. Choose the best answer

6. Which of the following is not a use of nitrogen?
   a. making matches b. production of ammonia c. making fertilizers d. as a refrigerant
7. Which of the following elements is not found as a free element in nature?
   a. Sulphur b. Oxygen c. Copper d. Chlorine
8. Explain why I_2 is solid, Br_2 is liquid, and Cl_2 and F_2 are both gases at room temperature.

Unit Summary

About 80% of the elements are metals.

They have common physical and chemical properties.

Metals are ductile, malleable, sonorous, and conductors of heat and electricity.

Metals are reducing agents and mostly form basic oxides.

The specific properties of metals vary widely from one metal to the other.

Active metals always occur in compounds in the form of minerals.

The most active metals are extracted from their compounds only by electrolysis because there is no stronger reducing agent that can remove them from their compounds.

The reactivity series is a useful guide to predict the relative reactivity of metals.

Aluminum is the most abundant metal in the earth's crust.

It is manufactured by the electrolysis of molten aluminum oxide mixed with cryolite using Hall's process.

Aluminum is used to make lightweight alloys that can be used for aircraft and similar constructions.

Aluminum resists corrosion due to the formation of a thin film of oxide on its surface.

Iron is the second-most abundant metal in the earth's crust.

Iron is extracted in a blast furnace.

The furnace is charged with iron ore, coke and limestone, and hot air is blown up from the bottom.

Limestone is used in the blast furnace to remove impurities like sand (silica) in the form of slag. The type of iron obtained directly from the blast furnace is called pig iron and it is impure.

Wrought iron is the purest form of iron obtained from pig iron by removing most of the impurities.

Steel is an alloy of iron containing definite amounts of carbon and other metals like chromium, nickel, tungsten, vanadium, manganese etc.

Steel is manufactured from pig iron by the Bessemer converter, Open-Hearth Furnace and Basic Oxygen Processes.

Copper is extracted by roasting chalcopyrites ($CuFeS_2$).

Copper that is obtained by roasting chalcopyrites is called blister copper.

Copper is impure, and it is refined further by electrolysis.

Copper is malleable and ductile, a good conductor of heat and electricity and is used to make electric wires and in the manufacture of alloys.

The properties of nonmetals are opposite to those of metals.

Some examples of nonmetals are nitrogen, oxygen, phosphorous and chlorine.

Nitrogen constitutes about 80% of the volume of atmospheric air.

Nitrogen is manufactured by the fractional distillation of liquefied air.

Nitrogen is relatively inert. However, its reactivity increases when heated and combined with metals of groups IA and IIA to form nitrides and with oxygen to form oxides like NO and NO_2.

Phosphorus is manufactured by heating a mixture of rock phosphate, coke (carbon) and silica in an electric furnace.

White phosphorus is highly reactive, while red phosphorous is relatively stable. White phosphorus is stored under water. ‘

Phosphorus reacts with oxygen and chlorine.

Oxygen makes up about 20% of the volume of air.

It is manufactured by the fractional distillation of liquid air.

Oxygen is the most abundant element in the earth’s crust.

Sulphur exists in its elemental state in underground deposits from which it is extracted by the Frasch process.

Sulphur reacts with oxygen to form sulphur dioxide and sulphur trioxide.

Sulphur is used for the manufacture of sulphuric acid by the Contact Process.

Chlorine is manufactured by the electrolysis of brine. Chlorine is a powerful oxidizing agent and reacts with heated metals to form chlorides.

Chlorine and chlorine water are used to bleach colored materials and as a disinfectant.

Self-Assessment Exercises

Part I. Multiple choice questions.

1. Which one of the following metals is the most ductile?
   a. Aluminum
   b. Copper
   c. Gold
   d. Silver
2. Which one of the following is the least dense?
   a. Mercury
   b. Gold
   c. Sodium
   d. Aluminum
3. Which one of the following metals will not liberate hydrogen gas when treated with dilute hydrochloric acid ?
   a. Magnesium
   b. Zinc
   c. Copper
   d. Iron
4. Which one of the following metallic elements is most likely to be found as the free metal in nature ?
   a. Ca
   b. Au
   c. Al
   d. Fe
5. What is the purpose of a converter in steel production?
   a. to reduce the iron in the ore to elemental iron
   b. to allow the addition of nitrogen for increased strength
   c. to allow slow solidification of the molten metal so it will purify as it crystallizes
   d. to remove impurity elements by oxidation
6. Which of the following is a non-renewable resource:
   a. soil
   b. water
   c. petroleum
   d. plants
7. Which of the following elements possess allotropes?
   a. carbon
   b. phosphorus
   c. Sulphur
   d. all

8. Which one is used as anode in the electrolytic refining of copper?
   a. Pure copper
   b. Graphite rod
   c. Impure copper
   d. Pure iron rod
9. Which of the following is not a use of nitrogen:
   a. making matches
   b. production of ammonia
   c. making fertilizers
   d. as a refrigerant
10. The most abundant element in the earth's crust is:
    a. Silicon
    b. Iron
    c. Oxygen
    d. Aluminium
11. Which of the following elements can sometimes found as a free element in nature?
    a. sodium
    b. Oxygen
    c. Copper
    d. Chlorine
12. Which of the statements about the extraction of iron in the blast furnace is true?
    a. limestone is added to combine with excess carbon dioxide
    b. a slag of iron oxide forms at the bottom of the furnace
    c. hot air is blown in at the top of the furnace
    d. carbon monoxide reduces iron (III) oxide to iron
13. Aluminium is used for making cooking utensils. Which of the following properties of aluminium are responsible for the same?
    a. Good thermal conductivity & ductility
    b. Good electrical conductivity and Good thermal conductivity
    c. High melting point and Good thermal conductivity
    d. High ductility and good malleability
14. Which of the following non-metals is a liquid at room temprature?
    a. Bromine
    b. Sulfur
    c. phosphorous
    d. carbon
15. What is the name of the process of extracting sulfur on commercial scale?
    a. Bosch process
    b. Boyle process
    c. Ostwald process
    d. Frasch process
16. Which phosphorus allotrope has the highest degree of reactivity?
    a. White phosphorus
    b. Red phosphorus
    c. black phosphorus
    d. None

Part II. Short answer questions

17. Define the following terms
    i) Mineral ii) Ore iii) gangue.
18. Answer the following referring to the occurrence and extraction of iron.
    a. Why is that iron does not occur as a metal in the crust of the earth?
    b. What are the common compound forms in which iron occurs?
    c. Which of these is more often used for extracting iron?
    d. Why are carbon and limestone mixed with iron ore before feeding it into the blast furnace?

  e. Write the chemical equations for the reduction step and the slag formation step.

19. A metal ‘X’ combines with a non-metal ‘Y’ by the transfer of electrons to form a compound Z.
    - i. State the type of bond in compound Z.
    - ii. What can you say about the melting point and boiling point of compound Z?
    - iii. Will this compound dissolve in kerosene or petrol?
    - iv. Will this compound be a good conductor of electricity?
20. Why do some metals like, Na, K, Ca, Mg not occur in nature as free elements?
21. Food cans are coated with tin and not with zinc because
    - a. Zinc is costlier than tin.
    - b. Zinc has a higher melting point than tin.
    - c. Zinc is more reactive than tin.
    - d. Zinc is less reactive than tin.
22. You are given, a hammer, a battery, wires, bulb and a switch.
    - a. How will you use them to distinguish between samples of metals and non-metals?
    - b. Assess the usefulness of these tests to distinguish between metals and nonmetals
23. In the electrolytic refining of a metal M what would you take as cathode, as the anode and as the electrolyte ?
24. State two ways to prevent the rusting of iron.
25. Give reason for the following:
    - a. Aluminum is a highly reactive metal, yet it is used for making cooking utensils
    - b. You must have seen tarnished copper vessels being cleaned with lemon or tarmarind juice

Part III. Fill in the blank space

26. Gold can be hammered in to sheets. Therefore, it is _______. (malleable/ductile)
27. Copper is used in electrical appliances because it is good conductor of electricity and ________. (ductile/brittle)
28. The extraction of metals from ores and then refining them for use is known as _____ (metallurgy/concentration).
29. The surface of some metals, such as iron, is corroded when they are exposed to moist air for a long period of time. This phenomenon is known as _____ (Rusting/corrosion).
30. Best conductor of electricity is_________(copper/silver)

Assignment for Submission (12 Points)

Answer the following questions correctly

1. What is rust? Write its chemical formula
2. What are amphoteric oxides? Give examples of two amphoteric oxides.
3. Define gangue?
4. Metals at the top of the activity series do not occur in the free state. Explain
5. What happens when:
    - i. Iron nail is placed in silver nitrate solution
    - ii. Iron strip is dipped in zinc sulphate solution
6. Name two metals which will displace hydrogen from dilute acids, and two metals

which will not.

7. Give reasons for the following:
   i. Metals are regarded as electropositive elements
   ii. Hydrogen gas is not evolved when zinc metal reacts with dil HNO_3
   iii. Articles made of Aluminum do not corrode even though aluminum is an active metal
8. A metal A, which is used in the thermite process, when heated with oxygen, gives an oxide B, which is amphoteric in nature. Identify A and B. Write down the reactions of oxide B with HI and NaOH.
9. When an iron nail is dipped in copper sulphate solution, then the blue colour of copper sulphate fades gradually and a reddish brown coating is formed on the iron nail. Explain the reason with chemical equation.

Answers to Self-Review Exercises

Part I. Multiple choice questions

1. c. Gold
2. c. Sodium
3. c. Copper
4. b. Au
5. d. to remove impurity elements by oxidation
6. c. petroleum
7. d. all
8. c Impure copper
9. a. making matches
10. c. oxygen
11. c. copper
12. d. carbon monoxide reduces iron (III) oxide to iron
13. c. High melting point and Good thermal conductivity
14. a. Bromine
15. d. Frasch
16. a. White phosphorus

Part II. Short answer questions

17.
   i. The inorganic elements or compounds which occur naturally in the earth's crust are known as minerals.
   ii. The minerals from which a metal can be profitably extracted are called ores.
   iii. The impurity of sand and rocky materials present in the ore is known as gangue.

18.
   a. Iron is quite reactive and so it does not occur as a metal in the crust of the earth.
   b. The common compounds formed are its oxide, a carbonate and a sulphide.
   c. The oxide ore of iron called haematite is more often used for extracting iron.
   d. The carbon and limestone which is mixed with iron ore is called the charge. This charge is responsible for the formation of iron metal. Coke acts the reducing agent and addition of limestone helps to remove the earthy impurities like sand from the blast furnace by forming fusible slag.
   e. $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$ (reduction step), $CaO + SiO_2 \rightarrow CasiO_3$ (slag formation step)

19. X being a metal loses electrons and Y being a non-metal gains electrons to form Z.
   i. The chemical bond formed by the transfer of electrons from one atom to another

is known as an ionic bond. Hence, Z is an ionic compound.

ii. Compound Z is an ionic compound thus, it has high melting and boiling points.

iii. Ionic compounds are insoluble in non-polar solvents such as kerosene or petrol.

iv. As Z is an ionic compound, it does not conduct electricity in the solid state because movement of ions in the solid is not possible due to their rigid structure. But it conducts electricity in the molten state or in aqueous solution due to the movement of ions freely.

20. Metals like Na, K, etc (alkali metals) and Ca, Mg etc (alkaline earth metals) are very reactive and hence they react with atmospheric oxygen and carbon dioxide and also with other non-metals like sulphur present in the earth's crust to form compounds like oxides, carbonates, sulphides, sulphates and chlorides. So they do not occur in free state, but are found in the form of the above compounds.

21. c. Zinc is more reactive than tin.

22. a. Up on hammering, a metal will expand, but a non metal will shatter. The bulb glows, on passing electric current through the metal but doesn't glow when passed through the nonmetal (except graphite)

b. The tests are useful in a majority of cases, except the graphite which is a nonmetal and yet a conductor of electricity

23. Anode : Impure metal, Cathode : A strip of pure metal, Electrolyte : An aquesous solution of the salt of the metal M

24. Painting and alloying

25.

a. Aluminum oxide first formed sticks on the surface of the cooking utensils and protect them from further attack of oxygen

b. Carbonates and basic hydroxide tarnish the copper vessels which are neutralized by the acid or lemmon juice or tamarind juice

Part III. Fill in the blank space

26. Malleable
27. ductile
28. metallurgy
29. corrosion
30. silver

Answer Key to Self Test Exercises

Self-Test Exercise -5.1

I. Answer the following questions correctly.

1. Naturally available = water, sunlight, land, minerals, fossil fuels (crude oil, coal, and natural gas)

Made by humans = statues, concrete, plastics, and buildings,

2. Renewable resources: soil, wood, air, water, and Biofuels

Nonrenewable resources: rocks, metal ores, soil, fossil fuels,

3. See the text.

4. Al and Cu are produced by electrochemical reduction and Fe is produced by reduction using coke.

5. Explain how Al, Fe and Cu behave in dry air, moisture and acidic solutions.

Ans. When iron is exposed to moist air, a reddish-brown coating of hydrated Iron (III) Oxide (Fe_2O_3) is deposited on its surface. This reddish-brown coating is called rust. Iron metal does not burn in dry air even on strong heating. Aluminum reacts with the atmospheric oxygen and creates a protective aluminum oxide sheath and prevents corrosion. Aluminum is not attacked by dry air.

When a copper statue (or copper vessel) is exposed to moist air for long, it acquires a dull green coating. The green material is a mixture of copper hydroxide [$Cu(OH)_2$] and copper carbonate ($CuCO_3$) formed due to the reaction of copper with moist air. Copper oxidizes to copper When copper is heated in air, it is oxidised to copper (II) oxide and the reddish brown metal turns black as the copper is oxidized to copper (II) ions. Hence the copper is changed to copper oxide.All copper, iron and Aluminum react with an acid to form a salt and hydrogen gas.

6. Lime removes impurities (silica, phosphorus, sulfur) from the steel being manufactured.
Ans. The lime fuses with the impurities to form slag, which separates from the steel and is removed. This process improves the quality of the steel. Lime is also used to enhance the refractory life of the furnaces.

7. Discuss the main areas of applications of Al, Fe and Cu in the home and industry.
Ans. Most copper is used in electrical equipment such as wiring and motors. This is because it conducts both heat and electricity very well, and can be drawn into wires. It also has uses in construction (for example roofing and plumbing), and industrial machinery (such as heat exchangers.

Aluminium is an extremely versatile metal with a number of advantages, it is recognized for being both lightweight and flexible. It can be cast, melted, formed, machined and extruded meaning that it can be manufactured into a variety of shapes and then subsequently fabricated to suit a whole variety of uses. Aluminium is also a great conductor of electricity. And it is much cheaper than its counterpart copper. So we often use aluminium in electric wires and other such power transmission lines.

Some of the applications of iron. Used as the primary constituent of ferrous metals/alloys and steels. Alloyed with carbon, nickel, chromium and various other elements to form cast iron or steel. Used in in magnets, fabricated metal products, industrial machinery, transportation equipment, instruments , toys and sport good
8. The kitchen utensils used for cooking foods are made of metals like aluminum, iron, copper or the alloys of some metals.

Ans. As metals are good in conducting heat, it can transfer heat very quickly and evenly. Generally, copper, aluminum metals are used for cooking vessels as they are very good conductors of heat. Due to this reason's metals are used in cooking vessels. Iron is used for cooking utensils because it is more durable than other metals. It is also cheaper material that can be used over open flame and high heat.

9. Why are wires employed in electrical appliances made of copper and/or aluminum?
Ans. Copper and aluminium are good conductors of electricity. They have very low

resistance and allow the current to flow through them easily. Hence, they are used to make wires for electrical transmissions.

II. Give an example of a metal for each of the following question.

1.a. Mercury is the only liquid metal at room temperature. There is no gaseous metal at normal temperature

b. Silver

c. Lead, titanium, mercury, and bismuth are poor conductors of heat

d. sodium, potassium.

2. The arrangement of metals in the descending order of their reactivities. The alkali metals are the most reactive metals and are top in the activity series.

3. Where are metals found ? How metals are exracted from their ores? Metals are found in minerals and extracted by a process known as metllurogy.

4. What is the advantage of alloying metals?

Alloying of metals increases its tensile strength, hardness, durability and resistance to corrosion

Self-Test Exercises-5.2

I. Answer the following questions appropriately

1. What are the main natural sources of N, P, O, S, and Cl?

Ans. N – air, P – phosphate rocks, O – air, S- Sulphur occurs in nature as an element and also as sulphates in the soil, water and rocks. Cl - sodium chloride

2. Describe the main processes involved in the production (extraction) of N, P, O, S and Cl.

Ans. N_2 and O_2 are produced by fraction liquefaction of air, Sulfur is extracted by the Frasch process, Cl- is produced by the electrolysis of molten salt , mostly NaCl.

P- white P is obtained by heating phosphate rock in the presence of carbon and silica in a furnace. Red phosphorus is made by gently heating white phosphorus to about 250°C in the absence of air.

3. How do N, P, and S behave when heated in air?

Ans. P burns spontaneously in air forms phosphorous pentoxide (P_2O_5), Nitrogen in hot air forms nitric oxide(NO) and sulfur forms sulfur dioxide (SO_2) in hot air.

4. Write an equation for the reaction of chlorine with water.

Ans. $Cl_2 + H_2O \rightarrow HCl + HClO$

5. Describe and discuss the common uses of CO_2, Na_2CO_3, NH3, HNO_3, H_3PO_4, $Ca_3(PO_4)$, SO_2,H_2SO_4

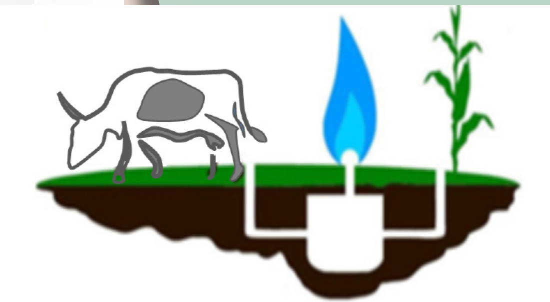
Ans.

Chemicals	**Common uses**
Carbon dioxide - CO_2	Refrigerant, fire extinguishers, carbonated beverages
Sodium carbonate - Na_2CO_3	Production of glass, soaps and detergents, paper. Cleaning agent, water softener
Ammonia - NH_3	Fertilizer, ingredient in cleaning products. refrigerant gas and in air-conditioning equipment
Nitric acid - HNO_3	plastics, dyes, and fertilizers. Making explosives such as TNT, nitroglycerine, and nitrocellulose.

Phosphoric acid- H_3PO_4	Fertilizer, rust remover from metals like iron, steel, etc,. Food additive like in soft drinks.
Calcium phosphate - $Ca_3(PO_4)$: $Ca_3(PO_4)$	ingredient of triple superphosphate fertilizer, $Ca(H_2PO_4)_2$.
Sulphur dioxide - SO_2	Bleaching agen, Making of other chemicals- H_2SO_4, $Na_2S_2O_6 \cdot 2H_2O$, etc.
Sulphuric acid - H_2SO_4	Making of fertilizers, detergents, dyes and pigments, explosives, and drugs, etc.

II. Choose the best answer

1. a
2. a
3. Chlorine is a gas, bromine is a liquid, and iodine is a solid because of the differences in the Strength of their dispersion forces. As atomic number increases the magnitude of vander waal's forces also increases, therefore iodine is solid



UNIT 6

HYDROCARBONS AND THEIR NATURAL SOURCES

❁ Dear student, welcome to the fascinating field of chemistry called organic chemistry. You are going to study a very small portion of this broad field of study known as hydrocarbons.

? Do you know the common saying,-"The kingdom of heaven runs on righteousness, but the kingdom of earth Runs on alkanes"? If you have guessed that the presence of underground crude oil deposits that consist chiefly of alkanes in a country contributes significantly to the development of the nation as a source of energy, you are right. You might also know that the development of the energy sector is key to national development. Therefore, alkanes, as a source of energy, are very useful compounds. For instance, the chemical components of gasoline or diesel oil ('naphtha') that people use for automobiles, 'bajaj', or a motorbike are mixtures of alkanes. In addition, a biogas plant that people use as a source of energy in rural areas produces the simplest alkane called methane.

Alkanes belong to a class of compounds called hydrocarbons. Hydrocarbons are organic compounds.

? But, what are organic compounds and organic chemistry? The answers to these questions are all around you.

Most of the foodstuff that you consume every day such as fruits, vegetables, sugar, fats, starch, and vinegar are basically organic compounds. Similarly, substances such as pesticides, herbicides, fuels, dry cleaning chemicals, soaps and detergents, pharmaceuticals, alcoholic beverages, etc. are also organic compounds. Every living organism is made of organic compounds.

In this unit, you will study hydrocarbons in detail. You will learn about the definitions and classification of hydrocarbons, nomenclature, and physical and chemical properties.

⏱ The Required Study Time (180 hours)

You should complete this unit in six weeks. If you schedule 4 hours a day, this will cost you a total of 180 hours.

Unit Learning Strategies

Dear student, you can adapt to different learning strategies depending on the circumstances. We kindly advise you to take a few minutes to read and understand the content in each section. It is a wise strategy to associate what you learn with your daily experiences. This helps you stabilize your memory of the learned material. Be assisted with examples. Frequently check your progresse with the help of the activities and self-test exercises provided under each section. Be assisted with the internet, especially video lessons. You can also find a friend attending a similar program, arrange a meeting, and hold joint discussion on topics that you find difficult at first. We assume that you can find schools in your area. Feel free to contact the school's chemistry teachers. They will help you. Similarly, students in grades 10 and above can also help you in enriching your understanding of the subject matter. Hiring a tutor is another alternative that you can think of if deemed necessary. Please be sure that you understand the contents of the current section very well before you proceed to the next one. Sketch your own study timetable and try to respect it.

Unit Contents

Section 6.1 History of Organic Chemistry
Section 6.2 Classes of Organic Compounds
Section 6.3 Saturated Hydrocarbons: Alkanes (C_nH_{2n+2})
Section 6.4 Unsaturated Hydrocarbons: Alkenes (C_nH_{2n})
Section 6.5 Unsaturated Hydrocarbons: Alkynes (C_nH2_{n-2})
Section 6.5 Unsaturated Hydrocarbons: Aromatic Hydrocarbons (Benzene, C_6H_6)
Section 6.6 Natural Sources of Hydrocarbons

Check Lists
Unit Summary
Review Exercises
Answers to Activity, Self-Test Exercises, and Review Exercises

Unit Outcomes

At the end of this unit, you should be able to

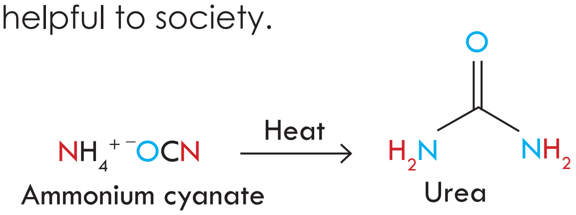
- Discuss the historical development of organic chemistry; classify organic compounds;
- Write the general formula of alkanes, alkenes and alkynes;
- Name simple alkanes, branched-chain alkanes, simple alkenes, branched-chain alkenes and simple alkynes;
- Write the molecular and structural formula of simple alkanes, branched chain alkanes, simple alkenes, branched chain alkenes and simple alkynes;
- Explain isomerism;
- Draw the possible isomers of alkanes, alkenes, and alkynes;
- Explain the physical and chemical properties; and the general methods of the preparation of alkanes; alkenes, alkynes, and benzene;
- List the major natural sources of hydrocarbons;
- Demonstrate scientific inquiry skills: observing, classifying, communicating, measuring, asking questions, interpreting data, drawing conclusions, applying concepts, predicting and problem-solving.

Section 6.1: History of Organic Chemistry

- At the end of this section, you should be able to narrate the historical development of organic chemistry.

Dear learner, take the next 30 minutes to read the following note. Take note of the important points. Shortly after you complete this activity, you have a self-test exercise.

- The science of organic chemistry began to flourish with the demise of a nineteenth-century theory called Vitalism. According to Vitalism theory, organic compounds were only those that came from living organisms, and only living things could synthesize organic compounds through the intervention of a vital force. Inorganic compounds were considered compounds that came from non-living sources. The German chemist Friedrich Wöhler, however, discovered in 1828 that an organic compound called urea (a constituent of urine) could be synthesized in the laboratory by evaporating an aqueous solution of the inorganic compound ammonium cyanate. With this discovery, the synthesis of an organic compound began the evolution of organic chemistry as a scientific discipline. Since Wohler's discovery, chemists have developed a remarkably sophisticated ability to design and synthesize new organic compounds in the laboratory-medicines, dyes, polymers, and a host of other substances that are helpful to society.



To date, over 50 million organic compounds are known. The list included organic compounds isolated from natural sources as well as those synthesized in laboratories. All organic compounds, whether of synthetic or natural origin, contain the element carbon. Therefore, organic chemistry today is defined as the study of carbon compounds except the oxides of carbon, carbonates, hydrogen carbonates, cyanides and cyanates. But why is carbon special? If you take a look at the periodic table, you will see over a hundred elements listed there. The question that comes to mind is this: why should an entire field of chemistry be based on the chemistry of compounds that contain this specific element, carbon?

- The reason is linked to the unique property of carbon called catenation. Catenation is the ability of atoms of the same element to join together to form short or long chains and rings. Carbon atoms can form strong covalent bonds to one another to form rings and chains of carbon atoms. And they can also form strong bonds with elements such as hydrogen, nitrogen, oxygen, and sulfur. Because of these bond-forming properties, carbon can be the basis for a huge diversity of compounds. A few other elements like sulphur, silicon and boron show this behavior, but to a much lesser extent.

Now that you understand how organic chemistry has given birth and how the initial thought of vitalism was turned wrong. To check your understanding, please take the next minute to perform the following exercise.

Self-Test Exercise 6.1

1. Despite the demise of vitalism in science, the word 'organic' is still used today by some people as 'organic vitamins', 'organic fertilizers', or 'organic food.' What do you understand from these terms? Is pure 'natural vitamin C from orange juice', for example, healthier than pure 'synthetic vitamin C', or are both important? Discuss!
2. How was the theory of vitalism proven wrong?
3. What are organic compounds?
4. Describe carbon compounds that are not organic compounds.
5. What properties of carbon make it unique among the many elements that are listed in the periodic table?
6. Why do you think an entire field of chemistry is be based on the chemistry of compounds that contain a specific element, carbon?

Section 6.2: Classes of Organic Compounds

In this section, you will learn about how organic compounds are classified, the definition of a functional group, and the ways compounds are classified based on their functional groups. You will also learn about the functional groups of the hydrocarbons-alkanes, alkenes, and aromatic compounds.

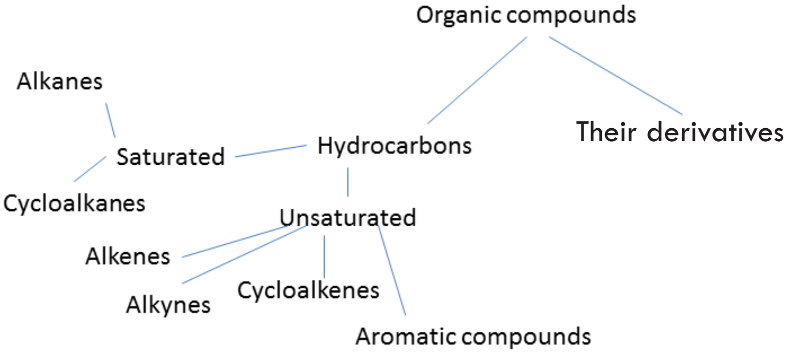
At the end of this section, you should be able to

- Classify organic compounds;
- Define the term functional group.

Dear learner, now take another 30 minutes to read the following note. Take note of the important points. Shortly after you complete this activity, you have a self-test exercise.

- We have noted in Section 6.1 the unique properties of carbon giving rise to a very vast number of organic compounds known. Indeed, more and more are being added to the list each day. Each of these compounds has its own physical properties, such as melting point and boiling point, and each has its own chemical reactivity. Chemists have learned through years of experience that organic compounds can be classified into families according to their structural features that are responsible for their properties so that members of a given family often have similar chemical behavior.

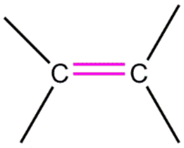
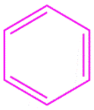
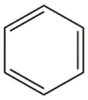
Thus, instead of having 50 million of compounds with random reactivity, it is better to have a few dozen families of organic compounds whose chemistry is reasonably predictable. The structural features that make it possible to classify compounds into families are called functional groups.



Functional Groups

☞ A functional group is a group of atoms and/or bonds within a molecule that has a characteristic chemical behavior. Chemically, a given functional group behaves in nearly the same way in every molecule it's a part of. Table 6.1 lists the common functional groups of hydrocarbons, their names ending, and specific examples. It also gives simple examples of their occurrence. The functional group of an alkene, for example, is its carbon-carbon double bond. The functional group of an alkyne is its carbon–carbon triple bond. Alkanes do not have a functional group. Their molecules have carbon–carbon and carbon–hydrogen single bonds only, but these bonds are present in the molecules of almost all organic compounds. In addition, C-C and C-H bonds are, in general, much less reactive than common functional groups.

Table 6.1 Some classes of organic compounds, their functional groups, name ending, and examples.

Organic compound	Functional group	Name ending	Example
Alkane	-	*-ane*	CH_3-CH_3 Ethane
Alkene		*-ene*	$H_2C=CH_2$ Ethene
Alkyne	$-C\equiv C-$	*-yne*	$H-C\equiv C-H$ Ethyne
Aromatic		None	 benzene

Dear learner, now take the next few minutes to answer the following questions.

Self-Test Exercise 6.2

1. Why do you think it is necessary to classify organic compounds? What is the basis of classification?
2. What is a functional group?
3. Write the functional groups of alkanes, alkenes, alkynes, and aromatic compounds.

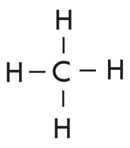
Section 6.3: Hydrocarbons: Important Definitions and Classifications

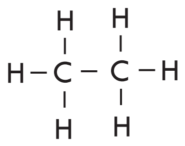
In this section we focus on the definition and classifications of hydrocarbons.

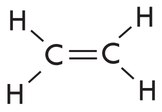
At the end of this subsection, you should be able to

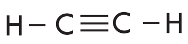
- Define hydrocarbon.
- Define saturated hydrocarbon.

? Dear learner, in Unit 2 of Module 1, you have classified a solution as saturated, unsaturated, or supersaturated based on the amount of solute it contains relative to the maximum dissolving capacity of the solvent. In grade 9, you also studied that the valence of carbon is 4; meaning the maximum number of atoms that carbon can form bonds to is 4. Based on this analysis, can you classify the following compounds as saturated or unsaturated?


I.


II.


III.


IV.

If you have answered that structures III and IV contain a lesser number of H-atoms than required, you are right. Compounds that contain only carbon and hydrogen atoms are called **hydrocarbons**. Hydrocarbons may be classified as aliphatic ("fat-like") or aromatic (*Figure 6.1A*). Aliphatic hydrocarbons exhibit "fat-like" behavior. This includes alkane, alkene, alkyne, and their derivatives. Aromatic hydrocarbons are those hydrocarbons that contain a low hydrogen-to-carbon ratio. Benzene (C_6H_6), for instance, is a typical aromatic hydrocarbon that has a ratio of only 1 hydrogen atoms to 1 carbon atom.

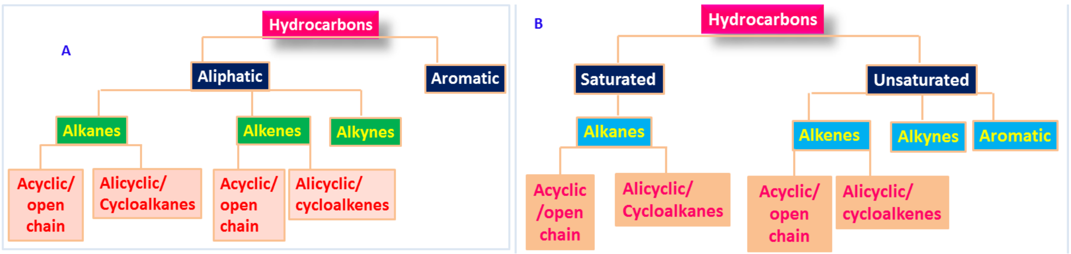


Figure 6.1 Classifications of hydrocarbons, A as aliphatic and aromatic and B as saturated and unsaturated.

☞ Hydrocarbons may also be classified as saturated and unsaturated. Generally speaking, compounds such as alkanes (e.g. methane, CH_4), whose molecules contain only single bonds are referred to as saturated compounds. Because they contain the maximum number of hydrogen atoms per carbon atom that the carbon compound can possess. Remember from Grade 9 that the valency of carbon is 4. This means C can form a maximum of 4 covalent bonds with 4 hydrogen atoms because each hydrogen can form only one (the valency of H is 1). Compounds with multiple bonds, such as alkenes (e.g. ethylene), alkynes (e.g. acetylene), and aromatic hydrocarbons (e.g. benzene), are called unsaturated compounds because they possess fewer than the maximum number of hydrogen atoms per carbon. They are capable of reacting with hydrogen under the proper conditions. Let's begin with the saturated compounds!

Self-Test Exercise 6.3

1. Define hydrocarbons.
2. How are hydrocarbons classified?
3. What is the difference between
   a. Saturated and unsaturated hydrocarbons?
   b. Aliphatic and aromatic hydrocarbons?
   c. Acyclic and alicyclic hydrocarbons?

6.3.1 Saturated Hydrocarbons: Alkanes (C_nH_{2n+2}): Important Definitions, Homologous Series, and General Formula

In this subsection, we will consider alkanes as saturated hydrocarbons, their general formula, homologous series, and the formula of some members of the series. You should spend a maximum of 30 minutes before the activity that follows.

At the end of this subsection, you should be able to

- Define homologous series.
- Drive the general formula of alkanes based on the number of hydrogen and carbon.
- Write the first ten members of the alkanes homologous series.
- Write the molecular formulas of alkanes from the given numbers of carbon atom.

☞ Alkanes are often described as saturated hydrocarbons: hydrocarbons because they contain only carbon and hydrogen; saturated because they have only C -C and C-H single bonds and thus contain the maximum possible number of hydrogens per carbon. Alkanes are also occasionally called aliphatic compounds, a name derived from the Greek aleiphas, meaning "fat." Alkanes can be unbranched (normal) or branched. ***Table 6.2*** lists the common names and formulae of some members of the unbranched alkane family.

Table 6.2 Some members of the unbranched alkane family.

Name	No of C atoms	Structure	Molecular formula	Name	No of C atoms	Molecular formula
Methane	1	CH_4	CH_4	Undecane	11	______
Ethane	2	CH_3CH_3	C_2H_6	Dodecane	12	______
Propane	3	$CH_3CH_2CH_3$	C_3H_8	Tridecane	13	______
Butane	4	$CH_3(CH_2)_2CH_3$	C_4H_{10}	Tetradecane	14	______
Pentane	5	$CH_3(CH_2)_3CH_3$	C_5H_{12}	Pentadecane	15	______
Hexane	6	$CH_3(CH_2)_4CH_3$	C_6H_{14}	Hexadecane	16	______
Heptane	7	$CH_3(CH_2)_5CH_3$	C_7H_{16}	Heptadecane	17	______
Octane	8	$CH_3(CH_2)_6CH_3$	C_8H_{18}	Octadecane	18	______

Nonane	9	$CH_3(CH_2)_7CH_3$	C_9H_{20}	Nonadecane	19	______
Decane	10	$CH_3(CH_2)_8CH_3$	$C_{10}H_{22}$	Eicosane	20	______

Dear learner, if you have carefully studied the above table, you will notice some trends. Now, take a few minutes and perform the following activity based on the information provided in ***Table 6.2***.

Activity 6.1

i. What trends do you observe from the ***Table 6.2***?

ii. What do a family name and a specific name for a member have in common?

iii. Based on the trend you have observed from the Table, write the general formula for an alkane having "n" carbon atoms.

iv. Using the general formula, complete the missing molecular formula in the Table for the members undecane through eicosane.

v. Draw condensed structures and bond line representations for the first ten alkanes.

vi. Discuss the analogy in the usage of the terms "saturated" and "unsaturated" in this section and in Unit 2.

Dear learner, did you answer these activity questions? You can check your answers with the answer keys provided at the end of this unit. Then, take 5 minutes to study the characteristics of the alkane homologous series and answer the self-test exercise that follows.

Alkane Homologous Series

☞ Dear student, if you examine the alkanes in ***Table 6.2***, you can notice that each alkane differs from the preceding alkane by one $-CH_2-$ group. Butane, for example, is $CH_3(CH_2)_2CH_3$ and pentane is $CH_3(CH_2)_3CH_3$. A series of compounds like this, where each member differs from the next member by a constant unit, is called a homologous series. A homologous series has the following characteristics:

has a constant unit between two consecutive members;
has a general formula;
shows trends in physical properties and
exhibit the same reactivity (chemical property). Members of a homologous series are called homologues.

Now, let me give you a chance to check your understanding. Do the following exercise in 5 minutes.

Self-Test Exercise 6.4

1. Define homologous series.
2. Describe the characteristics of a homologous series.
3. What is the molecular formula of an alkane containing the following carbon number?

   a) 15 b) 18 c) 26
4. Determine if each statement about the alkane homologous series is true or false.
   - a. It has a general formula and a name.
   - b. Consecutive members differ by a constant (-CH_2-) unit.
   - c. All members contain the same functional group.
   - d. Consecutive members differ by a constant molecular mass of 14.

Dear learner, I hope you have answered these questions correctly. In fact, you can check the answers with the answer keys at the end of the unit. Now let's proceed as usual to the next subsection.

6.3.2 Physical Properties of Alkanes

This is a short section and I suppose you can quickly master in 5 minutes and proceed to the self-test exercise.

At the end of this section, you should be able to explain the physical properties of alkanes.

Activity 6.2

Dear learner, you have learnt in Unit 2, that particles in the liquid and solid states are held together by intermolecular forces while the gaseous state is characterized by the absence of such forces. You have also studied that among the various intermolecular forces the dispersion forces are the ones possessed by nonpolar molecules and increase as molecular weight increases. You also learnt that polarity is the result of a difference in the electronegativity of bonded atoms. Given the fact that carbon and hydrogen atoms have similar electronegativity, answer the following questions:

- a. Do you think alkanes are polar or nonpolar molecules?
- b. What do you think are the intermolecular forces that could exist in alkanes that are liquids and solids at room temperature?
- c. Which members of alkanes do you think are gases, which of them have lower mass or higher mass?
- d. What happens to the boiling point and melting point of alkanes as the number of carbon atoms or molecular masses increases? Can you explain your reasoning?
- e. Are alkanes soluble in water? Explain based on the like dissolves like rule you learnt in Unit 2.

Table 6.3 Physical properties and isomers of some members of the alkane family.

Name	No of C atoms	Physical state (at room temp)	M.P (°C)	B.P (°C)	Density	No of isomers
Methane	1	gas	-183	-162	0.717 g/L	0
Ethane	2	Gas	-172	-89	1.35 g/L	0
Propane	3	Gas	-187	-42	2.02 g/L	0
Butane	4	Gas	-135	-0.5	2.48 g/L	2
Pentane	5	Liquid	-130	36	0.63 g/mL	3
Hexane	6	Liquid	-94	68	0.66 g/mL	5
Heptane	7	Liquid	-91	98	0.68 g/mL	9
Octane	8	Liquid	-57	126	0.70 g/mL	18
Nonane	9	Liquid	-54	151	0.71 g/mL	35
Decane	10	Liquid	-30	174	0.73 g/mL	75

☞ "Alkanes contain only C-C and C-H bonds which are nonpolar. Therefore, alkanes are also nonpolar compounds. The most important intermolecular forces in the liquid and solid states of nonpolar compounds are the London dispersion forces. These types of forces increase with increasing intermolecular forces. Therefore, the melting and boiling points of alkanes increase as their molecular weight increases. In addition, at room temperature (25oC and 1 atm pressure), the first four members of the homologous series of unbranched alkanes having C_1 to C_4 are gases (Table 6.3), the C_5-C_{17} unbranched alkanes (pentane to heptadecane) are liquids, and the unbranched alkanes with 18 and more carbon atoms are solids. As a class, the alkanes are the least dense of all groups of organic compounds. All alkanes have densities considerably less than 1.00 g mL−1 (the density of water at 4 °C). As a result, petroleum (a mixture of hydrocarbons rich in alkanes) floats on water. Since alkanes are nonpolar, they are soluble in nonpolar solvents such as benzene and carbon tetrachloride but insoluble in polar solvents like water." Dear student, did you answer the above questions like this? Great!

Now, take some minutes to do the following exercise.

Self-Test Exercise 6.5

Explain each of the following facts about alkanes.

1. Alkanes show regular increases in boiling point as their molecular weight increases.
2. Branching decreases the boiling point of alkanes.
3. Alkanes are insoluble in water.

6.3.3 Nomenclature of Alkanes

Well, this is a bit lengthy and requires more time and patience. As a strategy follow the following sequence to master the nomenclature rules:

Step 1: Learn the common names of some alkanes.

Step 2: Learn the common names of important alkyl groups.

Step 3: Study the IUPAC nomenclature rules step by step and try to cover all in 1 day including the exercises.

At the end of this section, you should be able to

- Apply IUPAC rules to name straight and branched chain alkanes.
- Write the structural formulas of the first ten alkanes.

Dear learner, do you notice that each of your friends has his/her name? Can you explain the purpose of naming? Is the way girls are named different from boys? If yes, why do you think so? Is there any pattern of systemic change in the way girls and boys are named? Why do you think we have such systematic naming for girls and boys? Discuss! How do your parents call you? Like you are called in school or different? If you have a different name commonly used by your parents, do you mind telling it to your classmate as if it were your common name "My common name is ____?" How do you think parents select a common name for their children? Any criteria?

As the science of organic chemistry slowly grew in the 19th century, so too did the number of known compounds and the need for a systematic method of naming them. Alkanes can be named in two ways: common names and IUPAC names.
Common Names of Alkanes

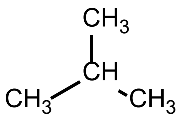
Lower members of the alkane homologous series have common names. The prefixes used in the common names are n- (normal), 'iso-' and 'neo-'. The prefix n- is used when all the carbon atoms form a continuous chain.

Example 6.1 $CH_3CH_2CH_2CH_2CH_3$ $CH_3CH_2CH_2CH_2CH_2CH_3$

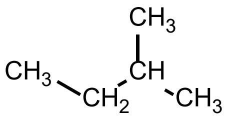
n-pentane n-hexane

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

Example 6.2:



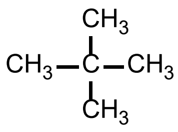
isobutane



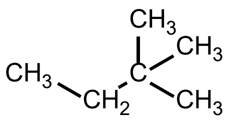
isopentane

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

Example 6.3:



neopentane



neohexane

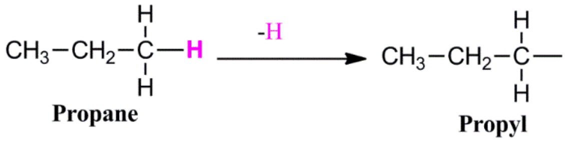
Before you proceed, check if you can draw the structures of isobutane, isopentane, neopentane, and neohexane.

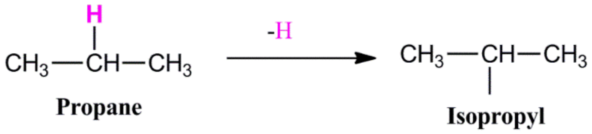
Alkyl Groups and the Symbol R

If we remove one hydrogen atom from an alkane, we obtain what is called an alkyl group or alkyl radical. These alkyl groups have names that end in -yl. When the alkane is unbranched, and the hydrogen atom that is removed is a terminal hydrogen atom, the names are straightforward as illustrated below:

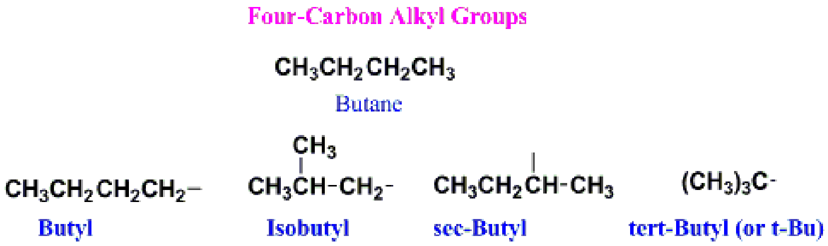
Alkane	Alkyl Group	Abbreviation
CH_3-H methane	CH_3- Methyl	Me-
CH_3-CH_2-H ethane	CH_3-CH_2- Ethyl	Et-
$CH_3-CH_2-CH_2-H$ propane	$CH_3-CH_2-CH_2-$ Propyl	Pr-
$CH_3-CH_2-CH_2-CH_2-H$ butane	$CH_3-CH_2-CH_2-CH_2-$ Butyl	Bu-

While only one alkyl group can be derived from methane or ethane (the methyl and ethyl groups, respectively), two groups can be derived from propane. Removal of a hydrogen atom from one of the end carbon atoms gives a group that is called the propyl group; removal of a hydrogen atom from the middle carbon atom gives a group that is called the isopropyl group.

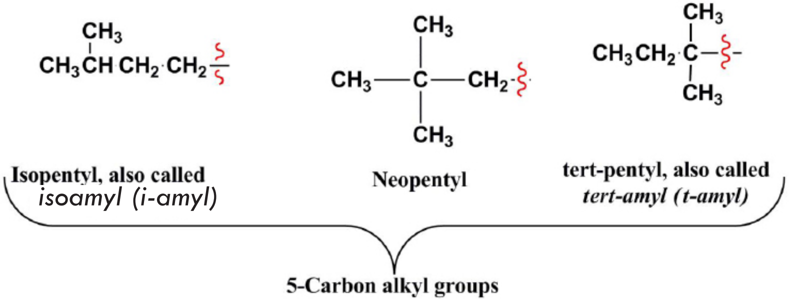




There are four C_4 alkyl groups.



There is one five-carbon group with an IUPAC-approved common name that you should also know: the 2,2-dimethylpropyl group, commonly called the neopentyl group. Other common names for five carbon alkyl groups include isopentyl and tert-pentyl groups.



IUPAC-approved the common names isopropyl, isobutyl, sec-butyl, tert-butyl, isopentyl, neopentyl, and tert-pentyl for the unsubstituted groups, and they are still very frequently used. You should learn these groups so well that you can recognize them any way they are written.

The symbol R is used as a general symbol to represent any alkyl group. For example, R might be a methyl group, an ethyl group, a propyl group, an isopropyl group, etc. in the general formula for alkane R-H. Similarly, in R-COOH which is the general formula for carboxylic acid, R can be any alkyl group (methyl, ethyl, isopentyl, etc.).

Before you proceed check if you can draw the structures of isopropyl, isobutyl, sec-butyl, t-butyl, i-amyl, neopentyl, and t-amyl.

The System of IUPAC Nomenclature

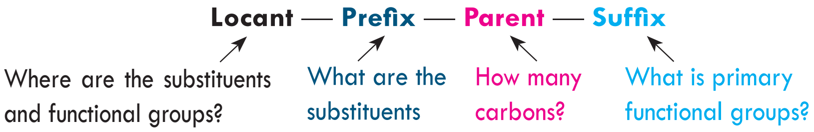
The system of nomenclature we'll use in here is the one that was devised by the International Union of Pure and Applied Chemistry (IUPAC, usually read as eye-you-pac). The IUPAC nomenclature can be applied to both branched and unbranched alkanes.

IUPAC Rules for Naming Unbranched Alkanes

Compounds like butane and pentane, whose carbons are all connected in a row, are called straight-chain alkanes, or normal alkanes. Compounds like 2-methylpropane (isobutane), 2-methylbutane, and 2, 2-dimethylpropane, whose carbon chains branch, are called branched-chain alkanes. In unbranched alkanes, each carbon atom within the chain is bonded to no more than two other carbon atoms and that unbranched alkanes contain only primary and secondary carbon atoms. Primary (connect directly to one carbon), secondary (connect directly to two carbons), and tertiary (connect directly to three carbons) carbon atoms, quaternary (connected to four other carbons). The names for several of the unbranched alkanes are listed in ***Table 6.2***. The ending (suffix) for all of the names of alkanes is -ane. The stems of the names of most of the alkanes (above C_4) are of Greek and Latin origin. Thus the parent names for one, two, three, four, and five become meth-, eth-, prop-, but-, and pent-.

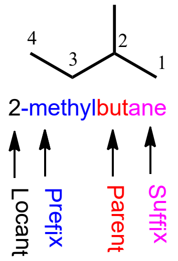
IUPAC Rules for Naming Branched-Chain Alkanes

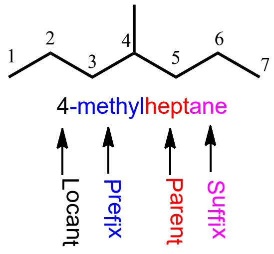
A chemical name for branched alkanes typically has four parts in the IUPAC system of nomenclature: locant, prefix, parent, and suffix.

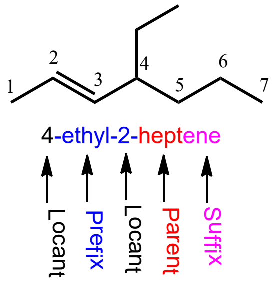


The prefix identifies the various substituent groups in the molecule, the parent selects the main part (longest chain) of the molecule and tells how many carbon atoms are in that part, the locants give the positions of the functional groups and substituents, and the suffix identifies the primary functional group.

The examples below illustrate the basic components of the IUPAC nomenclature. The methyl and ethyl groups in, for example, 2-methylbutane and 4-ethyl-2-heptene are substituents and are called alkyl groups. What are alkyl groups?



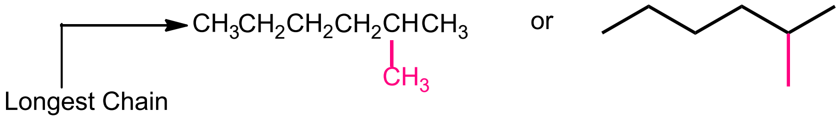




Before you proceed, check if you know the components of IUPAC nomenclature: the locants, prefix, parent, and suffix as applied in the indicated examples. Then, you can proceed to the IUPAC rules to name any complex alkanes.

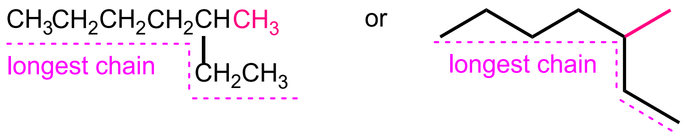
☞ Branched-chain alkanes are named according to the following rules:

1. Locate the longest continuous chain of carbon atoms; this chain determines the parent name for the alkane. The parent name for the following compound, for example, is hexane because the longest continuous chain contains six carbon atoms:



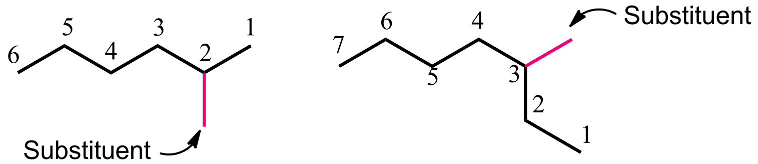
$$\underset{CH_3}{CH_3CH_2CH_2CH_2\overset{}{C}HCH_3}$$

The longest continuous chain may not always be obvious from the way the formula is written. Notice, for example, that the parent name of the following alkane is designated as a heptane because the longest chain contains seven carbon atoms:

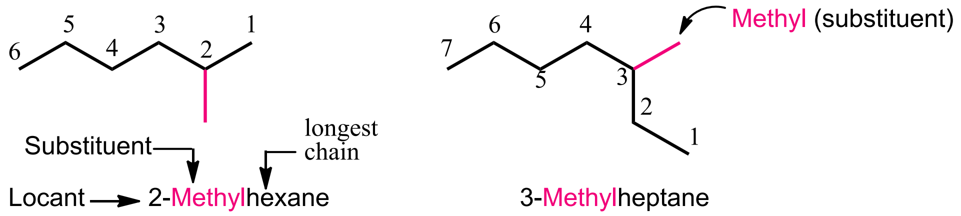


$$\underset{CH_2CH_3}{CH_3CH_2CH_2CH_2CHCH_3}$$

2. Number the longest chain, beginning with the end of the chain nearer to the substituent. Applying this rule, we number the two alkanes that were illustrated previously in the following way:

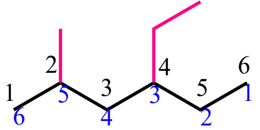


3. Use the numbers obtained by the application of Rule 2 to designate the location of the substituent group. The parent name is placed last, and the substituent group, preceded by the number designating its location on the chain, is placed first. Numbers are separated from words by a hyphen. Our two examples are 2-methylhexane and 3-methylheptane, respectively.



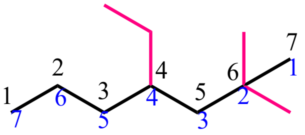
4. When two or more substituents are present, give each substituent a number

corresponding to its location on the longest chain. For example, we designate the following compound as 4-ethyl-2-methylhexane:



4-Ethyl-2-methylhexane

Not 3-Ethyl-5-methylhexane

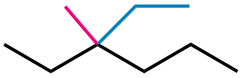


4-Ethyl-2, 2-dimethylheptane

Not 4-Ethyl-6,6-dimethylheptane

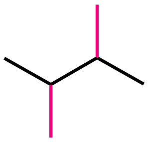
To check which direction of numbering is correct in this case, add the locants (numbers assigned to the carbon atoms to which substituents are attached). The sum of the locants in the first case is 2 + 4 = 6, and in the second case it is 3 + 5 = 8. So numbering should be done from left to right in this case. Thus, the first option is correct. The substituent groups should be listed alphabetically (i.e., ethyl before methyl). In deciding on alphabetical order, disregard multiplying prefixes such as ‘di’, ‘tri', and 'tetra'. Ethyl comes first compared to methyl when ‘di is ignored, as illustrated in 4-ethyl-2,2-dimethylheptane. In addition, disregard structure-defining prefixes that are written in italics and separated from the name by a hyphen. Thus, tert-butyl precedes ethyl (tert is ignored), but ethyl precedes isobutyl ('iso' not ignored).

5. When two substituents are present on the same carbon atom, use that number twice:

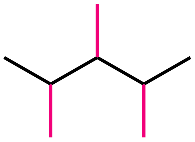


3-Ethyl-3-methylhexane

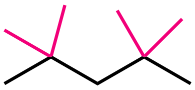
6. When two or more substituents are identical, indicate this by using the prefixes di-, tri-, tetra-, and so on. Then make certain that each substituent has a number. Commas are used to separate numbers from each other:



2,3-Dimethylbutane



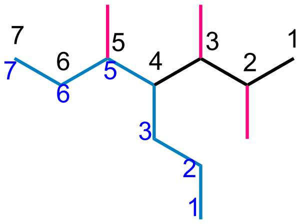
2,3,4-Trimethylpentane



2,2,4,4-Tetramethylpentane

The application of these six rules allows us to name most of the alkanes that we shall encounter. Two other rules, however, may be required occasionally:

7. When two chains of equal length compete for selection as the parent chain, choose the chain with the greater number of substituents.



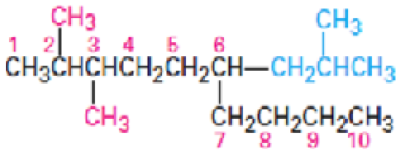
2,3,5-trimethyl-4-propylheptane

Not 4-(1,2-dimethylpropyl)-5-methylheptane

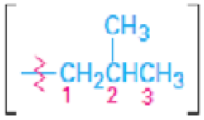
8. When branching first occurs at an equal distance from either end of the longest chain, choose the name that gives the lower number at the first point of difference:

2,3,5-trimethylhexane
Not 2,4,5-trimethylhexane

9. Name a complex substituent as though it were itself a compound. In some particularly complex cases, a fifth step is necessary. It occasionally happens that a substituent on the main chain has sub-branching. In the following case, for instance, the substituent at C_6 is a three-carbon chain with a methyl sub-branch. To name the compound fully, the complex substituent must first be named.

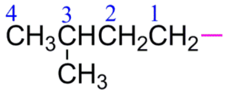

$CH_3\overset{CH_3}{C}H\underset{CH_3}{C}HCH_2CH_2\underset{CH_2CH_2CH_2CH_3}{C}H-CH_2\overset{CH_3}{C}HCH_3$

2,3-Dimethyl-6-(2-methylpropyl)decane
or 2,3-Dimethyl-6-isobutyldecane

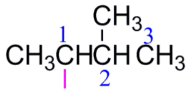

$-CH_2\overset{CH_3}{C}HCH_3$

A 2-methylpropyl group
(isobutyl group)

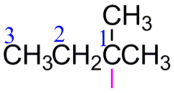
Note that, for alkyls group, numbering begins at the carbon directly connected to the parent chain and continues in the longest direction. Further examples:


$CH_3\underset{CH_3}{C}HCH_2CH_2-$

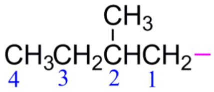
3-methylbutyl


$CH_3\underset{|}{C}H\overset{CH_3}{C}HCH_3$

1,2-dimethylpropyl

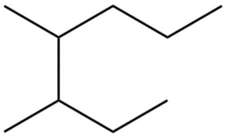

$CH_3CH_2\underset{|}{\overset{CH_3}{C}}CH_3$

1,1-dimethylpropyl

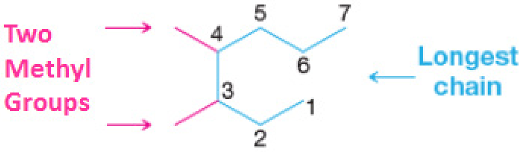

$CH_3CH_2\overset{CH_3}{C}HCH_2-$

2-methylbutyl

Example: Write IUPAC name for:



Strategy and solution: We find the longest chain (shown in blue) to be seven carbons; therefore the parent name is heptane. There are two methyl substituents (shown in red). We number the chain so as to give the first methyl group the lower number. The correct name, therefore, is 3,4-dimethylheptane. Numbering the chain from the other end to give 4,5-dimethylheptane would have been incorrect.



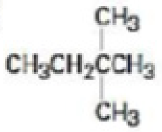
Self-test Exercise 6.6

1. Give IUPAC names for the following compounds:

(a)

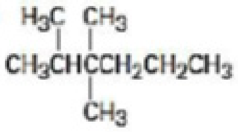
$CH_3\overset{CH_3}{CH}CH_2CH_2CH_3$

(b)



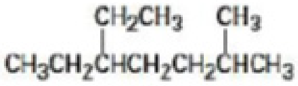
$CH_3CH_2\overset{CH_3}{\underset{CH_3}{C}}CH_3$

(c)



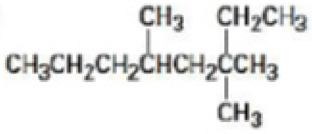
$CH_3\overset{H_3C}{CH}\overset{CH_3}{\underset{CH_3}{C}}CH_2CH_2CH_3$

(d)



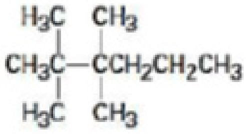
$CH_3CH_2\overset{CH_2CH_3}{CH}CH_2CH_2\overset{CH_3}{CH}CH_3$

(e)



$CH_3CH_2CH_2\overset{CH_3}{CH}CH_2\overset{CH_2CH_3}{\underset{CH_3}{C}}CH_3$

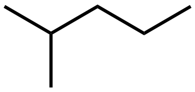
(f)



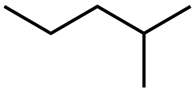
$CH_3\overset{H_3C}{\underset{H_3C}{C}}-\overset{CH_3}{\underset{CH_3}{C}}CH_2CH_2CH_3$

2. Which structure does not represent 2-methylpentane?

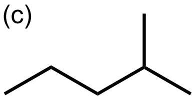
(a)



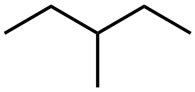
(b)



(c)



(d)



3. Draw structures for the following:

a. 2-Methylheptane b. 4-Ethyl-2,2-dimethylhexane

c. 4-Ethyl-3,4-dimethyloctane d. 2,4,4-Trimethylheptane

e. 3,3-Diethyl-2,5-dimethylnonane f. 4-Isopropyl-3-methylheptane

g. 4-ethyl-2,2,3-trimethylhexane h. 3-bromo-2-chlorohex-1-ene

4. Explain why each of the following names is incorrect:

a. 2,2-Dimethyl-6-ethylheptane b. 4-Ethyl-5,5-dimethylhexane

c. 3-Ethyl-4,4-dimethylhexane d. 5,5,6-Trimethyloctane

(e) 2-Isopropyl-4-methylheptane

Dear learner, before you proceed to the next section, I strongly advise you to practice naming alkanes according to IUPAC rules. Try more exercises using the references listed at the end of this unit. If you are familiar with the nomenclature of alkanes, that of other hydrocarbons-alkenes and alkynes will become easier. So, spend more time and be sure that you understand how to name alkanes, including complex ones.

6.3.4 Isomerism in Alkanes

This is a relatively short section which you can master it in 30 minutes before you proceed to the self-test exercise.

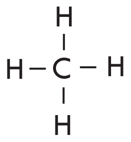
At the end of this section, you should be able to

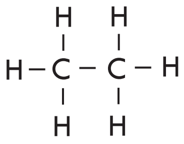
- Define isomerism.
- Define structural isomerism.
- Draw the possible structural isomers for C_4H_{10}, C_5H_{12} and C_6H_{14}.

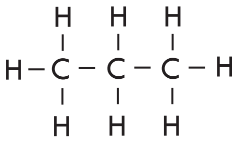
Dear learner, let's start this section with a brief activity. You know that among animals, it is very common to encounter some dogs that appear pretty much the same in terms of size, and colour. How would you identify them apart if you encountered two such dogs? Assume that one of the dogs is your friendly neighbor. What about chemicals? Can you name two compounds that have the same molecular formula and molecular weight but differ in the way their atoms are arranged? What do you call them? Do you think such compounds have identical or different properties?

Don't worry. We will answer these questions together. Although the dogs can be the same, you can easily identify your neighbor by the way it reacts to you. Similarly, organic compounds that have the same formula differ in the way they react with a particular reagent. In the subsequent section, you will learn about the definition and some examples of such a pair of compounds.

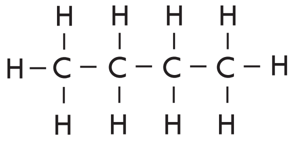
Unlike the first three members of the alkane homologous series, i.e., methane, ethane, and propane,

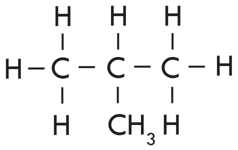

Methane


Ethane


Propane

in molecules having four or more carbon atoms, the carbons can be arranged in two or more ways. A molecule having the formula C_4H_{10}, which you know as butane can have two structures.


Butane


Isobutane

The two structures are drawn using the possibility of connecting the four carbon atoms in two different ways. In the first case, all four carbon atoms in butane are connected in row (linearly). In the second case, the four carbon atoms are connected in a branched manner to give isobutane. Butane and isobutane have the same molecular formula, C_4H_{10}, but have different structures and properties. Similarly, the 5 C atoms in pentane (C_5H_{12}) can be arranged in three ways. Compounds like the two C_4H_{10} molecules and the three C_5H_{12} molecules, which have the same molecular formula but different structures, are called structural isomers, from the Greek isos + meros, meaning "made of the same parts." A formula to determine the number of isomers of alkanes containing 4 – 7 carbon atoms is $2^{n-4} + 1$.

Definition: Isomers are compounds that have the same formula but differ in the way the atoms are arranged.

Definition: Structural isomers are two or more different compounds that have the same molecular formula but different connectivity and hence structures. We'll see shortly that other kinds of isomers are also possible, even among compounds whose atoms are connected in the same order. As ***Table 6.3*** shows, the number of possible alkane isomers increases dramatically as the number of carbon atoms increases.

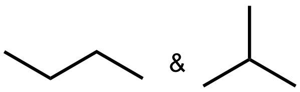
Note: Structural isomers have different physical properties. They are always found to have different melting points, boiling points, densities, indexes of refraction, and so forth.

Dear learner, now take the next few minutes to answer the following exercise.

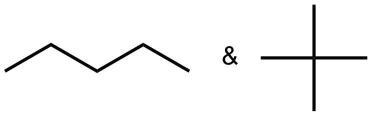
Self-Test Exercise 6.7

1. Consider two hypothetical compounds A and B having the same molecular formula, C_4H_{10}. Both are colorless and odorless gases at room temperature. Compound A has a boiling point of -1.0 °C whereas B has a boiling point of -11.7 °C. Draw the structures of compound A and compound B. What is the relationship between the two compounds? What conclusions can you draw about the physical properties of such pairs of compounds? You may revise your understanding of the physical properties of alkanes listed in Table 6.3 to answer these questions.
2. Is the statement "two compounds that have the same molecular formula always have the same properties" true or false? Explain your reason.
3. How many isomers does an alkane containing six carbon atoms exhibit?
4. Determine whether the pairs of structures in each of the following boxes are isomers or simply different structural representations of the same compound. Hint: If the IUPAC names are different, the structures are also different.

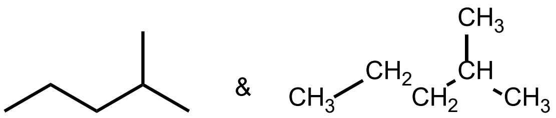
(a)



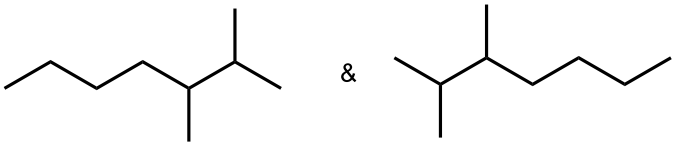
(b)



(c)



(d)



6.3.5 Preparation of Alkanes

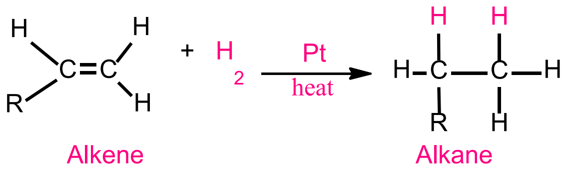
We said the principal sources of alkanes are natural gas and crude oil. But sometimes the need arises to synthesize alkanes of the desired structure in the laboratory. How do you do it? Here, you will study how alkanes are obtained via three routes: using alkenes, alkyl halides, and the sodium salt of an organic acid as precursors. This may cost you about 1 hour, including the time required to answer the self-test exercises that follow immediately.

At the end of this section, you should be able to

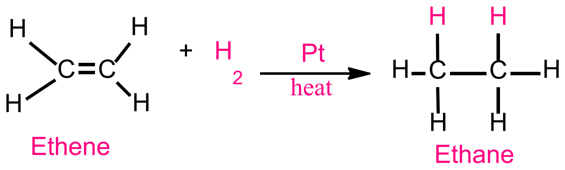
- Describe the general methods for preparation of alkanes in a laboratory.
- Synthesize methane in a laboratory by decarboxylation method.
- Carryout a project work to produce biogas from cow dung.

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

1. Hydrogenation of alkenes with a metal catalyst.



Example 6.4:



General Reaction:

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

General reaction: $2R\text{-}X + 2Na \longrightarrow R\text{-}R + 2NaX$

Halogenated alkane/ Alkyl halide; Alkane; Sodium halide

Example 6.5:

$2CH_3Cl + 2Na \rightarrow CH_3 - CH_3 + 2NaCl$

Methyl chloride; Ethane; Sodium chloride

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

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

Example 6.6: (Preparation of methane by decarboxylation reaction)

$$CH_3COONa + NaOH \xrightarrow[\text{heat}]{CaO} CH_3\text{-}H + Na_2CO_3$$

Sodium acetate; Methane; Sodium Carbonate

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

Note: The materials that can be used to produce biogas include dung from cattle, pigs, chickens, chopped green plants and plant wastes. The advantages of biogas technology include savings on fuels such as kerosene, wood and charcoal, and a decrease in local deforestation. The residue obtained after preparing the biogas can be used as fertilizer. Dear student, I hope you have studied well about the laboratory preparation of alkanes. Now, take 5 minutes to do the following exercise.

Self-Test Exercise 6.8

1. Write about the products when:
   a. $CH_3CH{=}CH_2$ reacts with hydrogen in the presence of Pt as a catalyst
   b. Ethyl bromide reacts with sodium metal
   c. Sodium propanoate (CH_3CH_2COONa) reacts with soda lime
2. The reaction of a halogenated alkane with sodium is named in honor of______________

Dear learner, I would appreciate it if you dared to accomplish the following project!

Project 6.1

1. In consultation with your friends, identify a place (your ‘Kebele’ or neighboring Kebeles) where a biogas plant is at work.
2. Prepare data collection instrument (e.g. a questionnaire).
3. Make a trip to visit the biogas plant and collect the information you require.
4. Describe the method involved and depict it graphically.
5. Develop a similar set-up and produce your own biogas. Collect it using balloons. Take photos of your set-up and videos while you are constructing and doing it, and show it to your tutor.
6. With your sample in a balloon, conduct tests to answer the following questions:

   a. What is the colour of the gas?
   b. Is the gas combustible? Write a balanced equation for the change.
   c. Is there any change when bromine water is added?

6.3.6 Chemical Properties of Alkanes

Now, we have already seen how alkanes can be synthesized in the laboratory. What about their conversion into other substances? Although alkanes have generally little affinity to react because they are saturated, they can undergo some reactions-combustion, substitution, and elimination. 1 hour is enough for this section.

At the end of this section, you should be able to

- Describe the general methods for the preparation of alkanes in a laboratory;
- Synthesize methane in a laboratory by the decarboxylation method;
- Carry out a project to produce biogas from cow dung.

Dear student, you have learnt in grade 9 that atoms achieve their valency by forming bonds with other atoms. Now, you have just learnt that alkanes are saturated compounds. Do you think they have the affinity to react with other atoms or molecules? Based on your experiences so far with this unit, can you suggest the most important reaction of alkanes? You will get answers to these questions as you read the following section.

Alkanes are sometimes referred to as paraffin, a word derived from the Latin parum affinis, meaning ‘little affinity.’ This term aptly describes their behavior, for alkanes show a little chemical affinity for other substances and are chemically inert to most laboratory reagents like acids, bases, oxidizing and reducing agents. They are also relatively inert

biologically and are not often involved in the chemistry of living organisms.
Alkanes do, however, react with oxygen, halogens, and a few other substances under appropriate conditions.

1. Combustion Reaction:

Combustion is the most important reaction for alkanes. A reaction with oxygen occurs during combustion in an engine or furnace when the alkane is used as a fuel. Carbon dioxide and water are formed as products, and a large amount of heat is released. The general equation for the combustion reaction of alkanes is:

$$C_nH_{2n+2} + \left[\frac{3n+1}{2}\right]O_2 \rightarrow nCO_2 + (n+1)H_2O$$

where n is the number of C atoms.
For example, methane (natural gas) reacts with oxygen according to the equation:

Example 6.7: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + 890\ \text{kJ/mol}\ (213\ \text{kcal/mol})$

$$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$$

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

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

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

$$Cl\text{-}Cl \xrightarrow{\text{light}} 2Cl\cdot$$

ii. Chain Propagating Step: This is a step that involves the reaction of the free radical from step i with the alkane, which consumes a reactive particle (free radical) produced in the chain initiation step and generates another free radical.

$$Cl\bullet + CH_4 \xrightarrow{\text{light}} HCl + CH_3^{\bullet}$$

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

$$CH_3^{\bullet} + Cl\bullet \xrightarrow{\text{light}} CH_3Cl$$

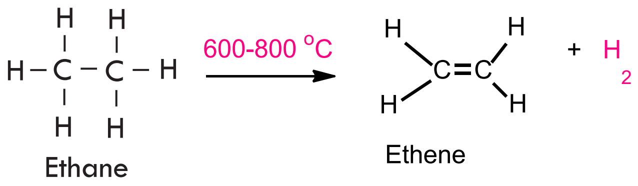
Such a detailed step-by-step description of a chemical reaction is called a **reaction mechanism**.

Depending on the relative amounts of the two reactants and on the time allowed, a sequential substitution of the alkane hydrogen atoms by chlorine occurs, leading to a mixture of chlorinated products. Methane, for instance, reacts with Cl_2 to yield a mixture of CH_3Cl, CH_2Cl_2, $CHCl_3$, and CCl_4.

$CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$
Methyl chloride
$CH_3Cl(g) + Cl_2(g) \rightarrow CH_2Cl_2(g) + HCl(g)$
Methylene chloride
$CH_2Cl_2(g) + Cl_2(g) \rightarrow CHCl_3(g) + HCl(g)$
Chloroform (trichloromethane)
$CHCl_3(g) + Cl_2(g) \rightarrow CCl_4(g) + HCl(g)$
Carbontetrachloride (tetrachloromethane)

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

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



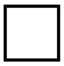
Self-Test Exercise 6.9

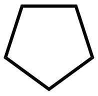
1. Alkanes are sometimes referred to as paraffin. Explain.
2. Write the balanced equation for the combustion reaction of hexane.
3. Write the major products of the reaction:
   a. methane with bromine in the presence of light.
   b. ethane is heated at 700°C
4. Explain why alkanes do not undergo an addition reaction.

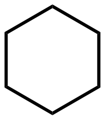
6.3.7 Cycloalkanes (Alicyclic Hydrocarbons)

Cycloalkanes are alkanes in which all or some of the carbon atoms are arranged in a ring. Alkanes have the general formula C_nH_{2n+2}; cycloalkanes containing a single ring have two fewer hydrogen atoms and thus have the general formula C_nH_{2n}, where $n \geq 3$. Since cycloalkanes are alkanes themselves, they have the same properties as the alkanes we have described in the preceding sections. They are also called **alicyclic hydrocarbons** ("ali" stands for aliphatic). Examples include cyclopropane, cyclobutane, cyclopentane, cyclohexane, etc.


cyclopropane


cyclobutane


cyclopentane


cyclohexane

Note that the simplest alicyclic compound is cyclopropane. You will learn more about this in upper grades.

6.3.8 Uses of Alkanes

Dear learner, have a look at the icon to the right. What comes to your mind is the gasoline or diesel supplied at fuel stations. You will soon learn that the liquid you see is principally a mixture of alkanes. You have also learnt that they are nonpolar molecules that have very little affinity to react with other substances. In this section you will learn about the most important uses of alkanes including the one displayed in the picture.

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

Dear learner, let's summuraise what you have studied through questions. Take 5 minutes to do the following exercise.

Self-Test Exercise 6.10

1. Define each of the following terms:
    a. Homologous series
    b. substitution reaction
    c. Alkyl radical
    d. combustion reaction
    e. Isomerism
    f. functional groups
2. Write the balanced chemical equation for the combustion of octane
3. How many chain isomers are there for an alkane that contains 7 carbon atoms?

Section 6.4: Unsaturated Hydrocarbons: Alkenes (C_nH_{2n})

Alkenes, alkynes, and arenes (aromatic compounds) all contain carbon–carbon multiple bonds and are unsaturated hydrocarbons. In this section, we focus on the homologous series (***Table 6.4***), nomenclature, and physical properties of alkenes.

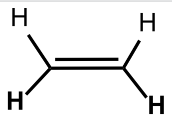
At the end of this section, you should be able to
- Define unsaturated hydrocarbons.
- Define alkenes.
- Write the general formula of alkenes.
- Write the molecular formula for the first nine homologous series of alkenes.

6.4.1 Alkenes or Olefins

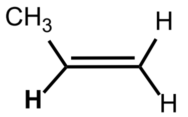
Alkenes are unsaturated hydrocarbons that contain at least one carbon–carbon double bond and have an -ene ending in their names. They are also known as olefins. They form a homologous series represented by the general formula C_nH_{2n}, where n = 2, 3, 4, …

A. Homologous series of Alkenes

Ethene is the simplest alkene. Propene is the second member of alkene homologoues serious.



Ethene



Propene

Table 6.4 The homologous series of alkenes and their physical constants.

IUPAC Name	Molecular formula	Condensed Formula	M.P	B.P	Density
Ethene	C_2H_4	$CH_2=CH_2$	-169	-102	0.61g/L
Propene	C_3H_6	$CH_2=CH_2CH_3$	-185	-48	0.61 g/L
1-butene	C_4H_8	$CH_2=CH_2CH_2CH_3$	-130	-6.5	0.63 g/L
1-pentene	C_5H_{10}	CH2=$CH_2(CH_2)_2CH_3$	-130.5	30	0.64 g/L
1-hexene	C_6H_{12}	$CH_2=CH_2(CH_2)_3CH_3$	-138	63	0.67 g/L
1-heptene	C_7H_{14}	$CH_2=CH_2(CH_2)_4CH_3$	-119	93	0.69 g/L
1-octene	C_8H_{16}	$CH_2=CH_2(CH_2)_5CH_3$	-104	122	0.72 g/L
1-nonene	C_9H_{18}	$CH_2=CH_2(CH_2)_6CH_3$	-95	146	0.73 g/L
1-decene	$C_{10}H_{20}$	$CH_2=CH_2\ (CH_2)_7CH_3$	-87	171	0.74 g/L

Dear learner, take the next few minutes to test your understaning of alkenes, their homologous series, and thier properties.

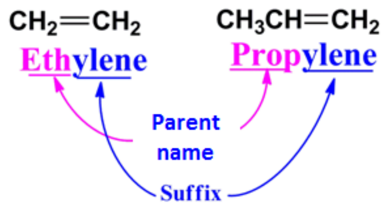
Self-Test Exercise 6.11

1. Define alkene and explain how it differs from alkanes
2. Describe the general characteristics of the homologous series of alkenes
3. The molecular formulas for the first three members of an alkene series are C_2H_4, C_3H_6 and C_4H_8. Derive the general formula for alkenes and compare it with that of alkanes. Is there a difference in the number of hydrogen atoms?
4. By referring to ***Table 6.4***, what relationship do you observe between the number of carbon atoms and the melting point, boiling point and density?
5. Write the molecular formula of the first 10 members of the alkene homologous series

B. Nomenclature of Alkenes

At the end of this section, students will be able to use IUPAC rules to name straight and branched chain alkenes.

Alkenes can have common names as well as IUPAC names. The common names of alkenes are obtained by replacing the –ane of the corresponding alkane with -ylene' as illustrated below:



The IUPAC rules for naming alkenes are similar in many respects to those for naming alkanes:

1. Determine the parent name by selecting the longest chain that contains the double bond and changing the ending of the name of the alkane of identical length from –ane to -ene. Thus, if the longest chain contains five carbon atoms, the parent name for the alkene is pentene; if it contains six carbon atoms, the parent name is hexene, and so on.
2. Number the chain so as to include both carbon atoms of the double bond, and begin numbering at the end of the chain nearer the double bond. Designate the location of the double bond by using the number of the first atom of the double bond as a locant. The locant for the alkene suffix may precede the parent name or be placed immediately before the suffix.

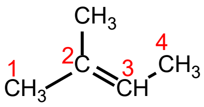
Example 6.8: $\overset{1}{CH_2}=\overset{2}{C}\overset{3}{H}CH_2\overset{4}{CH_3}$ $CH_3CH=CHCH_2CH_2CH_3$

1-Butene
(not 3-butene)

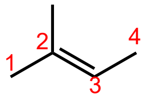
2-Hexene
(not 4-hexene)

3. Indicate the locations of the substituent groups by the numbers of the carbon atoms to which they are attached:

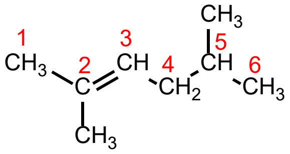
Structural Bond-line Structural Bond-line



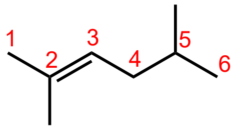
2-methyl-2-butene



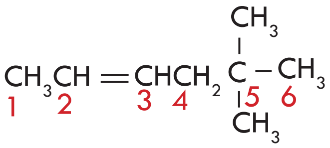
2-methyl-2-butene



2,5-dimethyl-2-hexene



2,5-dimethyl-2-hexene



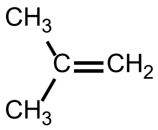
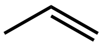
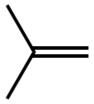
$$CH_3CH=CHCH_2\overset{CH_3}{\underset{CH_3}{\overset{|}{\underset{|}{C}}}}-CH_3$$

5,5-Dimethyl-2-hexene
or 5,5-dimethylhex-2-ene

$\overset{4}{C}H_3\overset{3}{C}H=\overset{2}{C}H\overset{1}{C}H_2Cl$

1-chloro-2-butene
or 1-chlorobut-2-ene

Many older names for alkenes are still in common use. Ethene is often called ethylene, Propene is often called propylene; 2-methylpropene is often called **isobutylene**.

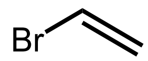
Condensed structures:	$CH_2=CH_2$	$CH_3-CH=CH_2$	
Line-bond formula:			
IUPAC name:	Ethene	Propene	2-Methylpropene
Common name:	Ethylene	Propylene	Isobutylene

4. Two frequently encountered alkenyl groups are the vinyl group and the allyl group:

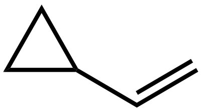
$CH_2=CH-$
vinyl

$CH_2=CH-CH_2-$
allyl

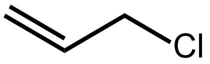
Using substitutive nomenclature, the vinyl and allyl groups are called **ethenyl and prop-2-en-1-yl**, respectively. The following examples illustrate how these names are employed:



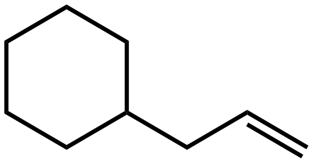
Bromoethene
or
vinyl bromide
(common)



Ethenylcyclopropane
or
vinylcyclopropane



3-chloropropene
or
allyl chloride
(common)



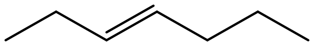
3-cyclohexylpropene
or
allylcyclohexane

Dear learner, I hope you have carefully studied the nomenclature of alkenes. Now, take 5 minutes to do the following exercise.

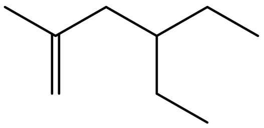
Self-Test Exercise 6.12

Give IUPAC names for the following alkenes:

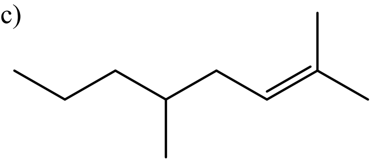
(a)



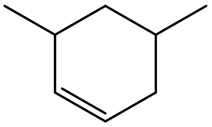
(b)



(c)



(d)



C. Physical Properties of Alkenes

At the end of this sub section, you should be able to describe physical properties of alkenes.

Dear learner, let's start this section with guiding questions. Do you think alkenes are polar or nonpolar molecules? Do you think the physical properties of alkenes are different from those of alkanes? Are alkenes soluble in water? How about in carbon tetrachloride? Can you explain the trends in boiling points, melting points, and density of alkenes as molecular weight increases? Which alkenes are gases, which liquids, and which ones are solids?

Note that alkenes, like alkanes, are nonpolar compounds, so their physical properties including mp, bp, and solubility are also the same as those of alkanes. The trends in the physical properties of alkanes you studied before also hold for alkenes.

D. Isomerism in Alkenes

In addition to the chain isomerism that you leant about in alkanes, alkenes can exhibit position isomerism and geometric or cis-trans isomerism. You may spend an hour on this topic.

At the end of this section, you should be able to

- Write possible structural isomers for C_4H_8 and $C_5H_{10.}$
- Define geometric (cis-trans) isomerism.
- Give examples of molecules that show geometric isomerism.
- Construct models that show cis-trans isomerism.

Dear learner, take a few minutes to study the following note and answer the questions that follow it.

Alkenes containing two or three carbon atoms have only one possible structure. Alkenes containing four or more carbon atoms exhibit isomerism. In the preceding section, you learnt that alkanes exhibit chain isomerism. In addition to chain isomerism, alkenes show two more types of isomerism:

Chain isomerism: This is due to the difference in the arrangement of the carbon atoms in the longest continuous carbon chain.

For example, in the two compounds 1-pentene and 2-methyl-1-butene, the position of the double bond is the same. However, in 1-pentene, the carbon chain is linear, whereas in 2-methyl-1-butene, it is branched. Thus, 1-pentene and 2-methyl-1-butene are chain isomers (see structures below).

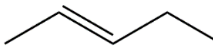
Position isomerism: This is due to the difference in the position of the double bond in the carbon chain.

For example, in the two compounds 1-pentene and 2-pentene (see structures below), the carbon skeleton is linear in both cases. However, the position of the double bond is at position 1 in 1-pentene and at position 2 in 2-pentene. Thus, 1-pentene and 2-pentene are position isomers; they differ by the position of the double bond. Similarly, 2-methyl-1-butene and 2-methyl-2-butene are position isomers. Note that all four compounds 1-pentene, 2-pentene, 2-methyl-1-butene, and 2-methyl-2-butene have the same molecular formula,

a

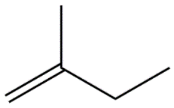
1-pentene

c



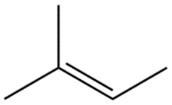
2-pentene

b



2-methyl-1-butene

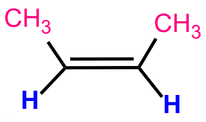
d



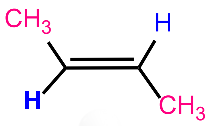
2-methyl-2-butene

Compounds (a) and (c) represent the position isomers of pentene, (b) and (d) are position isomers of methylbutene, (a) and (b) or (a) and (d) are the chain isomers, while all these compounds are the isomers of C_5H_{10}.

Geometrical isomerism. This results from the difference in the relative spatial arrangement of atoms or groups around the double bond. This isomerism exists because free rotation about the double bond is not possible. To differentiate geometrical isomers, we use the prefix 'cis' if two similar groups are on the same side of the double bond and 'trans' when the two similar groups are on opposite sides of it; 'cis' means the same and 'trans' means across. The geometrical isomers of 2-butene are:



cis-2-butene or cis-but-2-ene



trans-2-butene or trans-but-2-ene

Note: Not all alkenes have geometrical (cis-trans) isomers; alkenes cannot have geometrical isomers if two identical groups are attached to any one of the carbon atoms linked by a double bond. E.g. 1-pentene cannot exhibit cis-trans isomerism.

Self-Test Exercise 6.13

1. Explain the type of isomerism (chain or position) in:
   a. 2-pentene and 2-methyl-2-butene
   b. 1-hexene and 2-methyl-1-pentene
2. Explain why the boiling points and other physical properties of alkenes increase with increasing molecular weight
3. Write three positional isomers of hexene.
4. Write structural formulas for the following:
   a. cis-3-Octene
   b. 1-Bromo-2-methyl-1-(prop-2-en-1-yl) cyclopentane
   c. trans-2-Hexene
   d. 3,4-Dimethylcyclopentene
   e. 2,4-Dimethyl-2-pentene
   f. Vinylcyclopentane
   g. trans-1-Chlorobut-2-ene
   h. 1,2-Dichlorocyclohexene
   i. 4,5-Dibromo-1-pentene
   j. trans-1,4-Dichloro-2-pentene

Dear learner, I suggest you a project. Please do the following project as it can help you understand the cis-trans isomerism of alkenes.

Project 6.2

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

E. Preparation of Alkenes

Like I said for alkanes, alkenes can be obtained from crude oil. But more often, need arises to synthesize alkanes of desired structure in a laboratory. Here, you will study two routes to synthesize alkenes in the laboratory- dehydration and dehydrohalogenation. This may cost you about 1 hour, including the time required to answer the self-test exercises that follows immediately.

At the end of this section, you should be able to

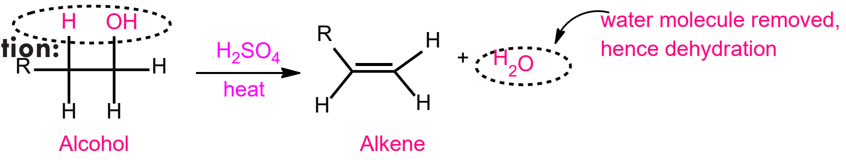
- Explain the general method for the preparation of alkenes in a laboratory.
- Produce ethylene in a laboratory by dehydrating of ethanol.

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

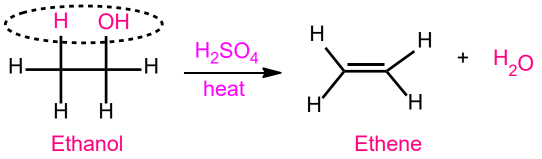
In the laboratory, one can prepare alkenes through one of the following methods:

I) The dehydration of alcohols with concentrated sulphuric acid or alumina (Al_2O_3). Dehydration means the removal of water.

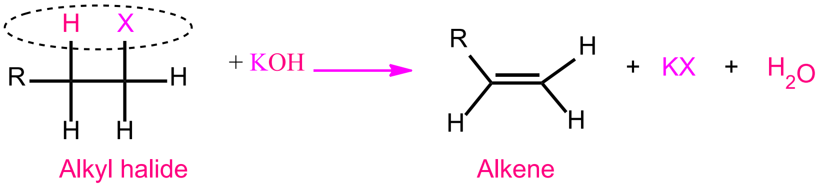
General Reaction:



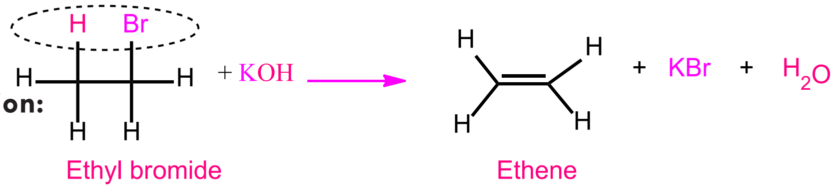
Example 6.9:



II) Dehydrohalogenation of alkyl halides with a base (KOH). Dehydrohalogenation means the removal of hydrogen and a halogen atom. Alkyl halides are compounds of an alkyl group and a halogen such as CH_3Cl and $CH_3 - CH_2 - Br$.



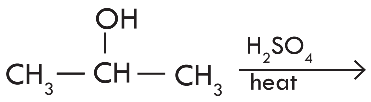
Example 6.10:
General Reaction:



Self-Test Exercise 6.14

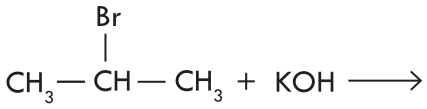
1. In the above two methods of preparation of alkenes, (a) what difference do you observe between the structures of the major reactant and the product?
2. Write the complete and balanced chemical equations for each of the following reactions:

a.



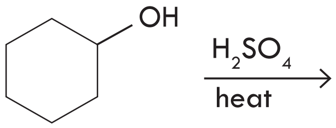
$CH_3-\overset{\overset{OH}{|}}{CH}-CH_3 \xrightarrow[heat]{H_2SO_4}$

b.



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

c.



F. Chemical Properties of Alkenes

We have seen how alkenes can be synthesized using other substances as precursors. What about converting them to other substances? This is possible too. Here, we consider some reactions of alkenes-combustion and most importantly addition. Because alkenes are unsaturated compounds, it is possible to add some atoms or groups to the C-C double bond. Let's see how! This may cost you an hour.

> At the end of this section, you should be able to explain chemical properties of alkenes.

But! Let me ask you some questions. Do you think alkenes are more or less reactive than alkanes? Can alkenes undergo a combustion reaction? What do you think is the most important reaction in alkenes? As you read the notes in this section, you will get answers to these questions.

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

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

General reaction:

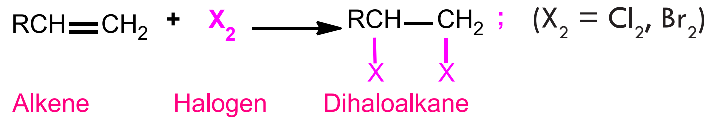
$$C_nH_{2n} + (3n/2)O_2 \rightarrow nCO_2 + nH_2O + Heat$$

Example 6.11:

$$C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O + Heat$$

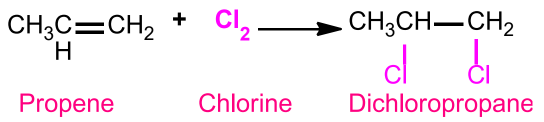
ii) Addition reaction. Alkenes undergo mainly addition reactions. The addition occurs at the carbon-carbon double bond.

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



$$RCH{=}CH_2 + X_2 \longrightarrow \underset{X}{RCH}-\underset{X}{CH_2}\ ;\ (X_2 = Cl_2, Br_2)$$

Example 6.12:



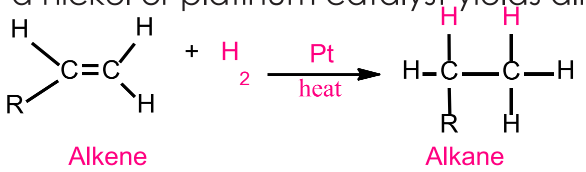
$$CH_3\underset{H}{C}{=}CH_2 + Cl_2 \longrightarrow CH_3\underset{Cl}{CH}-\underset{Cl}{CH_2}$$

General Reaction:

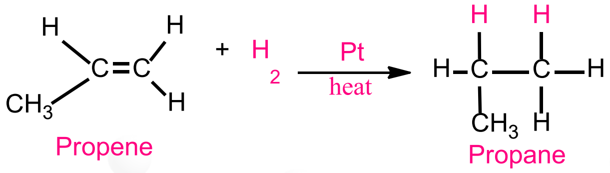
If bromine water (bromine in CCl_4) is added to alkenes, the reddish-brown colour of Br_2 in CCl_4 will disappear. This is due to the addition of bromine (Br_2) across the double bond. So, Br_2 in CCl_4 is used to detect unsaturation (presence of multiple bonds) in a compound.

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

General Reaction:

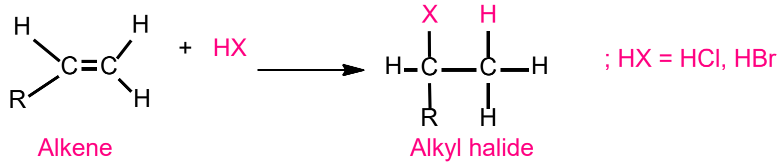


Example 6.13:

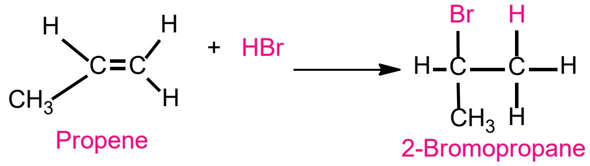


c. Addition of hydrogen halides, HX (hydrohalogenation): The addition of hydrogen halides (HCl, HBr or HI) to alkenes leads to the formation of alkyl halides. The product of the reaction can be predicted by Markovnikov's rule which states, "when an alkene reacts with a hydrogen halide to give an alkyl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

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



Example 6.14:



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

esence of an acid

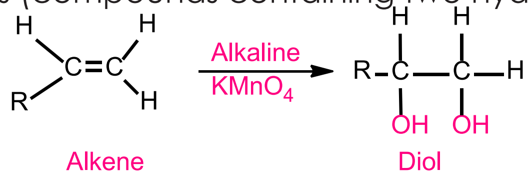
Example 6.14:

$$\underset{\text{Ethene}}{CH_2{=}CH_2} \xrightarrow{H_3PO_{4(aq)}} \underset{\text{Ethanol}}{CH_3{-}CH_2OH}$$

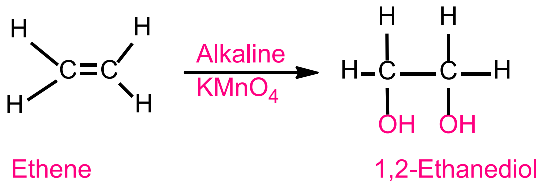
$$\underset{\text{Propene}}{CH_2{=}CHCH_3} \xrightarrow{H_3PO_{4(aq)}} \underset{\text{2-propanol}}{CH_3{-}CH(OH)CH_3}$$

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

General Reaction:



Example 6.15:



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

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

Example 6.16:

$$\underset{\text{Ethene}}{CH_2{=}CH_2} \xrightarrow[O_2\text{ (catalyst)}]{1000\text{ atm, }473\text{ K}} \underset{\text{Polyethene}}{(-CH_2{-}CH_2-)_n}$$

Dear learner, I hope you have understood the different types of reactions alkenes undergo. Now, please apply your knowledge of the reactions of alkenes to answer the following questions.

Self-Test Exercise 6.15

1. Write the balanced chemical equation for the combustion reaction of hexene.
2. Write the structures of the major products when $CH_3CH=CH-CH_3$ reacts with:
    a. Br_2
    b. H_2
    c. HCl
    d. H_2O (in the presence of dilute H_2SO_4)
    e. alkaline $KMnO_4$
3. Alkenes are more reactive than alkanes. Why do you think so?
4. Alkene reacts readily with Br_2 even in the dark, but alkanes react only in the presence of sunlight. Why? Are the reaction products the same? What about the type of reaction? Discuss!

G. Uses of Ethene (Ethylene)

At the end of this section, you should be able to explain the uses of ethylene.

Ethene is used as a starting material for the synthesis of many industrial compounds, including ethanol, ethylene oxide, ethanal, and the polymers polyethylene and polyvinylchloride, polystyrene and teflon. It is also used in the production of 1,2-ethanediol, which is used as an antifreeze material, and for the preservation as well as artificial ripening of fruits.

Project 6.3

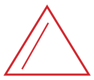
Put some green tomatoes in the first basket, and place a ripe banana in between them. In the second basket, put only green tomatoes (but not a banana). Compare the tomatoes in the two baskets. Have the tomatoes ripen at the same rate in both baskets? If not, why? Share your opinion with your classmates.

H. Cycloalkenes

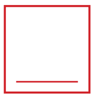
Cycloalkenes are unsaturated cyclic hydrocarbons. The carbon atoms are linked in such a manner as to form a closed chain or ring structure. They contain a double bond between carbon atoms in the ring and are represented by the general formula C_nH_{2n-2}; where n should be equal to or greater than 3.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

Unsubstituted cycloalkenes are named by adding the prefix "cyclo" to the name of the parent alkene. The simplest cycloalkene is cyclopropene.

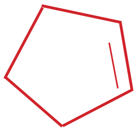
Example 6.17:



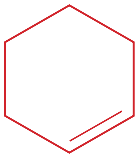
cyclopropene



cyclobutene

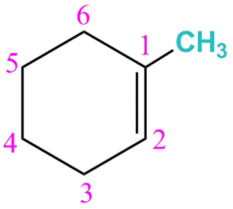


cyclopentene

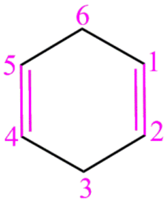


cyclohexene

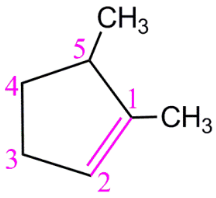
Substituted cycloalkenes are named similarly to alkenes, but because there is no chain end to begin from, we number the cycloalkene so that the double bond is between C_1 and C_2 and the first substituent has as low a number as possible. It's not necessary to indicate the position of the double bond in the name because it's always between C_1 and C_2. As with open-chain alkenes, newer but not yet widely accepted naming rules place the locant immediately before the suffix in a diene.



1-Methylcyclohexene



1,4-cyclohexadiene
(or cyclohexa-1,4-diene)



1, 5-dimethylcyclopentene

Now, take a few minutes to do the following exercise.

Self-Test Exercise 6.16

Complete each of the following equations and name the products:

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

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

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

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

Section 6.5: Unsaturated Hydrocarbons: Alkynes (C_nH_{2n-2})

Now, we are almost reaching the last section of our discussion on aliphatic hydrocarbons. As you are already familiar with most of the topics to be discussed in this section, including nomenclature, homologous series, and physical properties, it will be easier to understand this section. It should not take more time than a whole week.

At the end of this section, you should be able to

- Define alkynes.
- Write the general formula of alkynes.
- Write the molecular formula for the first nine homologous series of alkynes.
- Write the molecular formulas of alkynes from the given number of carbon atoms.
- Describe the physical properties of alkynes.

Alkynes are unsaturated hydrocarbons that contain at least one carbon–carbon triple bond as a functional group, and have a -yne ending in their names. The simplest alkyne is ethyne (also called acetylene). Alkynes occur in nature and can be synthesized in the laboratory.

The homologous series of alkynes is represented by the general formula C_nH_{2n-2}, where $n \geq 2$. The first member of the group is commonly known as acetylene. The homologous series of alkynes is also called the acetylene series.

Table 6.5 Homologous series of alkynes and their physical constants.

Formula of Alkyne	Condensed Structure	IUPAC Name	Melting Point (°C)	Boiling Point (°C)
C_2H_2	$CH\equiv CH$	Ethyne	-82	-75
C_3H_4	$CH\equiv C\text{-}CH_3$	Propyne	-105.5	-23
C_4H_6	$CH\equiv C\text{-}CH_2\text{-}CH_3$	1-butyne	-122	9
C_5H_8	$CH\equiv C\text{-}(CH_2)_2\text{-}CH_3$	1-pentyne	-98	40
C_6H_{10}	$CH\equiv C\text{-}(CH_2)_3\text{-}CH_3$	1-hexyne	-124	72
C_7H_{12}	$CH\equiv C\text{-}(CH_2)_4\text{-}CH_3$	1-heptyne	-80	100
C_8H_{14}	$CH\equiv C\text{-}(CH_2)_5\text{-}CH_3$	1-octyne	-70	126
C_9H_{16}	$CH\equiv C\text{-}(CH_2)_6\text{-}CH_3$	1-nonyne	-65	151
$C_{10}H_{18}$	$CH\equiv C\text{-}(CH_2)_7\text{-}CH_3$	1-decyne	-36	182

Self-Test Exercise 6.17

1. By looking at the trends for alkynes in ***Table 6.5***, write the molecular formula and the structures of the alkynes containing 11 and 12 carbon atoms.
2. Describe the general characteristics of the alkyne homologous series.
3. Compare the physical states, melting points and boiling points of alkynes, alkenes and alkanes as the number of carbon atoms increases. Discuss with your group and present to the class.

A. Nomenclature of Alkynes

At the end of this section, you should be able to

- Use IUPAC rules to name straight and branched chain alkynes.
- Write the structural formulas alkynes up to nine carbon atoms.
- Alkynes are commonly known as a derivative of acetylene.

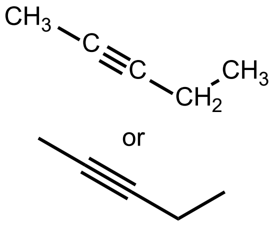
$CH\equiv CH$	$CH\equiv C-CH_3$	$CH\equiv C-CH_2CH_3$
acetylene	**methyl acetylene**	**ethyl acetylene**

Substituted alkynes are named in much the same way as alkenes using the IUPAC system. Unbranched alkynes, for example, are named by replacing the -ane of the name of the corresponding alkane with the ending -yne. The chain is numbered to give the carbon atoms of the triple bond the lowest possible number.

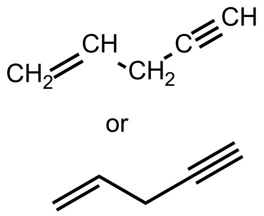
The lower number of the two carbon atoms of the triple bond is used to designate the location of the triple bond. When double and triple bonds are present, the direction of numbering is chosen so as to give the lowest overall set of locants. In the face of equivalent options, preference is given to assigning the lowest numbers to the double bonds. The IUPAC names of three unbranched alkynes are shown here:

$H-C\equiv C-H$

Ethyne or
acetylene (common name)

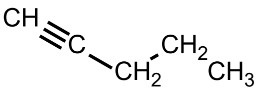


2-pentyne

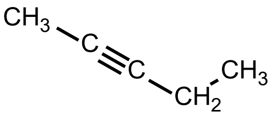


1-pentene-4-yne

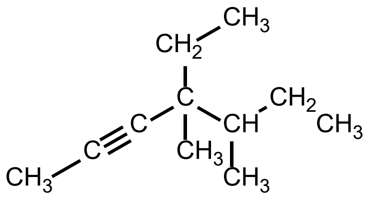
The locations of substituent groups in branched alkynes and substituted alkynes are also indicated with numbers.



1-pentyne



2-pentyne



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

Self-Test Exercise 6.18

Give the structures and IUPAC names for all the alkynes with the formula C_6H_{10}, and identify those that are to be position and chain isomers.

B. Isomerism in Alkynes

At the end of this section, students will be able to write the structural formulas of alkynes up to nine carbon atoms.

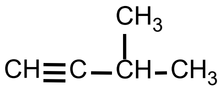
Alkynes show both chain and position isomerism, but not geometrical or cis-trans isomerism. Consider:

$CH\equiv C-CH_2\,CH_3$

1-butyne or but-1-yne

$CH_3-C\equiv C-CH_3$

2-butyne or but-2-yne



$CH\equiv C-\underset{}{\overset{CH_3}{\overset{|}{C}H}}-CH_3$

3-methyl-1-butyne or 3-methylbut-1-yne

$CH\equiv C-CH_2\,CH_2\,CH_3$

1-pentyne or pent-1-yne

1-Butyne and 2-butyne are position isomers, whereas 3-methyl-1-butyne and 1-pentyne are chain isomers.

Self-Test Exercise 6.19

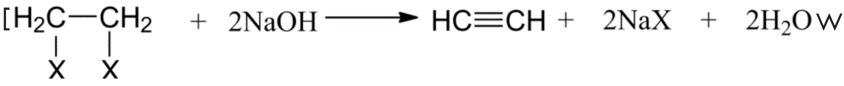
1. Write the structural formulae for pentane, 1-pentene, and 1-pentyne. Why are not these three hydrocarbons considered as isomers? Tell your idea to the class.
2. Write the structures of all isomers of 1-pentyne (C_5H_8) and
   a. name them
   b. identify chain isomers?
   c. identify position isomers?

C. Preparation of Alkynes

At the end of this section, you should be able to

- Describe the general method for preparation of alkynes in a laboratory.
- Prepare acetylene in a laboratory by the reaction of CaC_2 with water.

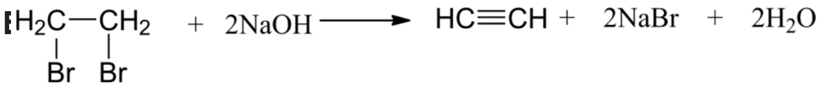
One can prepare alkynes using several methods. Some of the general methods of preparation of alkynes are the following:



$$[\underset{X}{H_2C}-\underset{X}{CH_2} + 2NaOH \longrightarrow HC\equiv CH + 2NaX + 2H_2O$$

with a base NaOH or KOH or $NaNH_2$.

Vicinal dihalide Ethyne



$$[\underset{Br}{H_2C}-\underset{Br}{CH_2} + 2NaOH \longrightarrow HC\equiv CH + 2NaBr + 2H_2O$$

1,2-dibromoethane Ethyne

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

General reaction:

Example 6.19

$$HC\equiv C^{-}Na^{+} + CH_2CH_2Br \longrightarrow HC\equiv C-CH_2CH_3$$

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

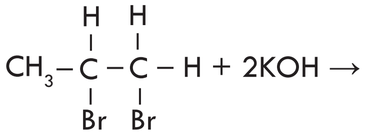
Reaction of calcium carbide with water:

$$CaC_2(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + C_2H_2(g)$$

Calcium Carbide Water Calcium hydroxide Acetylene/ ethyne

Self-Test Exercise 6.20

Write the major product of the following reactions:

a. 

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

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

D. Chemical Properties of Alkynes

At the end of this section, you should be able to explain chemical properties of alkynes. Alkynes are more unsaturated than alkanes and alkenes due to the presence of a carbon-carbon triple bond. They can undergo combustion and addition reactions.

Some of the common reactions of alkynes are these:

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

General equation:

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

Example 6.20:

$$C_3H_4(g) + 4O_2 \rightarrow 3CO_2 + 2H_2O + Heat$$

Addition reaction: Alkynes undergo an addition reaction at the carbon-carbon triple bond. Some of the addition reactions of alkynes are the following: (a) Addition of hydrogen (hydrogenation): In the presence of a nickel or palladium catalyst, alkynes produce alkanes.

General equation:

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

Example 6.21:

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

Partial hydrogenation of alkynes in the presence of Lindlar's catalyst gives alkenes. Lindlar's catalyst is powdered palladium partially deactivated with lead acetate. Lindlar's catalyst is a palladium catalyst poisoned with traces of lead and quinoline, whci reduce its activity such that it can only reduce alkynes, not alkenes. It always gives the cis-alkene.

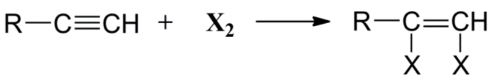
Genera

$$\underset{\text{Alkyne}}{C_nH_{2n-2}} + H_2 \xrightarrow[\text{Catalyst}]{\text{Lindlar's}} \underset{\text{Alkene}}{C_nH_{2n}}$$

Example 6.22:

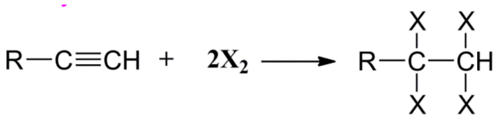
$$\underset{\text{2-butyne}}{CH_3{-}C{\equiv}C{-}CH_3} + H_2 \xrightarrow[\text{Catalyst}]{\text{Lindlar's}} \underset{\textit{cis}\text{-2-butene}}{CH_3\text{-}CH{=}CH\text{-}CH_3}$$

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



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

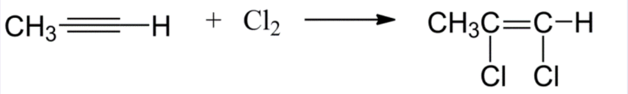
Alkyne Dihaloalkene



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

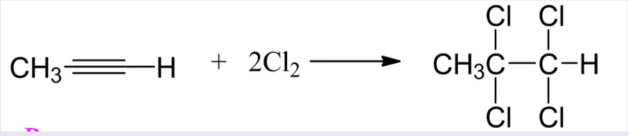
Alkyne Tetrahaloalkane

Example 6.23:



$$CH_3C\equiv C{-}H + Cl_2 \longrightarrow CH_3\underset{Cl}{\underset{|}{C}}{=}\underset{Cl}{\underset{|}{C}}{-}H$$

Propyne 1,2-dichloropropene



$$CH_3C\equiv C{-}H + 2Cl_2 \longrightarrow CH_3\overset{Cl}{\overset{|}{\underset{Cl}{\underset{|}{C}}}}{-}\overset{Cl}{\overset{|}{\underset{Cl}{\underset{|}{C}}}}{-}H$$

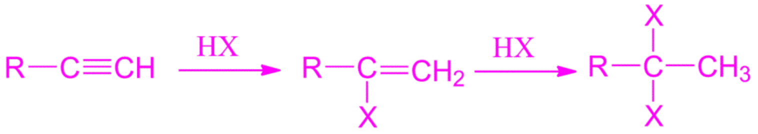
Propyne 1,1,2,2-tetrachloropropane

Self-Test Exercise 6.21

Do you expect alkynes to decolorize bromine water? If so, why? Write the balanced chemical equation for the reaction between C_2H_2 and Br_2.

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

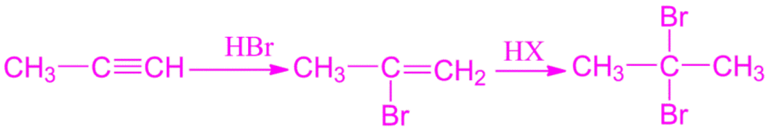
General reaction:



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

Alkyne Monohaloalkene Dihaloalkane

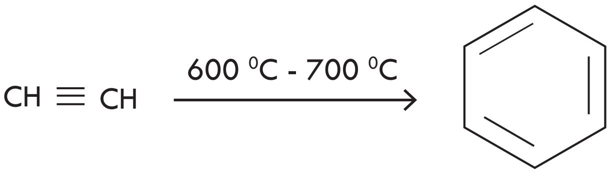
Example 6.24:



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

Propyne 2-Bromopropene 2,2-Dibromopropane

(d) Trimerization of Acetylene: Acetylene, on prolonged heating at 600 – 700 oC, yields benzene.



Acetylene benzene

E. Properties and uses of Acetylene or Ethyne

At the end of this section, you be able to

- Explain the uses of ethylene and acetylene.
- Compare and contrast the properties of ethane, ethene and ethyne.
- Test for unsaturation of ethylene and ethyne.

Acetylene is a colourless, sweet-smelling gas in pure form and is insoluble in water. It is usually stored as a solution of acetone in steel cylinders. The combustion of acetylene with oxygen produces an intensely hot flame of about 3000 °C. Thus, a large quantity of acetylene is used as a fuel in oxy-acetylene torches for cutting and welding metals.

It is a two-stage reaction where the primary chemical reaction involves the acetylene disassociating in the presence of oxygen to produce heat, carbon monoxide, and hydrogen gas: $C_2H_2 + O_2 \rightarrow 2CO + H_2$

The second reaction is the oxidation of carbon monoxide into carbon dioxide while the hydrogen formed in the above reaction forms water:

$CO + H_2 + O_2 \rightarrow CO_2 + H_2O$

Acetylene is also used to prepare acrylonitrile, which is a starting material for producing polyacrylonitrile, a raw material for textile fiber. It is also used for making vinyl chloride which polymerizes to give polyvinyl chloride (PVC) commonly used for making floor tiles, electrical insulators, shoe soles, water pipes, etc. Acetylene is used to produce 1,1,2,2-tetrachloroethane which serves as a solvent for wax, grease, rubber etc. See ***Table 6.6***.

Table 6.6 Comparison of Some Properties of Ethane, Ethene and Ethyne

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

Section 6.6: Unsaturated Hydrocarbons: Aromatic Hydrocarbons (Benzene, C_6H_6)

Dear learner, welcome to the last but not the least section of hydrocarbons. You are about to go through. You remember that we classified hydrocarbons as aliphatic and aromatic. I hope you enjoyed the discussion of aliphatic hydrocarbons. Let's take some hours to see only the most fundamental points about aromatic hydrocarbons. We will consider only the naming of some simple aromatic hydrocarbons like benzene and their properties. This section may take you 3 hours, including the time required to do the exercise activities.

At the end of this section, you should be able to

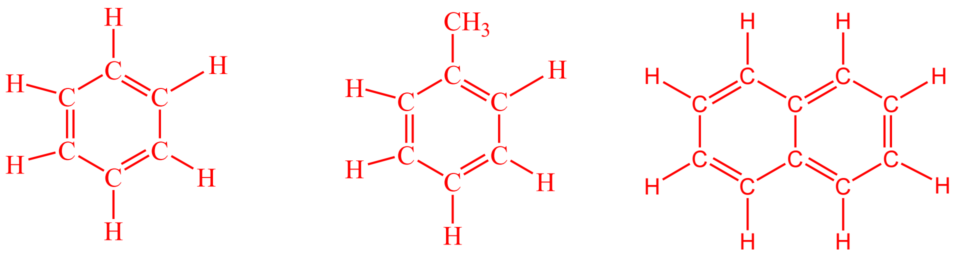
- Define aromatic hydrocarbons.
- Distinguish aromatic compounds from other hydrocarbons.
- Draw and explain the structure of benzene.
- Describe the main physical properties and chemical reactions of benzene.
- Perform simple chemical tests to identify alkanes, alkenes/alkynes, and aromatic compounds.

Dear learner, let me give you a chance to think about the following questions.

1. What comes to your mind when you hear the word 'benzene'?
2. What does the word "aroma" mean? Which substances have an aroma?
3. Are aromatic hydrocarbons saturated or unsaturated?

4. What are the main sources of aromatic compounds?

The term aromatic is derived from the word 'aroma' meaning pleasant smell, which was originally used to describe naturally occurring compounds with pleasant smells. At present, the term is used without its original significance. Aromatic hydrocarbons are generally obtained from petroleum and coal tar. They are a group of hydrocarbons characterized by the presence of a benzene ring or related structures. ***Figure 6.6*** gives some examples of aromatic hydrocarbon structures.

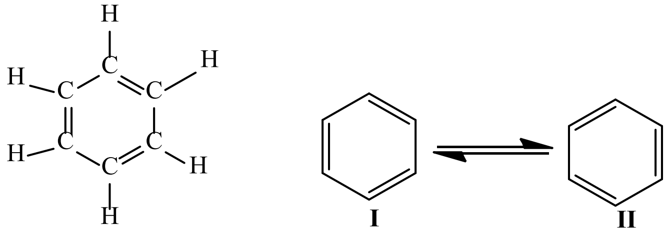


Benzene Methyl benzene (Toluene) Naphthalene

Figure 6.6 Structures of some Aromatic Hydrocarbons.

6.6.1 Benzene

Benzene is the simplest aromatic hydrocarbon. Its molecular formula is C_6H_6. August Kekulé proposed the first structure for benzene in 1872. It consisted of a six-membered ring with alternating single and double bonds and one hydrogen bonded to each carbon. He assumed that the ring contains three double bonds that shift back and forth so rapidly that the two forms (***Figure 6.7***) cannot be separated. Later on, Kekulé's assumption was found to be incorrect. Each structure has become known as the Kekulé structure.

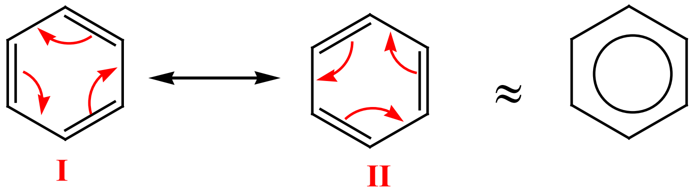


A Kekulé structure showing all atoms

A Kekulé structure as line-bond formulas

Figure 6.7 A Kekulé structure of benzene.

Today, we represent benzene as a hybrid of two equivalent Kekulé structures. Each Kekulé structure makes an equal contribution to the hybrid:



Benzene as a hybrid of two equivalent contributing structures

Resonance hybrid

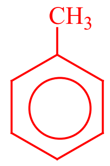
The bonds in benzene are neither single nor double, but have an intermediate character between those of single and double bonds. All the carbon-carbon bonds in the molecule are the same in length and nature. Since structures I or II given above are not the true structures of the benzene molecule, the benzene ring is written in its resonance hybrid form. However, chemists continue to use a single contributing structure to represent benzene. What do you think the reason is?

From structures I and II in ***Figure 6.7***, one may think that benzene has three double bonds and has the same chemistry as that of alkenes. But this is not true. Benzene and other aromatic hydrocarbons contain high degrees of unsaturation yet fail to undergo characteristic alkene addition and oxidation–reduction reactions. They are more stable than alkenes.

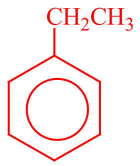
6.6.2 Nomenclature of Substituted Benzenes

i. Monosubstituted Benzenes

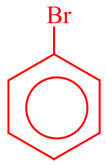
Generally, mono-substituted benzenes are named in a similar manner as hydrocarbons with -benzene as the parent name:



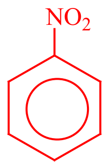
Methylbenzene (Toluene)



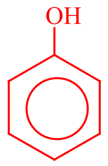
Ethylbenzene



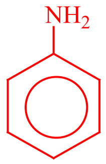
Bromobenzene



Nitrobenzene



Hydroxybenzene (Phenol)

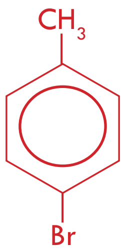


Aminobenzene (Aniline)

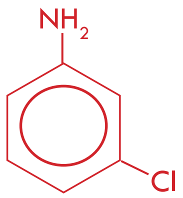
The IUPAC system retains certain common names for several of the simpler mono-substituted benzenes. Examples are toluene (rather than methylbenzene) and phenol (rather than hydroxybenzene).

ii. Disubstituted Benzenes

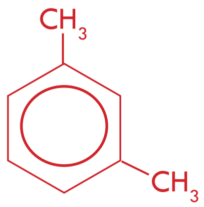
When two substituents occur on a benzene ring, three constitutional isomers are possible. We locate substituents either by numbering the atoms of the ring or by using the locators 1,2- or ortho (o), 1,3- or meta (m), and 1,4- or para (p).



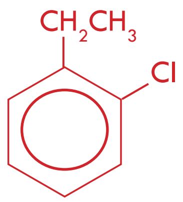
4-Bromotoluene
(p-Bromotoluene)



3-chloroaniline
(m-chloroaniline)



1,3-dimethylbenzene
(m-xylene)



1-Chloro-2-ethylbenzene
(o-Choloroethylbenzene)

6.6.3 Physical Properties of Benzene

In general, benzene resembles other hydrocarbons in its physical properties. Benzene is a flammable, colourless, and volatile liquid with a characteristic smell. It is less dense than water, non-polar and insoluble in water, but soluble in non-polar solvents like ether and carbon tetrachloride. At one time, benzene was widely used as a solvent, but exposure to it causes leukemia, a blood cancer. That is benzene is a carcinogenic (cancer-causing) substance.

6.6.4 Chemical Properties of Benzene

Benzene and other aromatic hydrocarbons are more stable than alkenes and alkynes due to the stability of the aromatic ring. It neither decolorizes bromine water (Br_2 in CCl_4) nor is reactive towards cold potassium permanganate solutions. 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.

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

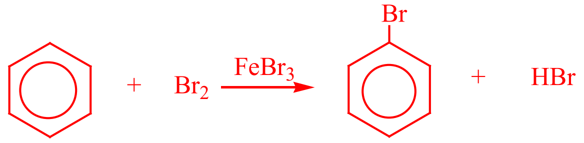
II. **Substitution reaction:** This is a characteristic reaction of benzene and other aromatic compounds. In this reaction, the hydrogen atom in the benzene ring is replaced by another atom or group. Under normal conditions, aromatic compounds do not undergo addition reactions.

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

$$C_6H_6 + Br_2 \xrightarrow{FeBr_3} C_6H_5Br + HBr$$

or

Example 6.25:

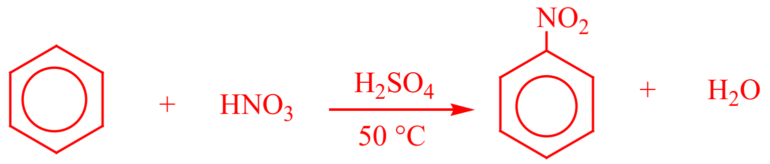


Benzene Bromobenzene

(b). Nitration: A mixture of concentrated nitric acid and concentrated sulphuric acid reacts with benzene at moderate temperatures to form nitrobenzene.

$$C_6H_6 + HNO_3 \xrightarrow[50\ °C]{H_2SO_4} C_6H_5NO_2 + H_2O$$

or



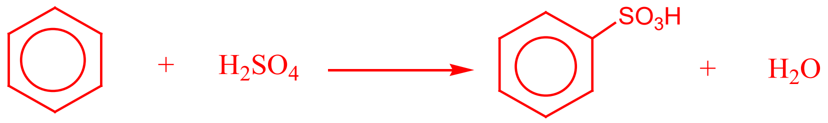
Benzene Nitrobenzene

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

$$C_6H_6 + H_2SO_4 \longrightarrow C_6H_5SO_2OH + H_2O$$

or

.

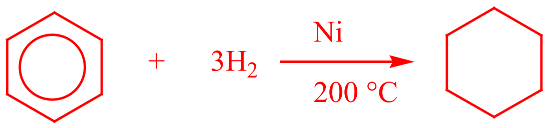


Benzene Benzenesulphonic acid

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

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

or



Benzene **Cyclohexane**

Self-Test Exercise 6.22

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

Section 6.7: Natural Sources of Hydrocarbons

I hope you are eager to know about the natural sources of hydrocarbons we mentioned in the previous sections. How are the various useful hydrocarbons including the ones supplied in fuel stations as gasoline and diesel (naphtha) oil are obtained from crude oil? This section will help you understand how.

At the end of this section, you should be able to

- List the major natural sources of hydrocarbons.
- Describe natural gas.
- Define crude oil.
- Explain fractional distillation of crude oil.
- Mention the products of fractional distillation of crude oil.
- Discuss the uses of petroleum products.

Let's begin this subsection with some guiding questions.

What do you think is the composition of the fuels people use for vehicles and motorbikes? What about bottled gas for cooking? Does Ethiopia have an oil (crude oil) deposit? What are the natural resources Ethiopia is gifted with? Discuss whether they are renewable or nonrenewable and their environmental impact. If you were the leader of the country, would you invest more in fossil fuel extraction or in the development of renewable energy sources such as hydroelectric dams?

Well, if you have read these questions you will soon realize that crude oil is a natural source of alkanes. I hope you understand that such oils end after usage and they are not renewable. That is why it is recommended to exploit renewable sources of energy such as hydroelectric dams and wind. In subsequent sections you learn about how alkanes and other hydrocarbons are obtained from crude oil and the composition of the various components derived from the oil.

By far, the major sources of alkanes are the world's natural gas and petroleum deposits followed by coal. Laid down eons ago, these deposits are thought to be derived primarily from the decomposition of tiny single-celled marine organisms called foraminifera.

A. Natural Gas

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

B. Petroleum (crude oil)

The word petroleum is derived from two Latin words, 'petra' meaning rock, and 'oleum' meaning oil. Thus, petroleum means rock oil. Petroleum (also called crude oil) is a complex mixture of fossil hydrocarbons that must be separated into fractions and then further refined before it can be used. It is generally found along with natural gas in the form of a dark-coloured viscous liquid, which is a complex mixture of hydrocarbons. Its composition varies according to its place of origin. However, crude oil mainly contains alkanes, cycloalkanes and aromatic hydrocarbons. It also contains organic compounds consisting of nitrogen, sulphur and oxygen in small amounts.

Refining of Crude Oil

Petroleum refining begins with the fractional distillation of crude oil into three principal cuts according to boiling point (bp): straight-run gasoline (bp 30–200 °C), kerosene (bp 175–300 °C), and heating oil, or diesel fuel (bp 275 – 400 °C). Further distillation under reduced pressure then yields lubricating oils and waxes and leaves a tarry residue of asphalt. The distillation of crude oil is only the first step in gasoline production, however. ***Figure 6.2*** shows the fractional distillation setup for separating crude oil into its component fractions.

The major products (fractions) obtained from the fractional distillation of petroleum and their uses are given in ***Table 6.7***.

Table 6.7 Typical fractions obtained by fractional distillation of petroleum

Fractions	Number of carbon atoms per molecule	Boiling point range (°C) of fractions	Uses
Natural Gases	$C_1 \rightarrow C_4$	Below 20	As fuel in the form of bottled gas.
Petroleum ether	$C_5 \rightarrow C_7$	20 → 60	As solvent in dry cleaning

Gasoline (Petrol)	$C_5 \rightarrow C_{10}$	40 → 200	Petrol fuel for internal combustion engines
Kerosene	$C_{12} \rightarrow C_{18}$	175 → 275	Jet engine fuel, household fuel
Fuel oil (diesel oil)	$C_{15} \rightarrow C_{18}$	250 → 400	Furnace fuel, diesel engine fuel
Lubricating oil Petroleum jelly	$>C_{19}$	Non-volatile liquids	- Lubrication, grease
Paraffin wax Residue	$>C_{20}$	Non-volatile solids	- Candles, polishes - bitumen for roof sealing and road surfaces

Note that the later fractions obtained at higher temperatures are more coloured, more viscous, and less inflammable.

Straight-run gasoline turns out to be a poor fuel in automobiles because of engine knock, uncontrolled combustion that can occur in a hot engine.

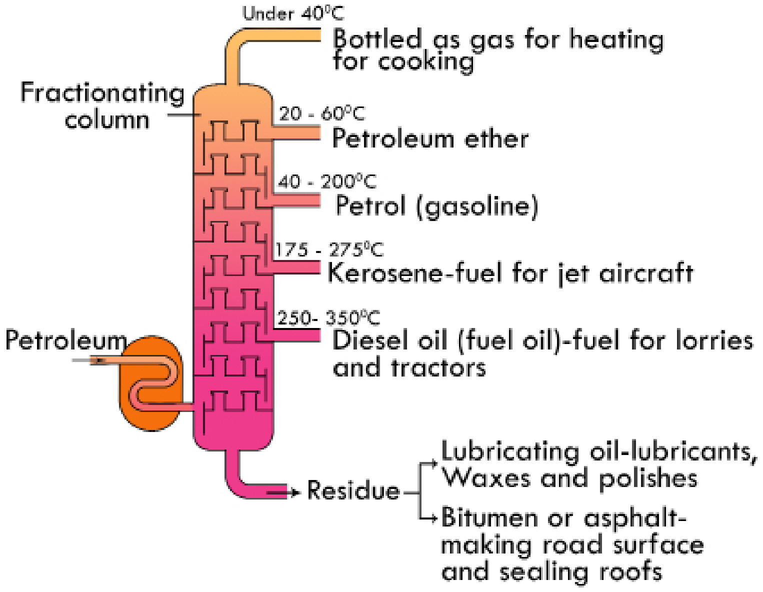
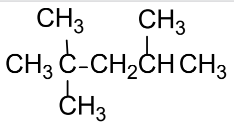


Figure 6.2 Fractional Distillation of Petroleum.

The octane number of a fuel is the measure by which its anti-knock properties are judged. Straight-chain hydrocarbons are far more likely to induce engine knock than highly branched compounds. The highly branched compound 2,2,4-trimethylpentane (called isooctane in the petroleum industry) burns very smoothly (without knocking) in internal combustion engines and is used as one of the standards by which the octane rating of gasoline is established. According to this scale, 2,2,4-trimethylpentane has an octane rating of 100. Heptane, $CH_3(CH_2)_5CH_3$, a compound that produces much knocking when it is burned in an internal combustion engine, is given an octane rating of 0. Mixtures of 2,2,4-trimethylpentane and heptane are used as standards for octane ratings between 0 and 100. A gasoline, for example, that has the same characteristics in an engine as a mixture of 87% 2,2,4-trimethylpentane and 13% heptane would be rated as 87-octane gasoline.

$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$

Heptane
(octane number = 0)



$CH_3C(CH_3)_2CH_2CH(CH_3)CH_3$

2,2,4-trimethylpentane
(octane number = 100)

Because straight-run gasoline burns so poorly in engines, petroleum chemists have devised numerous methods for producing higher-quality fuels. One of these methods, catalytic cracking, involves taking the high-boiling kerosene cut (C_{11}– C_{14}) and 'cracking' it into smaller branched molecules suitable for use in gasoline. What does cracking mean? Cracking is the decomposition of large hydrocarbon molecules into smaller ones by the application of heat (thermal cracking or pyrolysis)

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

or in the presence of catalysts (catalytic cracking). Hydrogen gas can be added during cracking to saturate the alkenes formed in the process.

Another process, called reforming, is used to convert C_6 – C_8 alkanes to aromatic compounds such as benzene and toluene, which have substantially higher octane numbers than alkanes. The final product that goes into the tank has an approximate composition of 15% C_4 – C_8 straight-chain alkanes, 25% to 40% C_4 – C_{10} branched-chain alkanes, 10% cyclic alkanes, 10% straight-chain and cyclic alkenes, and 25% arenes (aromatics).

C. Coal

At the end of this section, you should be able to
- Identify the composition of coal.
- Describe destructive distillation of coal.

Coal

The natural decomposition of plant matter over several millions of years produces what is called **coal.** Coal is not a pure form of carbon. It is an important source of aromatic hydrocarbons. Heating mineral coal in the absence of air, or oxygen is called destructive distillation of coal or coking of coal. When coal is heated in the absence of air, it produces volatile products and coke. The volatile products that are separated into coal gas and a liquid when cooled are called coal tar. Aromatic hydrocarbons and many other substances are isolated from coal tar by fractional distillation. Coke, which is a solid and relatively pure form of carbon, is used as a fuel in the blast furnace during the extraction of iron. It is also used to produce gaseous fuels, such as water gas (a mixture of H_2 and CO) and producer gas (a mixture of N_2 and CO).

Self-Test Exercise 6.23

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

Unit Summary

The 'vitalism' theory states that living organisms (plants and animals) have a special life force that helps them synthesize organic compounds and that organic compounds cannot be synthesized artificially by man in the laboratory.

Organic chemistry is the study of carbon compounds including natural and synthetic ones.

Organic compounds are classified based on the functional group they contain in their molecules.

"The functional group is part of a molecule that determines the chemical and physical properties of a compound.

"Hydrocarbons are compounds composed of carbon and hydrogen atoms only.

"Saturated hydrocarbons contain only single bonds between carbon atoms

"Unsaturated hydrocarbons are those containing one or more double or triple bonds between carbon atoms.

"A homologous series is a group of compounds in which each member of the group differs from the next member by $–CH_2–$ group.

''The general formula C_nH_{2n+2} representes alkanes.'' They are saturated hydrocarbons. Alkanes are named by using prefixes that indicate the number of carbon atoms and the suffix '-ane'.

"Isomerism is the existence of two or more compounds with the same molecular formula but different structures. These compounds are called **isomers**.

"Alkenes are unsaturated hydrocarbons containing a carbon-carbon double bond as their functional group. Their general formula is C_nH_{2n}. The suffix '-ene' in their names indicates the presence of a carbon-carbon double bond.

"Alkynes are unsaturated hydrocarbons containing a carbon-carbon triple bond as their functional group. They are represented by the general formula C_nH_{2n-2}.

The suffix '-yne' indicates the carbon-carbon triple bond.

"Alkenes and alkynes undergo mainly addition reactions while alkanes undergo substitution reactions.

"Aromatic hydrocarbons are compounds containing benzene rings. Benzene is the simplest aromatic hydrocarbon.

The natural sources of hydrocarbons are crude oil, natural gas and coal.

Crude oil is a complex mixture of hydrocarbons, mainly alkanes, and also contains cycloalkanes and aromatics.

Crude oil is separated into several useful fractions by fractional distillation.

Organic chemicals are also used as fuels and solvents for dry cleaning.

Checklist 6.1

Please put a tick (✓) if your answer is 'yes'. If not, go back and revise it or refer to relevant reference books to remove your doubts.

I can …

SN	Competencies	Check
1	discuss the historical development of organic chemistry?	
2	classify organic compounds and a tree diagram of it?	
3	classify hydrocarbons as saturated and unsaturated?	
4	classify hydrocarbons as aliphatic and aromatic?	
5	write the general formula of alkanes, alkenes and alkynes?	
6	name simple alkanes, branched-chain alkanes, simple alkenes, branched-chain alkenes and simple alkynes?	
7	write the molecular and structural formula of simple alkanes, branched chain alkanes, simple alkenes, branched chain alkenes and simple alkynes?	
8	explain isomerism?	
9	draw the possible isomers of alkanes, alkenes, and alkynes having C_4 to C_6 carbon atoms?	
10	explain the physical and chemical properties; and the general methods of the preparation of alkanes; alkenes, alkynes, and benzene?	
11	list the major natural sources of hydrocarbons?	

Self-Assessment Exercises

Part I: Multiple Choice Questions

1. The first organic compound that is artificially synthesized from inorganic starting materials is_____________.
   a. benzene
   b. methane
   c. urea
   d. hydrocarbons
2. Which of the following hydrocarbons does not belong to the homologous series of alkanes?
   a. C_3H_8
   b. C_8H_{18}
   c. C_6H_{10}
   d. $C_{10}H_{22}$
3. Which of the following alkanes is a liquid at room temperature?

a. CH_4 c. C_4H_{10}

b. $C_{10}H_{22}$ d. C_3H_8

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

a. C_2H_2 c. C_4H_{10}

b. C_2H_4 d. CH_4

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

a. C_nH_{2n+1} c. C_nH_{2n-2}

b. C_nH_{2n+2} d. C_nH_{2n}

6. The most common reaction that alkenes undergo is:

a. elimination c. addition

b. substitution d. decomposition

7. A compound having the molecular formula C_7H_8 that does not decolorize Br_2 in CCl_4 or $KMnO_4$ solution most likely belongs to a class of hydrocarbons called _______

a. Alkynes c. Alkenes

b. Alkanes d. Aromatic hydrocarbons

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

a. C_4H_{10} c. C_2H_6

b. CH_4 d. C_6H_{14}

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

a. separate the crude oil into different fractions.

b. vaporize the liquid components.

c. maximize the output of petrol or gasoline.

d. separate alkanes from alkenes.

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

a. 1,1-dibromoethane

b. 1,1,2,2-dibromoethene

c. 1,2-dibromoethane

d. 1,1,2,2-tetrabromoethane

11. The following reaction can be classified as: $CH_4 + Br_2 \rightarrow CH_3Br + HBr$

a. an addition reaction

b. an elimination reaction

c. a substitution reaction

d. a saponification reaction

12. Which one of the following substances is not used in dry cleaning?

a. CCl_4 c. $Cl_2C{=}CCl_2$

b. C_6H_6 d. CH_3COOH

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

a. Friedrich Wohler c. John Dalton

b. Kekule d. Wurtz

14. Which reagent is used to test for unsaturation of hydrocarbons?

a. Wurtz reagent c. Alkaline $KMnO_4$

b. Bromine in CCl_4 d. B & C

15. Which alkene doesn't exhibit cis-trans isomerism?

a. 2-butene c. 2,3-dimethylbut-2-ene

b. 2-pentene d. All

16. Which one of the following compounds does not decolorize bromine water?

a. C_3H_4 b. C_2H_2 c. C_6H_{14} d. All

Part II: Supply-Type Questions

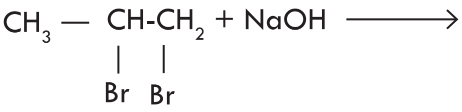
17. Complete the following reaction equations:

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

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

c. $CH_3-CH_2Br + 2Na \longrightarrow$

d.



$CH_3-\underset{Br}{\underset{|}{C}}H-\underset{Br}{\underset{|}{C}}H_2 + NaOH \longrightarrow$

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

f. $CH_3CH_2CH_2Cl + KOH \xrightarrow{Heat}$

g. $CH\equiv CNa + CH_3CH_2Br \longrightarrow$

h. $CH_3\text{-}CH=CH_2 + HBr \longrightarrow$

i. $HC\equiv C\text{-}CH_2-CH_3 + 2HCl \longrightarrow$

j. $CH_3CH_2\text{-}CH=CH_2 + H_2O \xrightarrow{H^+}$

k. $CH_3CH_2\text{-}CH=CH_2 + H_2O \xrightarrow[KMnO_4]{Alkaline}$

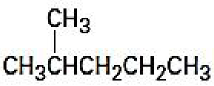
Part III. Workout-Type Questions

18. Draw structures for the following:
    - a. 2-Methylhexane
    - b. 4-Ethyl-2,2-dimethylheptane
    - c. 4-Ethyl-3,3-dimethyloctane
    - d. 2,3,3-Trimethylheptane

19. Name the five isomers of C_6H_{14}.

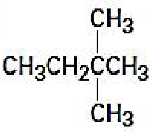
20. Give IUPAC names for the following compounds:

(a)



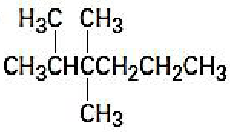
$CH_3\overset{CH_3}{\overset{|}{C}}HCH_2CH_2CH_3$

(b)



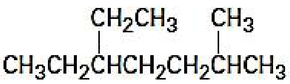
$CH_3CH_2\overset{CH_3}{\overset{|}{\underset{CH_3}{\underset{|}{C}}}}CH_3$

(c)



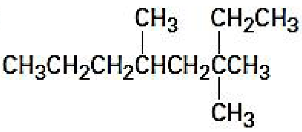
$CH_3\overset{H_3C}{\overset{|}{C}}H\overset{CH_3}{\overset{|}{\underset{CH_3}{\underset{|}{C}}}}CH_2CH_2CH_3$

(d)



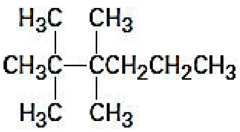
$CH_3CH_2\overset{CH_2CH_3}{\overset{|}{C}}HCH_2CH_2\overset{CH_3}{\overset{|}{C}}HCH_3$

(e)



$CH_3CH_2CH_2\overset{CH_3}{\overset{|}{C}}HCH_2\overset{CH_2CH_3}{\overset{|}{\underset{CH_3}{\underset{|}{C}}}}CH_3$

(f)



$CH_3\overset{H_3C}{\overset{|}{\underset{H_3C}{\underset{|}{C}}}}-\overset{CH_3}{\overset{|}{\underset{CH_3}{\underset{|}{C}}}}CH_2CH_2CH_3$

Assignment for Submission

Part I. Multiple Choice Questions

Direction: Choose The Best Answer and write the letter of Your Choice on a Separate Answer Sheet to be submitted to Your Tutor

1. The first organic compound that is artificially synthesized from inorganic starting materials is_____________.

a. benzene c. urea

b. methane d. hydrocarbons

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

a. C_3H_8 b. C_8H_{18}

c. C_6H_{10} d. $C_{10}H_{22}$

3. Which of the following alkanes is a liquid at room temperature?
   a. CH_4 c. C_4H_{10}
   b. $C_{10}H_{22}$ d. C_3H_8
4. The hydrocarbon used as a fuel in an oxyacetylene torch is:
   a. C_2H_2 c. C_4H_{10}
   b. C_2H_4 d. CH_4
5. The most common reaction of alkenes is:
   a. elimination c. addition
   b. substitution d. decomposition
6. A compound having the molecular formula C_7H_8 that does not decolorize Br_2 in CCl_4 or alkaline $KMnO_4$ solution most likely belongs to a class of hydrocarbons called _______
   a. Alkynes c. Alkenes
   b. Alkanes d. Aromatic hydrocarbons
7. Which hydrocarbon is the main constituent of natural gas and biogas?
   a. C_4H_{10} c. C_2H_6
   b. CH_4 d. C_6H_{14}
8. 8. During the fractional distillation of crude oil, the process of cracking is carried out to:
   a. separate the crude oil into different fractions.
   b. vaporize the liquid components.
   c. maximize the output of petrol or gasoline.
   d. separate alkanes from alkenes.
9. Ethyne decolorizes Br_2 in CCl_4. This is due to the formation of:
   a. 1,1-dibromoethane c. 1,2-dibromoethane
   b. 1,1,2,2-dibromoethene d. 1,1,2,2-tetrabromoethane
10. The most common reaction of aromatic hydrocarbons like benzene is?
    a. substitution reaction c. oxidation reaction
    b. addition reaction d. decomposition reaction
11. Which alkene doesn't exhibit cis-trans isomerism?
    a. 2-butene c. 2,3-dimethylbut-2-ene
    b. 2-pentene d. All
12. Which one of the following compounds does not decolorize bromine water?
    a. C_3H_4 c. C_6H_{14}
    b. C_2H_2 d. All
13. Graphite and diamond are
    a. isomers of C c. isotones of C
    b. isotopes of C d. allotropes of C
14. Which statement is true about cathode and anode?
    a. anode is a positive electrode and cathode is a negative electrode in galvanic cells
    b. oxidation takes place at anode and reduction takes place at cathode

c. electrons enter solution at anode in electrolytic cells

d. anode is a negative electrode and cathode is a positive electrode in electrolytic cells

15. How many isomers does an alkane containing seven carbon atoms exhibit?

a. 6	c. 8
b. 7	d. 9

16. Which of the following statements is not true about structural isomers?

a. they have the same molecular formula

b. they have different chemical properties

c. they have different physical properties

d. they have different C-C connectivity and structure

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

a. separate the crude oil into different fractions.

b. vaporize the liquid components.

c. maximize the output of petrol or gasoline.

d. separate alkanes from alkenes.

18. Which alkene doesn't exhibit cis-trans isomerism?

a. 2-butene	c. 2,3-dimethylbut-2-ene
b. 2-pentene	d. All

19. Which of the following is not true about a functional group?

a. it determines chemical properties of the molecule it is part of

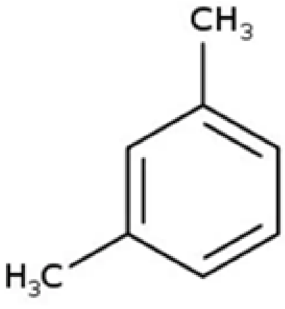
b. it is a common structural feature of a given homologous series

c. a given functional group may react differently towards common reagents depending on the complexity of the molecule it is part of

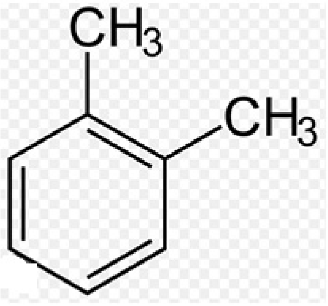
d. it serves as a basis for classification of organic compounds

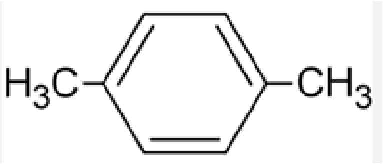
20. p-Xylene has the formula:

a.



b.



c. 

d. None

Part II: Supply- Type Questions

21. Draw structures for the following:
    a. 2-Methylhexane
    b. 4-Ethyl-2,2-dimethylheptane
    c. 4-Ethyl-3,3-dimethyloctane
    d. 2,3,3-Trimethylheptane
22. Name all the five isomers of C_6H_{14}.

Answer Key to Activities and Self-Test Exercises

Answer Key to Activity 6.1

i. Each member differ from the one proceeding it by a -CH_2- unit. As the number of C increases by 1 unit, the number of H atoms increase by 2 units.

ii. Both the family name alkane and the specific members have common prefix-ane.

iii. The general formula for an alkane having "n" carbon atoms is $CnH_{2n+2.}$

iv. Undecane has 11 carbon atoms. So n = 11. Therefore its formula is calculated as $C_{11}H_{(2x11)+2} = C_{11}H_{24}$. Please do the same for the rest.

v. See Table 6.1

vi. In unit 2, you learned the term saturated with reference to a 'saturated solution' a solution that contains maximum amount of solute that it can dissolve. Similarly, a saturated hydrocarbon contains maximum number of H atoms that it can contain for a given number of C atoms.

Answer Key to Activity 6.2

Refer to the note under section 6.3.2.

Self-Test Exercise 6.1

1. Properties and use of organic compounds depends on their structure not the source. So, both are important.
2. The theory of vitalism was proven wrong by Wohler's synthesis of an organic compound urea starting with an inorganic compound ammonium cyanate.
3. Organic compounds are compounds of carbon except the oxides of carbon, carbonates, hydrogen carbonates, cyanides and cyanates.
4. The oxides of carbon, carbonates, hydrogen carbonates, cyanides and cyanates
5. Its property of catenation-the ability to form strong covalent bonds to each other and other elements to give chains and rings of various sizes. This property of carbon gave rise to many millions of organic compounds and to the birth of organic chemistry as a separate branch of chemistry.
6. The unique property of carbon called catenation gave rise to many millions of organic compounds and to the birth of organic chemistry as a separate branch of chemistry.

Self-Test Exercise 6.2

1. Because it is almost impossible to deal with over 50 million of compounds individually with random reactivity, and it is better to have a few families of organic compounds whose chemistry is reasonably predictable. The basis of classification is functional group.
2. See section 6.2.
3. See Table 6.1.

Self-Test Exercise 6.3

1. Hydrocarbons are organic compounds that contain only C and H.
2. Hydrocarbons may be classified as aliphatic and aromatic or saturated and unsaturated; see Figure 6.1 for further details.
3. Read section 6.3.

Self-Test Exercise 6.4

1. A homologous series is a series of compounds where each member differs from the next member by a constant unit.
2. See subsection 6.3.1
3. a) C15H32 b) C18H38 c) C26H54
4. Determine if each statement about the alkane homologous series is true or false.

a. It has a general formula and a name. True

b. Consecutive members differ by a constant (-CH2-) unit. True

c. All members contain the same functional group. True

d. Consecutive members differ by a constant molecular mass of 14. True

Self-Test Exercise 6.5

1. Alkanes show regular increases in boiling point as their molecular weight increases. This is because the force holding molecules of alkanes together in liquid state increases as molecular weight increases. Therefore more energy is required to overcome such forces and free molecules to fly apart as molecular weight increases. Higher temperature provides higher thermal energy that can break the forces.
2. As branching increases, the surface area of the molecules decreases which results in a small area of contact with neighboring molecules. As a result, the Van der Waals force also decreases which can be overcome at a relatively lower temperature.
3. Alkanes are insoluble in water because alkanes are nonpolar and dissolve only in nonpolar solvent, not polar solvent-water.

Self-Test Exercise 6.6

1.

a. 2-methylpentane

b. 2,2-dimethylbutane

c. 2,3,3-trimethylhexane

d. 5-ethyl-2-methylheptane

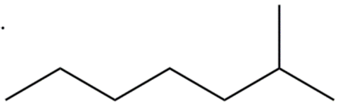
e. 3,3,5-trimethyloctane

f. 2,2,3,3-tetramethylhexane

2. D

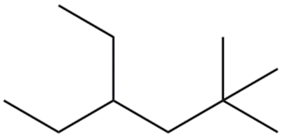
3.

a.



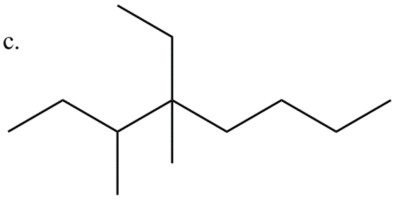
2-Methylheptane

b.



4-Ethyl-2,2-dimethylhexane

c.

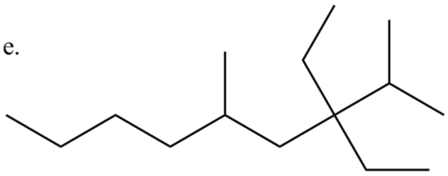


4-Ethyl-3,4-dimethyloctane

d.

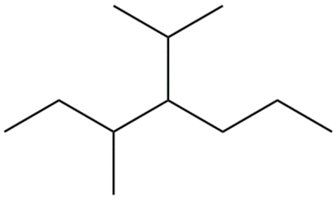
2,4,4-Trimethylheptane

e.



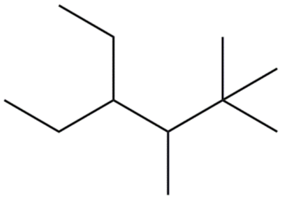
3,3-Diethyl-2,5-dimethylnonane

f.



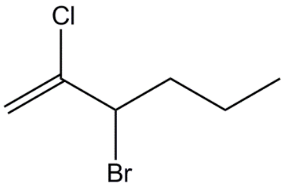
4-Isopropyl-3-methylheptane

g



4-ethyl-2,2,3-trimethylhexane

h.



3-bromo-2-chlorohex-1-ene

4.

(a) The multiplying prefix ‘di’ should have been ignored in alphabetical order. The correct name should be 6-Ethyl-2,2-dimethylheptane

(b) The direction of numbering is wrong. The structure can be named as 3-ethyl-2,2-dimethylhexane

(c) In this case too, the direction of numbering is wrong. It should be named as 4-ethyl-3,3-dimethylhexane

(d) The direction of numbering was wrong. It can be corrected as 3,4,4-trimethyloctane

(e) Alphabetical problem: In deciding on alphabetical order, the prefixes such as iso, sec, and tert should be ignored. Thus, the correct name is 4-methyl-2-isopropylheptane.

Self-Test Exercise 6.7

1. The compound C_4H_{10} has two isomers, namely n-butane and isobutane. The branched alkane isobutane has a lower boiling point than n-butane. Therefore, compound A is n-butane whereas compound B is isobutane.
2. False. Refer to Q1 of this exercise for reasoning.
3. 5
4.

a) These two structures have the same molecular formula but different structures. They are isomers. Their IUPAC names n-butane and 2-methylpropane.

b) These two structures have the same molecular formula but different structures; i.e. the ways the C atoms are connected are different. Their IUPAC names are n-pentane and 2,2-dimethylpropane. So, they are isomers.

c) These two structures have same IUPAC name. They are just different representations of the same compound 2-methylpentane. The first is the bond-line formula and the second is complete structural formula of the compound 2-methylpentane.

d) The IUPAC names for both of these structures are the same. So, one is just 180° rotated version of the other. So, the structures represent the same compound 2, 3-dimethylheptane.

Self-Test Exercise 6.8

1. (a) Propane (b) Ethane (c) Propane
2. Wűrtz

Self-Test Exercise 6.9

1. Because of their little tendency to react
2. $2C_6H_{14} + 19O_2 \rightarrow 12CO_2 + 14H_2O$
3. .

a. methyl bromide, dibromomethane, tribromomethane, carbontetrabromide.

b. Ethene

4. Because they are saturated

Self-Test Exercise 6.10

1. See your module
2. Write the balanced chemical equation for the combustion of octane

$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$

3. 9

Self-Test Exercise 6.11

1. See your module.
2. Same as that of alkanes.
3. C_nH_{2n}. It differs from alkanes (C_nH_{2n+2}) by 2 hydrogen atoms
4. Mp, bp, and density increase as the number of carbon atoms increases. Because the only intermolecular force in alkenes, like alkanes, is the induced dipole (London force) which increases as molecular weight increases.
5. C_2H_4, C_3H_6, C_4H_8, C_5H_{10}, C_6H_{12}, C_7H_{14}, C_8H_{16}, C_9H_{18}, $C_{10}H_{20}$

Self-Test Exercise 6.12

a. 3-heptene

b. 4-ethyl-2-methylhexene

c. 2,5-dimethyl-2-octene

d. 3,5-dimethylcyclohexene

Self-Test Exercise 6.13

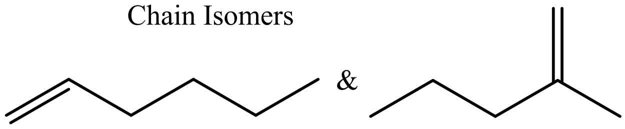
1. Explain the type of isomerism (chain or position) in:

(a)

2-pentene 2-methyl-2-butene

Chain Isomers

(b)



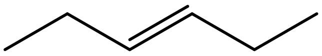
1-hexene 2-methyl-1-pentene

Chain Isomers

2. Because the intermolecular forces (London Forces in this case) increases as molecular weight increases
3. Write three position isomers of hexene.

1-hexene

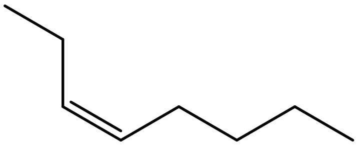
2-hexene



3-hexene

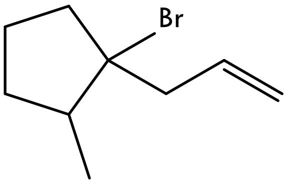
4. Write structural formulas for the following:

(a)



cis-3-octene

(b)

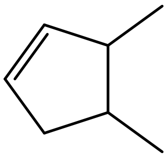


1-Bromo-2-methyl-1-(prop-2-en-1-yl) cyclopentane

(c)

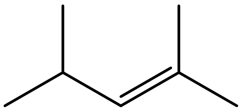
trans-2-Hexene

(d)



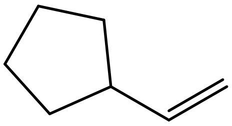
3,4-Dimethylcyclopentene

(e)



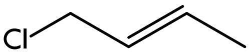
2,4-Dimethyl-2-pentene

(f)



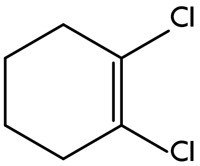
Vinylcyclopentane

(g)



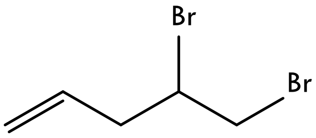
trans-1-Chlorobut-2-ene

(h)



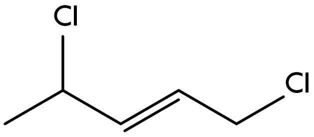
1,2-Dichlorocyclohexene

(i)



4,5-Dibromo-1-pentene

(j)



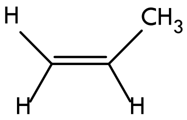
trans-1,4-Dichloro-2-pentene

Self-Test Exercise 6.14

1. See your module

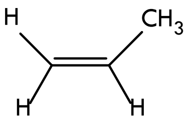
2.

(a)



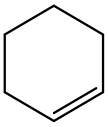
propene

(b)



propene

(c)



cyclohexene

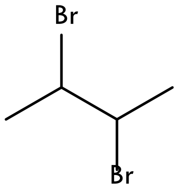
Self-Test Exercise 6.15

1.

$C_6H_{12} + 9O_2 \rightarrow 6CO_2 + 6H_2O$

2.

(a)

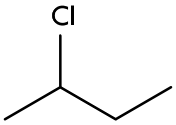


2,3-dibromobutane

(b)

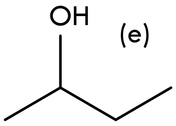
butane

(c)



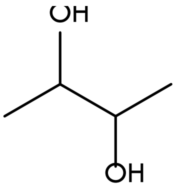
2-chlorobutane

(d)



butan-2-ol

(e)

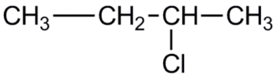


but-2,3-diol

3. Because alkene are unsaturated and alkanes are saturated.
4. Reaction products are different. Types of reaction are also different-substitution in alkanes and addition in alkenes.

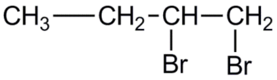
Self-test Exercise 6.16

a)



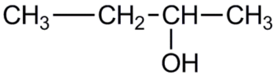
$CH_3—CH_2-\underset{Cl}{\underset{|}{CH}}—CH_3$ 2-Chlorobutane

b)



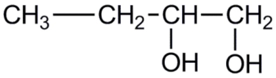
$CH_3—CH_2-\underset{Br}{\underset{|}{CH}}—\underset{Br}{\underset{|}{CH_2}}$ 1,2-Dibromobutane

c)



$CH_3—CH_2-\underset{OH}{\underset{|}{CH}}—CH_3$ 2-Butanol

d)



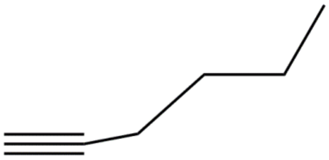
$CH_3—CH_2-\underset{OH}{\underset{|}{CH}}—\underset{OH}{\underset{|}{CH_2}}$ Butane-1,2-diol

Self-test Exercise 6.17

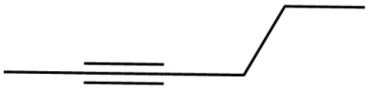
1. Refer to student textbook
2. Same as that of alkanes and alkenes
3.

State	Alkane	Alkene	Alkyne
Gas	C_1-C_4	C_2-C_4	C_2-C_4
Liquid	C_5-C_{17}	C_5-C_{14}	C_5-C_{12}
solid	$\geq C_{18}$	$\geq C_{15}$	$\geq C_{13}$

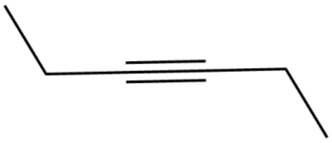
Self-test Exercise 6.18



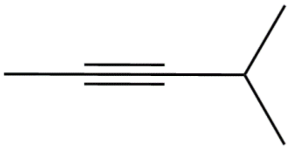
1-hexyne



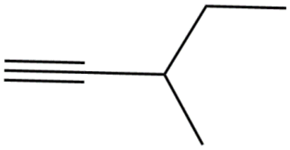
2-hexyne



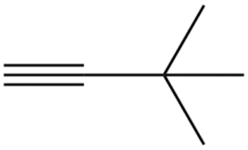
3-hexyne



4-methyl-2-pentyne



3-methyl-1-pentyne



3,3-dimethyl-1-butyne

Seven isomers are possible for hexyne

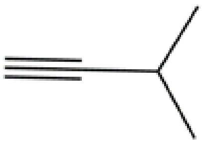
Self-Test Exercise 6.19

1. See your module for the structures. They don't have the same formula.

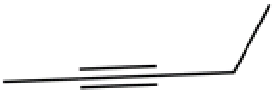
2.

a)

1-pentyne



3-methyl-1-butyne



2-pentyne

b) 3-methylbut-1-yne and 1-pentyne are chain isomers

c) 1-pentyne and 2-pentyne are position isomers

Self-Test Exercise 6.20

a) $CH_3-C\equiv C-H \ + 2KBr \ + \ 2H_2O$

b) $H-C\equiv C-CH_3 \ + NaBr$

Self-Test Exercise 6.21

Yes. Because they are unsaturated hydrocarbons and undergo addition reaction. 1,1,2,2-tetrabromoethane is a product. Read your module to write the balanced chemical equation.

Self-Test Exercise 6.22

1. A compound of carbon and hydrogen -containing a benzene ring
2. Benzene
3. Combustion, substitution
4. It neither adds bromine atoms nor is oxidized by $KMnO_4$ solution. It is stable.
5. By the reaction of
   a. Benzene with chlorine
   b. Benzene with concentrated HNO_3
   c. Benzene with concentrated H_2SO_4

Self-Test Exercise 6.23

1. As a source of energy
2. Petroleum, natural gas and coal
3. Alkanes
4. See your module
5. Destructive distillation of coal gives coke, coal gas, ammonical liquid and coal tar. Fractional distillation of coal tar yields different aromatic hydrocarbons and related compounds.
6. Gasoline or petrol
7. Cracking
8. a) as a solvent.
   b) As a fuel in jet engines and kerosene stoves.
   c) Motor fuel.
   d) Diesel engine fuel, furnace fuel.
   e) As fuel for stoves.

Answers to Review Questions

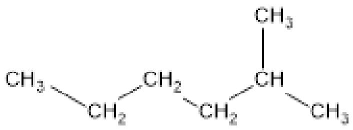
Part I

1. C
2. C
3. B
4. A
5. D
6. C
7. D
8. B
9. C
10. D
11. C
12. D
13. A
14. D
15. C
16. C

17. Refer to your module

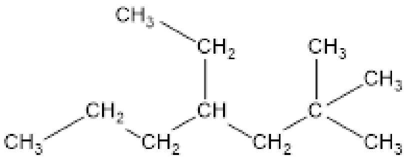
18.

(a)



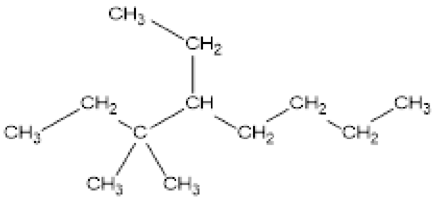
2-Methylhexane

(b)



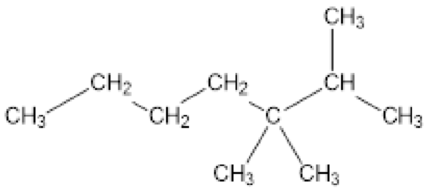
4-Ethyl-2,2-dimethylheptane

(c)



4-Ethyl-3,3-dimethyloctane

(d)

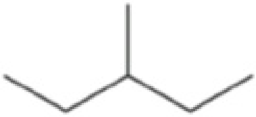


2,3,3-Trimethylheptane

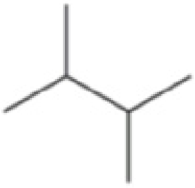
19.

hexane

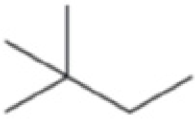
2-methylpentane



3-methylpentane



2,3-dimethylbutane



2,2-dimethylbutane

20.

a. 2-bromo-3,6-dimethyloctane

b. 2-bromo-6-methyloct-3-yne

c. 2-bromo-5,6-dimethyloct-3-ene

d. 3,6-dimethyloct-2-ene

e. 2,3,7 - trimethylnon-4-ene

f. 7-bromo-3,4- trimethyloct-2-ene

References

James E. Brady and Gerard E. Humiston, General Chemistry, 3rd edition, 1982, John Wiley and Sons. Inc., New York.

Raymond Chang, General Chemistry, 1986, RANDOM House, New York.

Bodner and Pardue, Chemistry and Experimental Science, 2nd edition, 1995, John Wiley and Sons. Inc., New York.

Davis, Gailey and Whitten, Principles of Chemistry, 1984, CBS College Publishing.

Martin S. Silberberg, Chemistry, The Molecular Nature of Matter and Change, 2nd edition, 2000, the McGraw–Hill Companies Inc., USA.

Linus Pauling, College Chemistry, 3rd edition, 1964, W. H. FREEMAN and COMPANY, SAN FRANCISCO.

Dr. S. K. Jain, Conceptual Chemistry, S. Ch and Company LTD, 2009. Encarta Premium 2009.

Rose Marie Gallagher, Complete Chemistry, Oxford University Press, 2007.

Catherine E. House Croft, E. C. Constable, Chemistry (an Introduction to organic, Inorganic and Physical Chemistry), 3rd edition, Pearson Educational limited, 2006

Gregg Hainen, Chemistry, Matter and Change, Glencoe, McGraw Hill, 2002.

Websites: http: //en. wikipedia.org/wiki/electrochemistry