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Textbook of CHEMISTRY

Grade 10

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CONTENTS

UNIT 01

HISTORY OF CHEMISTRY

Student Learning Outcomes (SLOs)

- Justify, with examples, to do science is to be involved in a community of inquiry.(For context in chemistry: a. The community adheres to certain common principles, methodologies, and processes, such as the use of empirical evidence and logical reasoning to develop scientific theories, For example, chemist based their research on the assumption on conservation of mass and energy and use this to verify whether their calculations and findings are sensible, b. Scientists in different fields often share similar methodologies, such as the use of controlled experiments and the peer review process. The scientific community also values objectivity and scepticism, which are essential for ensuring accuracy and validity of scientific findings).
- Explain with examples, that a scientific paradigm is a theoretical model of how nature works(some examples include: a. The belief that materials that burn do so because a material called "phlogiston" was the paradigm in chemistry in the 18th century, b. Historical models of the atom are paradigms, such as plum-pudding and the Rutherford model of atom, c. The periodic table of elements, and belief in the " periodicity" of atoms based on the arrangements of their electrons is a paradigm.

- Scientific paradigms in chemistry provide a framework for understanding the properties of materials and developing new materials with specific properties. Overall, scientific paradigms in chemistry guide research and development in the field, and help scientists to better understand the behaviour of chemicals and their interactions).
- Explain with examples, how scientists speak of " levels of confidence" (or uncertainty) when discussing experimental outcomes.
- Explain the difference between repeatability and reproducibility in chemistry. (For context: a. Repeatability as the idea that scientific results from experiments should be possible to verify by conducting the experiment again under the same physical conditions, b. Reproducibility as the idea that the same or similar result is obtained when the measurement is made under either different conditions or by a different method or in a different experiment.)

1.1 Principles and Methods in Chemistry

To do science, you need to work within a scientific community where people share ideas, methods, and practices to build knowledge. This is especially true for chemistry, where scientists follow set principles and techniques. Below are some key principles and methods in chemistry explained in simple terms:

(a) Conservation of Mass and Energy

In chemistry, we follow a rule called the conservation of mass and energy. This means that mass and energy cannot be created or destroyed in a closed system. For example, in a chemical reaction, the total mass of the reactants is always equal to the total mass of the products. This principle, first shown by Antoine Lavoisier in the 18th century, changed the way chemists do experiments by making them more accurate and reliable. If an experiment doesn't follow this rule, chemists check their procedures and calculations to find what went wrong.

(b) Using Observations and Logical Thinking

Chemists create theories and models based on what they observe in experiments. They use logical thinking to make sense of their findings. For example, Dmitri Mendeleev created the periodic table by observing patterns in the properties of elements. He even predicted elements that hadn't been discovered yet based on these patterns. This way of using evidence and reasoning is an important part of how science works.

(c) Controlled Experiments

Chemists, like other scientists, use controlled experiments to test their ideas. They change one variable at a time while keeping others constant to see what happens. For example, in pharmaceutical chemistry, controlled experiments are used to test if new medicines work and are safe. This method is also used in other sciences, like biology and physics, to find cause-and-effect relationships.

(d) Peer Review

Before scientific work is published, it is reviewed by other scientists to make sure it is correct and reliable. Chemists share their results in journals, where experts check the experiments, data, and conclusions for mistakes or unclear parts. For example, if a chemist discovers a new catalyst, it must be reviewed and tested by other scientists to confirm the findings. This process ensures the quality of scientific research.

(e) Being Objective

In science, results must come from facts, not opinions or biases. Chemists aim to be objective when performing experiments and analyzing data. For example, when identifying the structure of a molecule using spectrometry, they rely on precise measurements and standard methods instead of guesses or personal beliefs.

(f) Skepticism and Proof

Scientists are naturally skeptical and always double-check new discoveries. They repeat experiments and have others test their work before accepting it. For example, if someone claims to discover a new element or reaction, other scientists will conduct many tests to verify it. This skepticism helps ensure that only trustworthy information becomes part of science.

1.2 Evolution of Scientific Ideas (Paradigms)

What is a Scientific Paradigm?

A scientific paradigm is a set of ideas, methods, and rules that guide scientists in their research. It helps scientists understand the natural world and explain their discoveries. Paradigms give scientists a consistent way to study and share knowledge. However, when new evidence challenges an existing paradigm, it may be replaced with a better one. Here are some examples of scientific paradigms and how they changed over time:

1. The Phlogiston Theory

In the 1700s, scientists believed in the phlogiston theory to explain burning (combustion) and rusting. According to this idea, materials that could burn contained a substance called "phlogiston," which was released during burning. For example, when metals rusted, people thought they absorbed "deflogisticated air."

Later, Antoine Lavoisier proved that combustion happens because of oxygen combining with substances, not because of phlogiston. His work introduced a new way of thinking about chemical reactions, replacing the phlogiston theory with the modern concepts of oxidation and reduction.

2. Historical Models of the Atom

Scientists have changed their ideas about what atoms look like as they learned more through experiments:

- **The Plum Pudding Model (1904):** J.J. Thomson suggested that atoms are like a "pudding" with negatively charged electrons (the "plums") scattered in a positively charged "soup."
- **Rutherford's Model (1911):** Ernest Rutherford's gold foil experiment showed that atoms have a small, dense, positively charged centre called a nucleus, with electrons orbiting around it.
- **Bohr's Model and Quantum Model:** Later, scientists improved Rutherford's model by adding ideas about energy levels (Bohr's model) and quantum mechanics, which is the current way we understand atoms.
- These changes happened because new experiments provided better evidence.

3. The Periodic Table

Dmitri Mendeleev created the periodic table in 1869 to organize elements based on their atomic masses and properties. His table was powerful because it predicted the existence of elements that had not been discovered yet.

Modern Periodic Table

As scientists learned about atomic structure and quantum mechanics, they updated the periodic table. Today, elements are arranged based on their atomic numbers and electron configurations. This modern version explains why elements show similar chemical properties at regular intervals (periodicity) and helps us understand their behaviour in reactions.

1.3 Scientific Paradigms in Chemistry

Scientific paradigms in chemistry are ideas and rules that help us understand how substances behave and interact. These paradigms guide scientists in creating experiments, testing ideas, and interpreting results. They help us learn more about the materials we already know, and they also inspire the creation of new materials and technologies. This is important for progress in fields like medicine, materials science, and environmental protection.

1.4 Confidence and Uncertainty in Chemistry

Chemistry, like other sciences, involves both confidence and uncertainty when analyzing experimental results. Scientists use tools to measure how precise or reliable their data is:

1. Confidence Intervals

Confidence intervals show how precise a measurement is. For example, if a pharmacist measures the concentration of a solution to be **0.50 molar** with a **95% confidence interval (0.48-0.52 molar)**, it means they are 95% sure that the true value is within this range.

2. P-Values

P-values help scientists check if experimental results are meaningful. For example, if a chemist tests whether a new catalyst works faster than an old one and finds a **p-value of 0.01**, it means there's only a 1% chance that the result is random. This shows the new catalyst is almost certainly better.

3. Standard Error and Standard Deviation

These tools measure how much data varies. For example, if a chemist measures the melting point of a substance and finds the average is **120°C** with a **standard deviation of 0.5°C**, it means the results are consistent. A small **standard error (e.g., 0.1°C)** shows that the average value is accurate.

4. Bayesian Probability

This method updates our confidence in an idea based on new evidence. For example, if a chemist first believes there's a 60% chance a reaction happens in a certain way, but new data raises their confidence to 80%, they've used Bayesian probability to update their understanding.

5. Quantifying Uncertainty

Uncertainty tells us how reliable a measurement is. For example, if a chemist measures the concentration of a solution as **0.250 molar ± 0.005 molar**, the uncertainty is **±0.005 molar**, meaning the true value is close to 0.250 molar.

1.5 Repeatability and Reproducibility

In chemistry, repeatability and reproducibility are important for proving that experimental results are reliable.

Repeatability

This means getting the same result when repeating an experiment under the same conditions, using the same tools and procedures. For example, if a chemist measures the melting point of a substance several times in the same lab and gets the same result each time, the experiment is repeatable.

Reproducibility

This means getting the same result even when the experiment is done in different labs, with different tools, methods, and scientists. For example, if different chemists in different labs measure the same substance's melting point and get similar results, the experiment is reproducible.

Why Are These Important?

- Repeatability shows that the experiment is well-controlled and consistent in one setting.
- Reproducibility shows that the findings are reliable and not limited to one lab or method.

Both help scientists ensure their discoveries are accurate and accepted by others.

KEY POINTS

- Chemists generally follow the principle of conservation of mass and energy.
- Skepticism drives scientists to consistently challenge and validate new discoveries.
- According to this theory, all combustible materials contained a substance called "phlogiston" that was released when burned.
- Chemical paradigms are frameworks that explain chemical properties.
- In chemistry, Bayesian methods involve updating the likelihood of a hypothesis by combining previous data with new evidence.
- Uncertainty is a measure used by chemists to indicate how reliable their measurements and predictions are.
- Repeatability is the ability to repeat an experiment under the same conditions, such as using the same equipment, processes, location, time frame, and (if applicable) operator.
- The reproducibility of a measurement is the ability to produce same or similar results when the measurements are made in different environments, with different equipment, with different methods, and at different times.

EXERCISE

1. Multiple Choice Questions (MCQs)

i. What is the principle of conservation of mass?
   a) Mass is created during a chemical reaction
   b) Mass is destroyed during a chemical reaction
   c) Mass remains constant during a chemical reaction
   d) Mass can be converted into energy

ii. What does the peer review process ensure in scientific research?
   a) Faster publication b) Accuracy and validity of findings
   c) Higher funding d) Reduced experimentation

iii. Which of the following was an 18th-century chemical paradigm?
   a) Atomic theory b) Phlogiston theory
   c) Quantum mechanics d) Periodic table

iv. What does the periodic table of elements organize?
   a) Elements by alphabetical order b) Elements by their properties and atomic number
   c) Elements by colour d) Elements by discovery date

v. What does a 95% confidence level mean in scientific reporting?
   a) Results are 95% accurate b) There is a 5% chance the results are incorrect
   c) 95% of scientists agree d) The experiment is repeated 95 times

vi. Which model of the atom includes a central nucleus?
   a) Plum-pudding model b) Rutherford model
   c) Bohr model d) Quantum mechanical model

vii. What does repeatability in scientific experiments refer to?
   a) Different results under the same conditions b) Same results under the same conditions
   c) Different methods d) Multiple publications

viii. What is reproducibility in scientific experiments?
   a) Different results under the same conditions b) Same results using different methods
   c) Results not verified d) Repetition by the same scientist

ix. What paradigm replaced the phlogiston theory?
   a) Atomic theory b) Theory of combustion
   c) Quantum mechanics d) Periodic table

x. Which property does the periodic table help to predict?
   a) Colour of elements b) Properties of elements
   c) Weight of elements d) Discovery date of elements

2. Short Answer Questions

i. Explain the principle of conservation of mass in chemical reactions.

ii. What is the role of empirical evidence in scientific research?

iii. Describe the peer review process and its importance in science.

iv. How did the phlogiston theory explain combustion?

v. What is the significance of Rutherford's model of the atom?

vi. How does the periodic table organize elements?

vii. Define scientific paradigm with an example.

viii. What does a confidence level in scientific research indicate?

ix. Differentiate between repeatability and reproducibility in experiments.

x. Why is skepticism important in the scientific community?

3. Long Answer Questions

i. Discuss the transition from the phlogiston theory to the oxygen theory of combustion and its impact on chemistry.

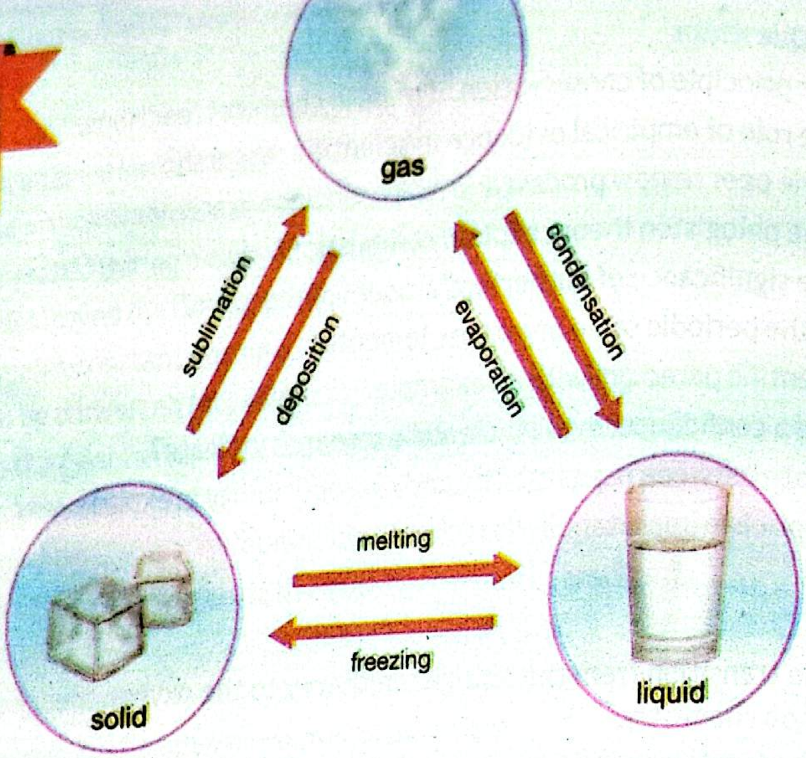
ii. Explain the development of atomic models from the plum-pudding model to the quantum mechanical model.

iii. Analyze how the periodic table serves as a paradigm in chemistry, guiding research and discovery of new elements.

iv. Evaluate the importance of repeatability and reproducibility in maintaining scientific integrity and progress.

v. Describe how levels of confidence and uncertainty are expressed and interpreted in scientific research, providing examples from chemistry experiments.

UNIT 02



MATTER

Students Learning Outcomes (SLO's)

- Explain changes of state and internal energy without change in temperature (melting, boiling, freezing, condensation, sublimation and deposition) in terms of kinetic particle theory.
- Distinguish between evaporation and boiling
- Interpret heating and cooling curves in terms of kinetic theory.
- Interpret heating in terms of kinetic particle theory the effects of changing pressure, temperature and volume of a gas on the other two with regards to Boyle`s law, Charles` law, and Avogadro`s law.
- Explain qualitatively the effect of external pressure on the rate of boiling and evaporation.
- Explain diffusion of gasses in terms of kinetic particle theory.
- Examine qualitatively the effect of molecular mass and temperature on the rate of diffusion.
- Discuss applications of sublimation around us. (examples may include: solid air fresheners and 3D printing).
- Explain, with the help of kinetic particle theory, the importance of rates of diffusion of medicines in the body.

2.1 Changes of states of matter

A state change (or phase transition) is the transition of matter from one state to another, such as a solid state to a liquid state, a liquid state to a gas state, or a state of matter directly between a solid state and a gas state. These transitions occur without a temperature change and can be understood through kinetic particle theory and the internal energy. Internal energy is composed of kinetic energy (temperature-related) potential energy (particle positions and interactions) during phase transitions. During phase transitions, the temperature remains constant (and hence the kinetic energy), however, the potential energy significantly changes. This shift in potential energy causes the overcoming or generation of inter-particle forces during phase transitions.

1. Melting (Solid to Liquid)

When a solid melts, it becomes a liquid. In a solid, the particles are tightly packed in a stable, well-ordered state and vibrate in fixed positions. When energy (usually heat) is added to the solid, it causes the particles to vibrate more strongly. When energy is added to a solid at the melting point, it increases its potential energy. This weakens the forces that hold the particles in place without increasing their kinetic energy, so the temperature stays the same. When the energy is strong enough to overcome the forces holding the particles in place, the solid melts into a liquid where the particles are in a stable state but can move freely around one another.

2. Boiling (Liquid to Gas)

When a liquid boils, it turns into a gas.

According to the Kinetic Particle Theory in a liquid, particles are closely packed but can move past each other. As energy is added, particles move faster and eventually have enough energy to break free from the liquid's surface into the gas phase.

The added energy increases the potential energy of the particles, allowing them to overcome the attractive forces holding them in the liquid. This occurs at the boiling point, where the temperature remains constant as the liquid turns into gas.

3. Freezing (Liquid to Solid)

When a liquid freezes, it turns into a solid.

According to the Kinetic Particle Theory in a liquid, particles have enough energy to move around each other. As the liquid loses energy, particle motion slows down, and the forces of attraction pull the particles into a fixed, orderly arrangement characteristic of a solid.

Energy is released during freezing, decreasing the potential energy of the particles. The temperature remains constant during this process as the energy released is used to form the solid structure.

4. Condensation (Gas to Liquid)

When a gas condenses, it turns into a liquid.

According to the Kinetic Particle Theory in a gas, particles move away rapidly and are far apart. As the gas loses energy, particle motion slows down, and attractive forces pull the particles closer together, forming a liquid.

Energy is released during condensation, reducing the potential energy of the particles. The temperature remains constant as the gas turns into a liquid.

5. Sublimation (Solid to Gas)

When a solid sublimates, it turns directly into a gas without passing through the liquid phase.

According to the Kinetic Particle Theory in a solid, particles are tightly packed in fixed positions.

When the solid gains enough energy, the particles gain sufficient energy to break free directly into the gas phase.

Energy is added, significantly increasing the potential energy of the particles to overcome the forces holding them in the solid structure. This occurs without a change in temperature during the sublimation process.

6. Deposition (Gas to Solid)

When a gas undergoes deposition, it turns directly into a solid without passing through the liquid phase.

According to the Kinetic Particle Theory in a gas, particles are far apart and move freely. When the gas loses energy, the particle motion slows significantly, and attractive forces pull the particles directly into a solid arrangement.

Energy is released, greatly reducing the potential energy of the particles. This happens without a change in temperature during the deposition process.

2.2 Heating and cooling curves

Heating and cooling curves are shown in figure. These curves show how the energy of particles changes during phase transition.

2.2.1 Heating Curve

A heating curve typically shows temperature change over time as a substance is heated. It consists of several distinct regions (Figure 2.1).

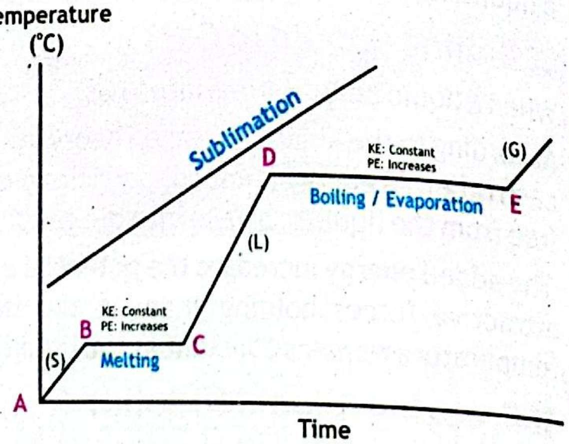


Figure 2.1: Heating Curve

Solid Phase (A to B)

Segment A to B: The temperature of the solid increases as it absorbs heat. According to kinetic theory, the kinetic energy of the particles (atoms or molecules) increases, causing the particles to vibrate more vigorously.

Melting (B to C)

Segment B to C: The temperature remains constant as the solid melts into a liquid. Here, the absorbed heat energy is used to overcome the intermolecular forces holding the solid together, rather than increasing kinetic energy. This is known as the latent heat of fusion.

Liquid Phase (C to D)

Segment C to D: The temperature of the liquid increases as it continues to absorb heat. The kinetic energy of the particles increases, causing them to move more rapidly.

Boiling (D to E)

Segment D to E: The temperature remains constant as the liquid changes into a gas. The absorbed heat energy is used to overcome the intermolecular forces in the liquid, a process that requires latent heat of vaporization.

Gas Phase (E onward)

Segment E onward: The temperature of the gas increases as it absorbs more heat. The kinetic energy of the gas particles increases, causing them to move even more rapidly.

2.2.2 Cooling Curve

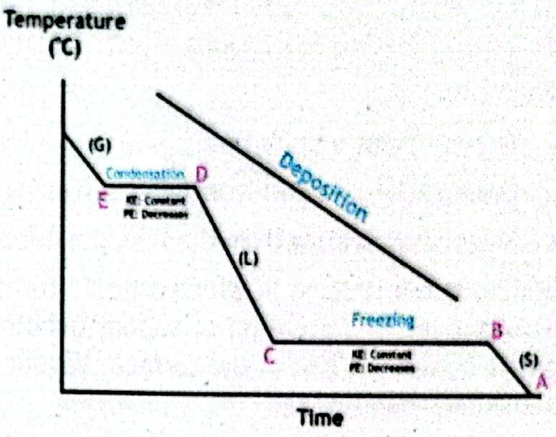


Figure 2.2: Cooling Curve

A cooling curve shows the reverse process as a substance is cooled. It consists of similar distinct regions, but in reverse order (Figure 2.2).

Gas Phase (Higher Temperature to E)

Segment higher temperature to E: The temperature of the gas decreases as it loses heat. The kinetic energy of the gas particles decreases, causing them to move less rapidly.

Condensation (E to D)

Segment E to D: The temperature remains constant as the gas condenses into a liquid. The lost heat energy is released as the intermolecular forces bring the particles closer together, resulting in the latent heat of vaporization being released.

Liquid Phase (D to C)

Segment D to C: The temperature of the liquid decreases as it loses more heat. The kinetic energy of the particles decreases, causing them to move more slowly.

Freezing (C to B)

Segment C to B: The temperature remains constant as the liquid freezes into a solid. The lost heat energy is released as the intermolecular forces arrange the particles into a solid structure, resulting in the latent heat of fusion being released.

Solid Phase (B to A and below)

Segment B to A and below: The temperature of the solid decreases as it continues to lose heat. The kinetic energy of the particles decreases, causing them to vibrate less.

2.2.3 Kinetic Theory Interpretation

Kinetic Energy and Temperature

In the regions where the temperature is changing (A to B, C to D, and E onward for heating) the kinetic energy and potential energy increase. E to D, C to B for cooling, KE of the particle is constant but PE is decreasing.

Potential Energy and Phase Changes

In the regions where the temperature remains constant (B to C and D to E for heating; D to C and B to A for cooling), the energy absorbed or released is used to change the phase of the substance. This involves changing the potential energy associated with intermolecular forces, rather than changing the kinetic energy of the particles.

2.3 Evaporation and Boiling

Evaporation is the process by which molecules at the surface of a liquid gain enough kinetic energy to escape into the gaseous phase. Only molecules at the liquid's surface participate in evaporation. These molecules must have sufficient kinetic energy to overcome intermolecular forces. Energy for evaporation comes from the surrounding environment. This absorption makes surroundings cooler than before. Evaporation can occur at any temperature below the liquid's boiling point. Higher temperatures increase the rate of evaporation since more molecules have sufficient energy to escape.

As high-energy molecules leave the liquid, the average kinetic energy of the remaining molecules decreases, leading to a cooling effect. This is why sweating helps cool the body.

Examples:

- Drying of clothes on a line.
- Evaporation of water from lakes and oceans contributing to the water cycle.
- Sweat evaporating from the skin, providing a cooling effect.

Boiling is the process in which a liquid turns into vapor when it is heated to its boiling point, resulting in the formation of vapour bubbles within the liquid. Boiling occurs throughout the entire liquid, not just at the surface. Vapour bubbles form within the liquid, rise to the surface, and burst, releasing gas.

Boiling occurs at a specific temperature known as the boiling point. This temperature varies depending on the liquid and the external pressure. For water at sea level, the boiling point is 100°C (212°F).

Continuous heat input is required to maintain the liquid at its boiling point. The temperature of the liquid remains constant during boiling, as the added energy is used to convert the liquid into gas. Boiling is characterized by the vigorous formation of bubbles and steam, making it a highly visible process.

The boiling point changes with external pressure. Higher pressure increases the boiling point, while lower pressure decreases it. This is why water boils at lower temperatures at high altitudes.

2.3.1 Effect of pressure on evaporation and boiling

The effect of pressure on evaporation and boiling is primarily related to how it influences the rate at which molecules escape from the liquid's surface into the gas phase. Here are the key points regarding the effect of pressure on evaporation:

Effect of Lower Pressure

At lower atmospheric pressures, the rate of evaporation increases. This is because there is less external pressure exerted on the liquid surface, making it easier for molecules to escape into the vapor phase.

For example, water will evaporate more quickly at high altitudes where the atmospheric pressure is lower than at sea level.

Lower pressure reduces the boiling point of a liquid, which means the liquid can transition to the gas phase at a lower temperature. This indirectly affects evaporation by facilitating the conditions under which it can occur more readily.

Effect of Higher Pressure

At higher atmospheric pressures, the rate of evaporation decreases. The increased external pressure on the liquid surface makes it more difficult for molecules to escape into the vapour phase.

For example, in a pressure cooker, the high pressure suppresses evaporation until a higher temperature is reached, allowing food to cook faster.

Higher pressure increases the boiling point of a liquid, which means the liquid requires a higher temperature to transition into the gas phase. This indirectly affects evaporation by making the conditions less favorable for it to occur

For example, in a pressure cooker, the high pressure suppresses boiling until a higher temperature is reached allowing water to boil at a higher temperature. This allows food to cook faster.

Evaporation is a gradual process occurring at any temperature below the boiling point and at the surface of a liquid, while boiling is a rapid, vigorous process that occurs throughout the liquid at a specific boiling point.

2.4 Kinetic Particle Theory and Gas Laws

A sample of a gas can be characterized by four variables:

1. The number of moles of a gas(n)
2. Volume(V)
3. Pressure(P)
4. Temperature(T)

The relationships that express the influence of one variable on another with two variables constant are called gas laws.

2.4.1 Boyle's Law

It states that for a fixed amount of gas at a constant temperature, the volume of a gas is inversely proportional to its pressure. Mathematically,

$$V \propto \frac{1}{P}$$

$$V = k\frac{1}{P}$$

$$PV = \text{constant}$$

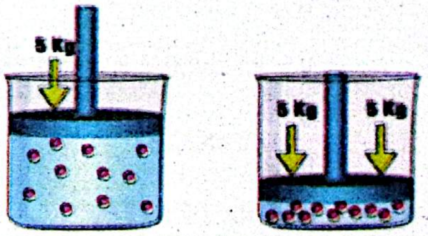


Figure 2.3: Effect of pressure on the volume of a gas

Kinetic Particle Theory Interpretation

Effect of Volume on Pressure:

When the volume of a gas decreases, the gas particles have less space to move around. This results in more frequent collisions with the walls of the container, thereby increasing the pressure. Conversely, if the volume increases, the particles collide with the walls less often, decreasing the pressure.

Constant Temperature:

The average kinetic energy of the particles remains constant since the temperature does not change. The speed of the particles does not change, but the frequency of collisions with the container walls changes due to the volume change.

2.4.2 Charles's Law

It states that for a fixed amount of gas at constant pressure, the volume of a gas is directly proportional to its absolute temperature. Mathematically,

$$V \propto T$$

$$V = kT$$

$$\frac{V}{T} = k$$

$$\frac{V}{T} = \text{constant}$$

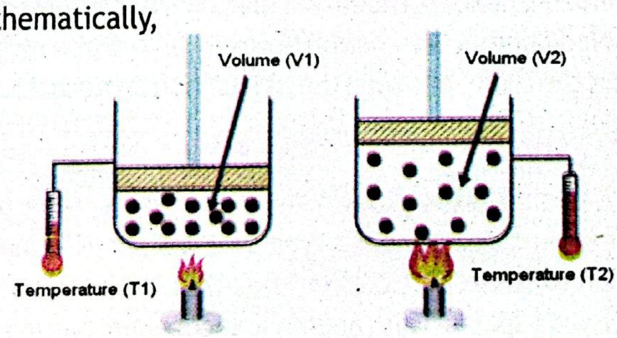


Figure 2.4: Effect of temperature on the volume of a gas

Kinetic Particle Theory Interpretation:

Effect of Temperature on Volume:

When the temperature of a gas increases, the kinetic energy of the gas particles increases. This means the particles move faster. To maintain constant pressure, the volume of the container must increase to allow the particles to travel further between collisions with the container walls, thus keeping the pressure constant. Conversely, if the temperature decreases, the kinetic energy of the particles decreases, the particles move slower, and the volume must decrease to maintain constant pressure.

Constant Pressure:

The volume changes to balance the increased or decreased frequency and force of collisions due to temperature changes, maintaining constant pressure.

2.4.3 Avogadro's Law

It states that for a gas at constant temperature and pressure, the volume of the gas is directly proportional to the number of moles of gas. Mathematically,

$$V \propto n$$

$$V = kn$$ where k and n are constant

$$\frac{V}{n} = \text{constant}$$

n = no. of moles

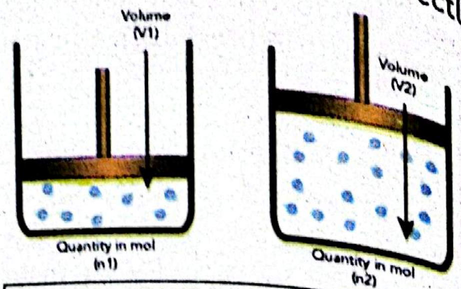


Figure 2.5: Relation between the number of moles of a gas and its volume

Kinetic Particle Theory Interpretation

Effect of Number of Particles (Moles) on Volume:

When the number of gas particles (moles) increases, there are more particles colliding with the walls of the container. To keep the pressure constant, the volume of the container must increase to accommodate the additional particles and maintain the same number of collisions per unit area. Conversely, if the number of particles decreases, the volume must decrease to maintain constant pressure.

Constant Temperature and Pressure:

The temperature ensures the kinetic energy of each particle remains the same, and the pressure remains constant by adjusting the volume according to the number of particles.

2.5 Diffusion of gases

One of the simplest examples of diffusion in everyday use is when perfume is sprayed and dispersed across a room. At first, perfume molecules are concentrated in the sprayer and dispersed across the room. However, as the perfume particles travel and collide, they disperse across the room, allowing the perfume to be detected even at a distance from the source.

2.5.1 Diffusion Process Explained by Kinetic Particle Theory

When two different gases come into contact, their particles begin to move together. Because of their kinetic energy, each type of a gas particle moves randomly in all directions. The random motion of these particles ensures that the particles from each of the two gases move into the other gas's space. This random and constant motion causes the gases to spread and mix up. The gas particles change direction as they move and collide with each other. As they change direction they spread out and move through the space available to them. As time goes on, this random motion causes the particles to spread out evenly across the space. Eventually, the concentration of both types of gas particles is uniform across the entire space, and equilibrium is achieved.

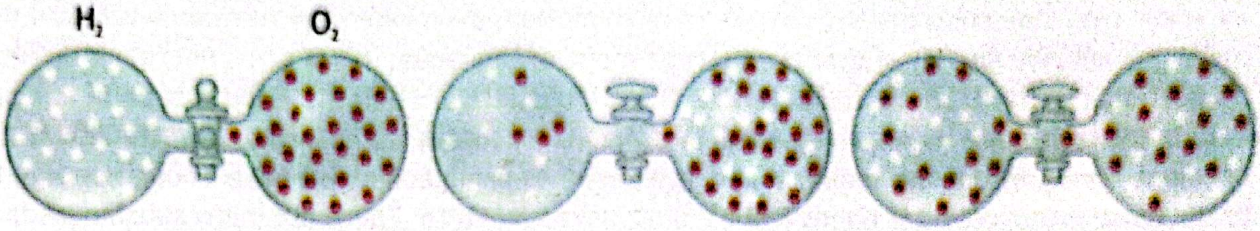


Figure 2.6: Shows the diffusion of two gases

2.5.2 Factors affecting diffusion

The rate of diffusion, the process by which molecules spread from areas of high concentration, is affected by several factors, including molecular weight and temperature.

Molecular weight

According to Graham's law of diffusion

The rate of diffusion is inversely proportional to the square root of the molar mass of the gas particles.

$$\text{Rate of diffusion } r \propto \frac{1}{\sqrt{m}} \text{ at constant T and P}$$

This means that lighter molecules diffuse faster than heavier ones.

According to kinetic particle theory, all molecules at the same temperature have the same average kinetic energy.

Since kinetic energy (K.E) = $1/2mv^2$, where m is the molecular mass and v is the velocity, lighter molecules (smaller m) have a greater velocity (v) than heavier molecules with the same kinetics.

Because lighter molecules move faster, they can travel greater distances in a given time than heavier molecules, resulting in a higher rate of diffusion.

Temperature

Diffusion rate increases with temperature. Higher temperatures give molecules more energy, which increases their kinetic energy. As the temperature increases, the average kinetic energy of the molecules increases. Since kinetic energy is proportional to the square of the velocity, this results in a higher molecular velocity. Higher molecular velocities at higher temperatures cause more frequent and energetic collisions between molecules, facilitating faster diffusion.

CONCEPT ASSESSMENT EXERCISE 2.1:

Explain why?

(a) When you apply perfume to your palm, it makes you feel cold.

(b) We all sweat. As our sweat evaporates, it cools us

2.6 Sublimation

Sublimation is the process in which molecules of a substance in the solid state go to the vap[...] state directly, without going through the liquid state. According to the kinetic molecular theo[...] we know that molecules are in constant random motion, even when the substance is below t[...] melting point. We also know that the average speed of the molecules (kinetic energy) is direct[...] proportional to the absolute temperature. If the molecules are below the melting point and a[...] kept in the solid state by relatively weak intermolecular forces (compared to the strength of t[...] covalent bonds within the molecule) then sometimes a molecule will have enough energy t[...] break those intermolecular bonds and go into the vapour state. There are many substances th[...] undergo sublimation. Carbon dioxide, camphor, and naphthalene are material that easi[...] undergoes sublimation.

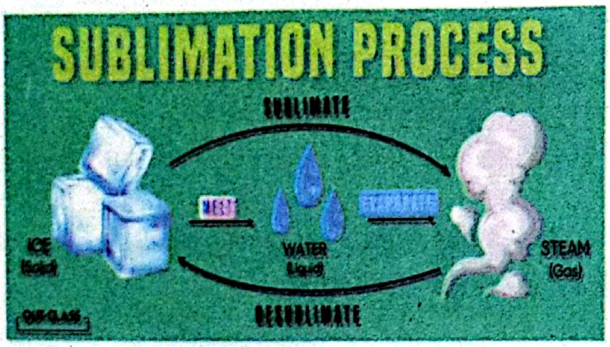


Figure 2.7: Sublimation

Figure 2.8: Sublimation of dry ice.

Application of Sublimation in our life

- The solid air fresheners we often use in our cars and homes rely solely on the magic [...] sublimation. The solid fragrance within slowly transforms into a delightful vapour, fillin[...] the entire space with an enticing aroma that lingers in the air.
- In the textile industry 3D printing uses a sublimation process. Dye sublimation printers ar[...] now widely used for the printing process for a reduced cost. Dye sublimation is used [...] print a variety of objects such as T-shirts, pens, coffee mugs, and bags.
- In the food industry, freeze-drying food items for preservation for a longer duration is du[...] to the process of sublimation.

Simple examples of deposition in daily life. Did you get it.!!

- The formation process of snow from water vapour.
- Black Soot inside a Vehicle Exhaust.
- The Making Process of Dry Ice Using Carbon Dioxide.

2.6.1 Importance of Diffusion Rates in Medicine

Kinetic particle theory is one of the most important theories for understanding drug distributio[...] rates in the human body. When you take a drug, whether it's taken by mouth or injected, it need[...] to diffuse from the injection site into your bloodstream. The diffusion rate determines ho[...] quickly a drug reaches its target area in your body. Drug molecules need to spread throug[...] different tissues and organs to reach your body's cells where they do their work. Higher levels [...] diffusion usually mean your drug will work faster. For example, a fast-acting drug like a pai[...] relievers needs to dissolve quickly to provide immediate pain relief. Kinetic particles theor[...]

explains that drug diffusion rates are affected by a concentration gradient between your drug and your surrounding tissues. If your drug is at a high concentration at the time of administration, and your surrounding tissues are at a low concentration, then your drug diffusion rate will be faster.

The rate of diffusion also depends on the composition of the drug (e.g. liquid, gel, tablet). Generally, liquid drugs move more quickly than solid drugs, as their particles have already dispersed. Controlled-release formulations are used to control the rate of drug diffusion so that the therapeutic effect remains consistent over time.

KEY POINTS

- Solids, liquids and gases change state when they are heated or cooled.
- A state change (or phase transition) is the transition of matter from one state of matter to another.
- A heating curve typically shows temperature change over time as a substance is heated.
- The temperature remains constant as the solid melts into a liquid.
- The temperature remains constant as the liquid changes into a gas.
- The temperature remains constant as the gas condenses into a liquid.
- Evaporation is the process by which molecules at the surface of a liquid gain enough kinetic energy to escape into the gaseous phase.
- Boiling is the process in which a liquid turns into vapor when it is heated to its boiling point.
- Boyle's Law: It states that for a fixed amount of gas at a constant temperature, the volume of a gas is inversely proportional to its pressure.
- Charles's Law: It states that for a fixed amount of gas at constant pressure, the volume of a gas is directly proportional to its absolute temperature.
- Avogadro's Law:It states that for a gas at constant temperature and pressure, the volume of the gas is directly proportional to the number of moles of gas.
- Graham's law of diffusion: The rate of diffusion is inversely proportional to the square root of the molar mass of the gas particles.
- Sublimation is the process in which molecules of a substance in the solid state go to the vapor state directly, without going through the liquid state.

References

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EXERCISE

1. Multiple Choice Questions (MCQs)

i. What happens to the internal energy of a substance during melting?
   a) It decreases
   b) It stays the same
   c) It increases
   d) It fluctuates

ii. Which process involves a solid turning directly into a gas?
   a) Melting
   b) Freezing
   c) Sublimation
   d) Condensation

iii. Boiling occurs at:
   a) Any temperature
   b) A fixed temperature
   c) Only at room temperature
   d) Any pressure

iv. During condensation, the particles in a gas:
   a) Gain energy and move faster
   b) Lose energy and move slower
   c) Gain energy and move slower
   d) Lose energy and move faster

v. Which law states that the volume of a gas is directly proportional to its temperature at constant pressure?
   a) Boyle's Law
   b) Charles's Law
   c) Avogadro's Law
   d) Dalton's Law

vi. Evaporation differs from boiling because:
   a) Evaporation occurs at the surface of a liquid at any temperature
   b) Boiling occurs only at the surface
   c) Evaporation requires a fixed temperature
   d) Boiling occurs at any temperature

vii According to kinetic particle theory, the pressure of a gas increases when:
   a) The volume increases
   b) The temperature decreases
   c) The number of particles decreases
   d) The temperature increases

viii. Which factor affects the rate of diffusion of gases?
   a) Molecular mass
   b) Temperature
   c) Both a and b
   d) Neither a nor b

ix. Solid air fresheners use the process of:
   a) Condensation
   b) Deposition
   c) Sublimation
   d) Freezing

x. The diffusion of medicine in the body is important because:
   a) It controls the temperature of the medicine
   b) It ensures the medicine reaches all parts of the body
   c) It keeps the medicine in one place
   d) It increases the molecular mass of the medicine

2. Short Answer Questions

i. Explain why the temperature remains constant during the phase change from ice to water.

ii. What is the name given to the phase change when a solid is converted directly to a gas?

iii. What is the difference between evaporation and boiling?

iv. Interpret a heating curve for water, identifying key phase changes.

v. Explain the effect of increasing temperature on the pressure of a gas in a sealed container.

vi. How does increasing the external pressure affect the boiling point of a liquid?

vii. Describe how molecular mass influences the rate of diffusion.

viii. Give an example of sublimation and explain its practical application.

ix. Why is the diffusion of gases faster at higher temperatures?

x. How does Avogadro's law relate to the volume and number of moles of gas?

3. Long Answer Questions

i. Describe in detail the kinetic particle theory and how it explains the phase changes of melting, freezing, boiling, and condensation.

ii. Interpret a cooling curve, identifying and explaining the significance of the flat regions on the curve.

iii. Explain how diffusion works in gases and discuss the factors affecting the rate of diffusion, including molecular mass and temperature.

THINK TANK

1. Analyze the impact of altitude on the boiling point of water and how it affects cooking times. Provide a detailed explanation based on kinetic particle theory and external pressure.
2. Discuss the importance of understanding diffusion rates in the development of pharmaceuticals..
3. Evaluate the environmental and practical implications of using sublimation in various industries, such as air fresheners and 3D printing, considering both benefits and potential drawbacks.

UNIT 03

STOICHIOMETRY

Student Learning Outcomes (SLOs)

- Use the molar gas volume, 24 dm^3 at room temperature and pressure, in calculations involving gases.
- Define concentration, use both g/dm^3 mol/dm^3, and convert between them.
- Calculate stoichiometric relationships between substances(specially: reacting masses, limiting reactants, volume of gases at RTP., volumes of solutions and concentrations of solutions in g/dm^3 or mol/dm^3, including conversion between cm^3 and dm^3).
- Calculate concentration of a solution in titration using empirical data.
- Calculate empirical formula and molecular formula from appropriate data.
- Calculate percentage yield, Percentage composition by mass and percentage purity from appropriate data.

Stoichiometry is an integral part of the chemical industry and has a wide range of practical applications. For example, the chemical composition of everyday products such as soap, detergent, toothpaste, shampoos, cosmetics, medicines, and fertilizers is determined by stoichiometry.

Stoichiometry comes from the Greek word "Stoichen" meaning element and the word "Metron" which means measure. The study of relative amounts of the substances involved in the chemical reaction is known as stoichiometry. It helps in the application of balanced chemical equations for the calculation of the quantities of the reactants and the products. It is based on a balanced chemical equation that shows the mole-to-mole quantity of the reactant and products.

3.1 Mole

Recall that the atomic mass, formula mass, and molecular mass of a substance expressed in grams is called Mole.

For Example,

One mole of O (atom)	= 16 g	One mole of O_2 (molecule)	= 32 g
One mole of H_2O (molecule)	= 18 g	One mole of Na^+(ion)	= 23 g
One mole of NaCl (Formula unit)	= 58.5 g		

Mole ratios in Stoichiometric Calculations:

Let's look at the following chemical reaction.

$$2H_{2\,(g)} + O_{2(g)} \longrightarrow 2H_2O_{(l)}$$

What does this chemical equation tell us? It tells us that 2 moles of hydrogen + 1 moles of oxygen will form 2 moles of water. Any chemical reaction can be interpreted in terms of a mole. Moles can easily be converted into the mass of reactants/products. A balanced chemical equation will tell you the ratio of the reactants/products to the mole. The mole is the unit of measurement used to express the amount of a substance.

The mole is the SI unit to express the amount of a substance. It is symbolized as mol.

Example 3.1

Methanol burns according to the following equation.

$$2CH_3OH + 3O_{2(g)} \longrightarrow 2CO_{2(g)} + 4H_2O_{(g)}$$

If 3.50 moles of methanol are burnt in oxygen, calculate

(a) How many moles of oxygen are used?

(b) How many moles of water are produced?

Solution

(a) Moles of methanol = 3.50 moles

Moles of oxygen = ?

According to the balanced chemical equation

2 moles of CH_3OH = 3 moles of O_2

1 moles of CH_3OH = 3/2 moles of O_2

3.5 moles of $CH_3OH = \frac{3.50 \times 3}{2}$ moles of O_2

$= 5.25$ moles of O_2

So the number of moles of O_2 consumed = 5.25 moles

(b) No. of Moles of CH_3OH = 3.5 moles

No. of Moles of H_2O =?

According to the balanced chemical equation

2 moles of CH_3OH = 4 moles of H_2O

1 moles of CH_3OH = 4/2 moles of H_2O

3.5 moles of CH_3OH $= \frac{3.50 \times 4}{2}$ moles of H_2O

$= 7.00$ moles of H_2O

So the number of moles of H_2O produced = 7.00 moles

Concept Assessment Exercise 3.1

NH_3 is an important raw material in the manufacture of fertilisers. It is obtained by the combination of N_2 and H_2 as shown by the following balanced equation.

$$N_{2(g)} + 3H_{2(g)} \longrightarrow 2NH_{3(g)}$$

How many moles of the following are required to manufacture 8.0 moles of NH_3?

(a) Nitrogen (b) Hydrogen

Example 3.2

Iron can be produced from iron ore Fe_2O_3 by reacting the ore with carbon monoxide (CO). What mass of iron can be formed from 425 g of iron ore?

Solution

The balanced equation can be written as

$$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$$

Mass of iron ore = 425 g (given mass)

No of moles of iron ore $= \frac{\text{mass}}{\text{molecular mass}} = \frac{425\,g}{159.6\,g\,\text{moles}^{-1}}$

$= 2.66$ moles of Fe_2O_3

According to the balanced chemical equation

1 mole of Fe_2O_3 = 2 moles of Fe

2.66 moles of Fe_2O_3 $= 2.66 \times 2$ Moles of Fe = 5.32 Moles of Fe

Mass of Fe produced = no. of moles of Fe × Molar mass of iron

$= 5.32 \times 55.9$ g

Mass of iron produced = 297.388g

Concept Assessment Exercise 3.2

1. Hydrogen burns with oxygen according to the following equation.

$$2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(g)}$$

How many grams of oxygen are needed to burn 100 g of hydrogen completely?

2. Calculate the mass of O_2 produced by thermal decomposition of 49 grams of $KClO_3$

$$2KClO_{3\,(s)} \longrightarrow 2KCl_{(s)} + 3O_{2(g)}$$

Molar Volume

One mole of any gas at RTP (room temperature and pressure) occupies a volume of 24 dm^3. This volume is called Molar volume. RTP stands for 25°C and 1 atm. With the help of this relationship, we can convert the mass of a gas at RTP into its volume and vice versa.

24 dm^3 of any gas at RTP = 1 mole

24 dm^3 of H_2 gas at RTP = 2g = 1 mole

24 dm^3 of NH_3 gas at RTP = 17g = 1 mole

Example 3.3

Determine the volume that 2.5 moles of chlorine molecules occupy at RTP.

Solution

We know that

24 dm^3 of Cl_2 (Chlorine) at RTP = 1 mole

Or 1 mole of Cl_2 occupies a volume of 24 dm^3 at RTP.

2.5 mole of Cl_2 occupy a volume of 24 $dm^3 \times 2.5 = 60\ dm^3$

Concept Assessment Exercise 3.3

(a) How many moles of oxygen molecule are there in 50.0 dm^3 of oxygen gas at RTP?

(b) What volume does 0.80 mole of N_2 gas occupy at RTP?

(Ans: (a) 2.08 moles, (b) 19.2 dm^3)

3.2 Percentage Composition

The relative amounts of each element in a compound are expressed as the percentage composition. For example, the percentage composition by mass in MgO is as follows,

To determine the percentage composition of a known compound,

a) Calculate the molar mass of the compound

b) Calculate the percentage of each element in one mole of the compound. This is done by dividing the mass of each element in one mole of the compound by the molar mass multiplied by 100.

$$\%\text{ of an element} = \frac{\text{mass of element in 1 mole of compound}}{\text{molar mass of compound}} \times 100$$

Molar mass of MgO = 24+16

= 40 g/mol

% of Mg = $\frac{24}{40}\times 100$

= 60.3

% of O = $\frac{16}{40}\times 100$

= 39.7

The sum of percentages of all the elements in a compound must be equal to 100.

Concept Assessment Exercise 3.4

Determine the percentage composition of the following compounds.

1. Water H_2O
2. Sulphuric acid H_2SO_4
3. Glucose $C_6H_{12}O_6$
4. Ammonium nitrate NH_4NO_3

3.3 Limiting and Non-Limiting Reactants

A limiting reactant is the reactant that is completely consumed in a reaction. A limiting reactant can also be defined as the reactant that produces the lowest moles of products in a reaction. The reactant in excess is the reactant left unutilised or unreacted after the reaction is complete. It is also referred to as a Non-Limiting reactant.

3.3.1 Identification of a Limiting Reactant in a Reaction

A limiting reactant can be recognised by calculating the number of moles of products formed from data of the given amounts of the reactants, using a balanced chemical equation. The reactant, that produces the least number of moles of products, is the limiting reactant. For example, 10 moles of H_2 and 10 moles of O_2 were reacted to produce H_2O. Which one of the reactants is the limiting reactant? We can calculate as follows:

The reaction is $2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(l)}$

According to the balanced chemical equation

$2H_2 = 2H_2O$

2 moles of H_2 give = 2 moles of H_2O

10 moles of H_2 will give = $\frac{2}{2}\times 10$ = 10moles of H_2O

$O_2 = 2H_2O$

1 mole of O_2 gives = 2 moles of H_2O

7 moles of O_2 = 2 x 7 = 14 moles of H_2O

Since H_2 gives the least number of moles of H_2O, i.e. 10 moles, so H_2 is the limiting reactant.

Example 3.4

200 g of Zn were reacted with 200g dil. H_2SO_4. Determine

(a) Limiting Reactant

(a) Mass of hydrogen produced

$$Zn_{(s)} + H_2SO_{4(aq)} \longrightarrow ZnSO_{4(aq)} + H_{2(g)}$$

Solution

(a) Mass of Zn = 200g

Molar mass of Zn = 63.5 g mol^{-1}

No of moles of Zn = $\frac{200}{63.5}$

= 3.15 mol

Mass of H_2SO_4 = 200g / mol

Molar mass of H_2SO_4 = 2 +32 +16x4 = 98 g/ mol

No of moles of H_2SO_4 = $\frac{200}{98}$

= 2.04 mol

According to the balanced chemical equation

1 mole of Zn produces = 1 mol of H_2

3.15 mol of Zn = 1×3.15 mol of

= 3.15 mol of H_2

1 mol of H_2SO_4 = 1 mol of H2

2.04 moles of = 1 × 2.04

= 2.04 mol of H_2

As H_2SO_4 is producing lesser moles of product so, H_2SO_4 is the limiting reactant.

Mass of hydrogen produced = No. of moles of hydrogen × molar mass of hydrogen

= 2.04 × 2 = 4.08 g

Concept Assessment Exercise 3.5

1. Magnesium metal reacts with Sulphur to produce MgS. How many grams of magnesium sulphide (MgS) can be made from 1.50g of Mg and 1.50g of sulphur by the reaction?

$$Mg_{(s)} + S_{(s)} \longrightarrow MgS_{(s)}$$

2. Zinc and Sulphur react to form Zinc Sulphide according to the following balanced chemical equation $Zn_{(s)} + S_{(s)} \longrightarrow ZnS_{(s)}$

   If 10.0g of Zinc and 10.0g of Sulphur are available for reaction, then determine

   (a) The limiting reactant.

   (b) The mass of Zinc Sulphide produced.

3. Aluminium reacts with bromine to form Aluminium bromide, as shown by the balanced chemical equation, $2Al_{(s)} + 3Br_{2(l)} \longrightarrow 2AlBr_{3(s)}$

   If 54g of Al and 200g of Br_2 are available for reaction, then determine

   (a) The limiting reactant (b) The mass of $AlBr_3$ produced

3.4 Theoretical Yield, Actual yield and Percent yield

The amount of product as calculated from a balanced chemical equation is known as the theoretical yield of a chemical equation. The actual yield is the amount of product actually produced in the reaction. The percent yield of a chemical reaction can be calculated as follows:

$$\text{Percentage Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100$$

For many reactions, the theoretical yield is close to the actual yield. These reactions are quantitative and can be used for chemical analysis. For some reactions, however, the actual yield is below the theoretical yield, and the percent yield is less than 100%. This is because of the following reasons:

Side reactions may result in by-products. Some reactions may be reversible. Mechanical loss can occur as a result of filtration or distillation. Separation by a funnel, washing or crystallization can also cause mechanical loss.

Example 3.5

In an industry copper metal was prepared by the following reaction,

$$Fe_{(s)} + CuSO_{4(aq)} \longrightarrow FeSO_{4(aq)} + Cu_{(s)}$$

1.274g of $CuSO_4$ when reacted with excess of Fe metal a yield of 0.392g of Cu metal is obtained. Calculate the percentage yield.

Solution

Mass of $CuSO_4$ = 1.274g

Molar mass of $CuSO_4$ = 63.5 + 32 + 64 = 159.5 g/mol

159.5g of $CuSO_4$ = 1 mole

1.274 g of $CuSO_4$ $= \frac{1}{159.5} \times 1.274$

$= 7.982 \times 10^{-3}$ mol

1 mol of $CuSO_4$ = 1 mole of Cu

7.98×10^{-3} moles of $CuSO_4$ = 7.982×10^{-3} mol of Cu

As, 1 mole of Cu = 63.5 g

so, 7.982×10^{-3} moles of Cu = $63.5 \times 7.982 \times 10^{-3}$

= 0.5072 g of Cu.

Hence, Theoretical yield = 0.5072 g

Actual yield = 0.392 g

So, % yield $= \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$

$= \frac{0.392}{0.5072} \times 100 = 77.3\%$

Concept Assessment Exercise 3.6

1. In a reaction, 2.00 moles of CH_4 were reacted with an excess of Cl_2. As a result, 177.0 g of CCl_4 is obtained. What is the
   (a) theoretical yield (b) actual yield (c) % yield of this reaction?

$$CH_{4(g)} + 4Cl_{2(g)} \longrightarrow CCl_{4(l)} + 4HCl_{(g)}$$

2. Phosphorus reacts with bromine to form phosphorus tribromide. When 35g of bromine is reacted with 27.9g of phosphorus tribromide is produced. What is the (a) theoretical yield (b) actual yield (c) % yield of this reaction?

$$2P_{(s)} + 3Br_{2(l)} \longrightarrow 2PBr_{3(s)}$$

3.5 Determining Empirical and Molecular Formulas

Remember that the empirical formula of a compound tells you the simplest ratio of elements in the compound. On the other hand, the molecular formula tells you the actual ratio of elements in the compound.

Determining the empirical formula of a compound involves the following steps:

Step 1. Find the number of moles of each element from its mass or percentage composition.

Step 2. Divide each element`s molar amount by the smallest or least molar amount to get the simplest whole-number ratio of the compound.

Step 3. Write the empirical formula using the simplest ratio as subscripts.

Determining the molecular formula of a compound involves the following steps:

Step 1. Find the molar mass of the empirical formula.

Step 2. Divide the compound's molar mass by the empirical formula's molar mass. This will give you a whole number (n).

Step 3. Multiply all the subscripts in the empirical formula by n to get the molecular formula.

Example 3.6

A compound has the following composition:

Carbon = 40% , hydrogen = 6.7% and oxygen = 53.3%

The molar mass of the compound is 180 g/mol. Determine its empirical and molecular formulas.

Solution

Moles of elements

C = 40/12 = 3.33

H = 6.7/1 = 6.7

O = 53.3/16 = 3.33

Mole ratio

C	:	H	:	O
3.33	:	6.7	:	3.33
3.33/3.33	:	6.7/3.33	:	3.33/3.33
1	:	2	:	1

Empirical formula $= C_1H_2O_1$

$= CH_2O$

Molar mass of empirical formula = 1x12 + 2x1 +1x16

= 12 + 2 + 16

= 30 g/ mol

n = Molar mass / Empirical formula molar mass

= 180 /30

= 6

Therefore molecular formula = $(CH_2O)_6$

$= C_6H_{12}O_6$

Concept Assessment Exercise 3.7

1. Determine the empirical and molecular of a compound from the following data.
   26.4 % Carbon 3.3 % Hydrogen 70.3 % Oxygen, Molar Mass: 91.0 g/mol
2. Determine the empirical and molecular formula of a compound composed of 18.24 g Carbon, 0.51 g Hydrogen, and 16.91 g Fluorine, which has a molar mass 562.0 g/mol.

Percentage purity

The amount of the pure substance in a sample represented as a percentage of the sample`s total mass is known as percentage purity.

You can determine the purity of a compound by comparing the amount of pure compound compared to the total mass of a sample. The formula for percentage purity is:

Percentage purity = Actual mass of compound x 100/ Total mass of sample

Example 3.7

A student synthesized a compound and obtained a sample weighing 6.3g. Then he performed chemical analysis and found that the sample contains 4.2g of pure compound. Calculate the percentage purity of the compound.

Solution

Actual mass of compound = 4.2g

The total mass of the sample = 6.3g

Percentage purity of compound = Actual mass of compound x 100/ Total mass of sample

= 4.2 x100/6.3

= 66.67 %

Concept Assessment Exercise 3.8

An impure sample of calcium carbonate has a mass of 70g. After purification, 56g of calcium carbonate is recovered. What is the percentage purity of calcium carbonate?

3.6 Concentration Units

When solid solutes are dissolved in water, their molecules or ions readily move about in solution. They come in contact with one another readily in solution, so they combine easily. The quantity of a solute present in a given amount of solvent or solution is called the concentration of a solution.

Recall that you have learned the difference between a dilute and a concentrated solution. A dilute solution is that whose concentration is relatively low while a concentrated solution is a solution whose concentration is relatively high. You can find dilute and concentrated solutions of common acids and bases in your chemistry laboratory. Chemists use many concentration units. Here we will discuss molarity and strength.

i. Molarity (M)(mol/dm^3)

If you read the label on the bottle of concentrated H_2SO_4 you will notice 98% by mass and also 18M. What does 18M stand for? This means there are 18 moles of H_2SO_4 in each dm^3 of solution. Similarly, conc. HCl is 37% and 12.1 M HCl. This means there are 12.1 moles of HCl in each dm^3 of solution. We can express the concentration in terms of moles of solute in the given volume of solution.

Molarity is the concentration unit in which the amount of solute is expressed in moles and the quantity of solution in dm^3.

Molarity is defined as the number of moles of solute dissolved per dm^3 of solution.

Mathematically,

$$M = \frac{\text{moles of solute}}{\text{dm}^3 \text{ of solution}}$$

3.6.1 Problems Involving the Molarity of a Solution

Example 3.8

Urea is a white solid used as fertilizer and starting material for synthetic plastic. A solution contains 40g urea dissolved in 500 cm^3 of solution. Calculate the molarity of this solution.

Problem Solving Strategy

To calculate the molarity, you need the number of moles of solute (which are not given) and the volume of solution in dm^3. Convert the volume of solution 500 cm^3 to dm^3. Determine moles of solute from its mass using its molar mass.

Solution

Mass of urea = 40g

Molar mass of urea $= 14+1\times2+12+16+14+1\times2$

$= 60 g/mol$

Moles of urea $= \frac{40}{60} = 0.667 mol$

Volume of solution $= 500 cm^3 = \frac{500}{1000} = 0.5 dm^3$

Now

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{dm}^3 \text{ of solution}}$$

$$\text{Molarity} = \frac{0.667}{0.5}$$

$$= 1.334 \text{ M}$$

Example 3.9

Calculating molarity from moles of solute and volume of solution.

Potassium permanganate ($KMnO_4$) is a dark blue-black compound. When it is dissolved in water, it forms a bright purple solution. It is used as a disinfectant in water tanks. It is also known as pinky. A solution contains 0.05 moles of ($KMnO_4$) in 600cm^3 of solution. Calculate the molarity of this solution.

Problem Solving Strategy

To calculate molarity, you need moles of solute which are given, and the volume of solution in dm^3. But volume is given in cm^3. So convert the cm^3 to dm^3 by dividing with 1000. Use formula to calculate molarity.

Solution

Moles of ($KMnO_4$) $= 0.05$

Volume of solution $= 600 \text{ cm}^3$

$$= \frac{600}{1000}$$

$$= 0.6 \text{ dm}^3$$

Now

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{dm}^3 \text{ of solution}}$$

$$\text{Molarity} = \frac{0.05}{0.6}$$

$$= 0.083\text{M}$$

Concept Assessment Exercise 3.9

Potassium chlorate ($KClO_3$) is a white solid. It is used in making matches and dyes. Calculate the molarity of the solution that contains. (a) 1.5 moles of this compound dissolved in 250cm^3 of solution (b) 75g of this compound dissolved to produce 1.25dm^3 of solution. (c) What is the molarity of a 50cm^3 sample of potassium chlorate solution that yields 0.25g residue after evaporation of the water.

ii. Strength of a Solution

The strength of a solution refers to the concentration of solute in a given volume of solution. It is expressed in terms of grams of solute per unit volume of solution. It is typically represented as:

- g/dm^3 (grams per cubic decimeter) or
- g/cm^3 (grams per cubic centimeter).

These units express how much solute is dissolved in a specified volume of solution. Mathematically

$$\text{Strength of solution} = \frac{\text{Mass of solute (g)}}{\text{Volume of solution } (dm^3 \text{ or } cm^3)}$$

Mass of solute is measured in grams (g). Volume of solution is measured in cubic decimeters (dm^3) or cubic centimeters (cm^3).

Unit Conversion:

$$1\ dm^3 = 1000\ cm^3$$

So, to convert between g/dm^3 and g/cm^3:

$$1\ g/dm^3 = 0.001\ g/cm^3$$

Example 3.10 (g/dm^3)

A solution contains 20 g of salt dissolved in 2 dm^3 of solution. Calculate the strength of the solution.

Solution

Mass of solute (g) = 20g

Volume of solution = $2dm^3$

$$\text{Strength of solution} = \frac{\text{Mass of solute (g)}}{\text{Volume of solution } (dm^3)}$$

$$\text{Strength of solution} = \frac{20g}{2dm^3}$$

$$= 10\ g/dm^3$$

Example 3.11 (g/cm^3)

A solution contains 25g of sugar dissolved in 500 cm^3 of solution. Calculate the strength of the solution.

Solution

Mass of solute = 25g

Volume of solution = 500 cm^3

$$\text{Strength of solution} = \frac{\text{Mass of solute (g)}}{\text{Volume of solution } (cm^3)}$$

$$\text{Strength of solution} = \frac{25g}{500cm^3}$$

$$= 0.05\ g/cm^3$$

Example 3.12 (Unit Conversion)

A solution has a strength of 50 g/dm^3. Express this strength in g/cm^3.

Solution

Strength of solution = 50 g/dm^3.

Strength of solution in g/cm^3 = ?

$$1\ g/dm^3 = 0.001\ g/cm^3$$

$$50\ g/dm^3 = 50 \times 0.001$$

$$= 0.05\ g/cm^3$$

3.6.2 Problems Involving Interconversion of Molarity and Strength

Example 3.13

Converting the molarity of a solution into its concentration in g/dm^3 and g/cm^3

A flask contains 0.25M NaOH solution. What mass of NaOH is present per dm^3 of solution?

Problem Solving Strategy

Molarity means the number of moles per dm^3 of solution. So, 0.25M NaOH means 0.25 mol of NaOH dissolved per dm^3 of solution. You need to convert moles of solute to mass usi molar mass.

Solution

Molarity = 0.25M

Moles of NaOH = 0.25

Volume of solution = $1 dm^3$

Molar mass of NaOH = 23+16+1

= 40g/mole

$$\text{Moles of solute} = \frac{\text{mass of solute}}{\text{molar mass of solute(g/mole)}}$$

$$0.25\ \text{moles} = \frac{\text{mass of NaOH}}{40\text{g/mole}}$$

Mass of NaOH = 0.25 moles x 40g/mole

=10g

Thus, the solution contains 10g NaOH per dm^3.

Now

As $1\ dm^3 = 1000 cm^3$

The solution contains 10g/ dm^3 of solution

or the solution contains 10g of NaOH per $1000 cm^3$

So, $1000 cm^3$ of solution contains = 10g NaOH

$1 cm^3$ of solution contains = 10g/1000

= 0.01g NaOH

Therefore concentration of solution is = 0.01 g/ cm^3

Example 3.14

Converting concentration in g/dm^3 into molarity.

Potassium hydroxide (KOH) is used in the manufacturing of shaving creams, paints and varnish. An analyst makes up a solution by dissolving 5.8g of KOH in one dm^3 of solution. Calculate the molarity of this solution.

Problem solving strategy

To calculate the molarity, you need moles of solute per dm^3 of solution. Moles of solute are not given. But the mass of solute per dm^3 of the solution is given, Convert the mass of the solute into moles by using its molar mass.

Solution

Mass of KOH dissolved in one dm^3 of solution = 5.6g

Molar mass of KOH = 39+16+1

= 56g/mol

$$\text{Moles of KOH} = \frac{\text{mass of KOH(g)}}{\text{molar mass of KOH(g)}}$$

$$= \frac{5.6}{56}$$

= 0.1 mol

Thus, the solution contains 0.1 moles of KOH in one dm^3 of the solution, so the molarity of the solution is 0.1M.

Teacher's Point

A teacher may give different concentration interconversion numerical to students as homework.

Concept Assessment Exercise 3.10

1. Sodium hydroxide solutions are used to neutralize acids and in the preparation of soaps and rayon. If you dissolve 25g of NaOH to make 1 dm^3 of solution, what is the molarity of this solution?
2. A solution of NaOH has a concentration of 1.2M. Calculate the mass of NaOH in g/dm^3 and g/cm^3 in this solution.
3. A solution is prepared by dissolving 10g of haemoglobin in enough water to make up $1dm^3$ in volume. Calculate molarity of this solution. Molar mass of haemoglobin is $6.51 \times 10^4 g/mol$.

3.6.3 Dilution of Solutions

Dilution is a process by which you make a solution less concentrated by adding more of the liquid (usually water). Suppose you have a cup of strong lemonade. If you add more water, the lemonade becomes weaker or less strong. This means that dilution reduces the strength or concentration of a solution. By using the dilution formula, you can determine how much of a concentrated solution is to be mixed with water to get the desired concentration and volume.

To understand how to dilute a solution, we use a simple formula:

$$M_1 \times V_1 = M_2 \times V_2$$

where:

M_1 is the concentration of the original (concentrated) solution.
V1 is the volume of the original solution you use.
M_2 is the concentration you want after dilution.
V_2 is the total volume of the final solution.

Plug the known values into the formula to find out how much of the concentrated solution you need. Mix the calculated amount of the concentrated solution with enough water to reach the final volume you want.

Activity 3.1

Prepare 250 cm^3 solution of 0.1M from concentrated hydrochloric acid.

Materials required

- Conc.HCl
- 250 cm^3 volumetric flask
- Graduated pipette
- Distilled water

Steps

- Concentrated HCl is 12M. Using formula calculate the volume of Conc.HCl required to be diluted to 250 cm^3.

$$M_1 \times V_1 = M_2 \times V_2$$

Molarity of Conc. HCl × its volume to be diluted = Required molarity of HCl × required volume of HCl solution.

$$12 \times V_1 = 0.1M \times 250$$

$$V_1 = 0.1 \times 250/12$$

$$= 2.08\ cm^3$$

- Transfer 2.08 cm^3 of conc. HCl with the help of a graduated pipette into a 250 cm^3 volumetric flask.
- Add distilled water up to the mark and shake well.
- This is required 0.1M HCl solution

Example 3.15

If you have 150 cm^3 of a 4 M potassium nitrate (KNO_3) solution, what volume of this solution will be needed to prepare 500 cm^3 of a 1 M potassium nitrate solution?

Solution

The formula for dilution is:

$$M_1 \times V_1 = M_2 \times V_2$$

where:

M_1 is the concentration of the initial (concentrated) solution of KNO_3 = 4 MV_1 is the volume of the initial solution of KNO_3 that you need to find.

M_2 is the concentration of the final (diluted) solution = 1M

V_2 is the volume of the final solution = 500 cm^3

Substitute the known values into the formula:

$$4\ M \times V_1 = 1\ M \times 500$$

$$V_1 = \frac{1\ M \times 500\ cm^3}{4\ M}$$

$$V1 = 125\ cm^3$$

To prepare 500 cm^3 of a 1 M potassium nitrate solution, you need to use 125 cm^3 of the 4 M potassium nitrate solution.

Mix 125 cm^3 of the 4 M solution with enough water to make a total of 500 cm^3 to achieve the desired concentration.

3.6.4 Calculating the concentration of a solution through titration

Activity 3.2

To standardise the given solution of hydrochloric acid.

Note: Perform this activity in the chemistry laboratory.

You will need:

- Burette, Pipette, burette stand, beakers, conical flash, glass rod.
- Standard 0.1M NaOH solution and phenolphthalein.

Chemical equation

$$HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

n_1 = 1 mole n_2 = 1 mole

Carry out the following

- Fit up a clean burette in the burette stand vertically.
- Fill the burette with HCl solution up to zero mark.
- Take 10 cm^3 of NaOH solution in a conical flask with the help of a pipette.
- Add a few drops of phenolphthalein as an indicator.
- Note the initial reading on the burette.
- Run the acid solution in the conical flask drop by drop, and shake the flask constantly.

- Go on adding the acid solution till the pink colour just disappears.
- Note down the final reading from the burette.
- The difference between the final and initial readings gives the volume of the acid used to neutralize 10.0 cm^3 of NaOH solution.
- Repeat the experiment to get three concordant readings.
- Find the mean volume of the HCl solution used.

Observations and calculations

Suppose the volume of HCl solution used = V_1= 10 cm^3

Molarity of HCl solution = M_1=?

Volume NaOH solution used = V_2= 10 cm^3

Molarity of NaOH solution = M_2= 0.1M

No. of moles of HCl = n_1= 1

No. of moles of NaOH = n_2= 1

$$\frac{M_1 \times V_1}{n_1} = \frac{M_2 V_2}{n_2}$$

$$\frac{M_1 \times 10}{1} = \frac{0.1 \times 10}{1}$$

$$M_1 = 0.1\ M$$

Strength of HCl solution = Molarity x Molar mass

= 0.1 x 36.5

= 3.65 g/dm^3

Result: Molarity of HCl solution is 0.1 M

M_1 = 0.1M

Strength of HCl solution = Molarity x Molar mass

= 0.1 x 36.5

= 3.65 g/dm^3

Concept Assessment Exercise 3.11

1. When 10 cm^3 solution of NaOH solution is titrated against 9.8 cm^3 of 0.1M HCl solution for complete neutralization.

$$HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

Calculate (i) the molarity of NaOH solution (ii) the amount of NaOH present per cm^3 of solution.

2. A chemist has a 200 cm^3 solution of hydrochloric acid with a concentration of 6 M (molar). He wants to dilute it to a concentration of 2 M. How much of the original solution should be mixed with water to achieve the desired concentration?

KEY POINTS

- The study of relative amounts of the substances involved in the chemical reaction is known as stoichiometry
- The atomic mass, formula mass and molecular mass of a substance expressed in grams is called Mole.
- A balanced chemical equation will tell you the ratio of the reactants/products to the mole.
- The mole is the SI unit to express the amount of a substance.
- The relative amounts of each element in a compound are expressed as the percentage composition.
- A limiting reactant is the reactant that is completely consumed in a reaction.
- Reactant in excess is the reactant left unutilized or unreacted after the reaction is complete. It is also referred to as a Non-Limiting reactant.
- The amount of product a chemical reaction produces is known as the theoretical yield of a chemical equation.
- The actual yield is the amount of product produced in the reaction.
- Molarity is defined as the number of moles of solute dissolved per dm3 of solution.

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- Chemistry, The central Science.
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EXERCISE

1. **Multiple Choice Questions (MCQs)**

i. What mass of CO_2 is produced by the combustion of each mol of CH_4?

$$CH_{4(g)} + 2O_{2(g)} \longrightarrow CO_{2(g)} + 2H_2O_{(l)}$$

(a) 16g (b) 44g
(c) 32g (d) none

ii. A flask contains 500 cm^3 of SO_2 at RTP. The flask contains;

(a) 32 g (b) 2.4 g
(c) 64 g (d) 1.33g

iii. A necklace has 6g of diamond in it. How many carbon atoms are present in it?

(a) 1 (b) 0.5
(c) 1.5 (d) 0.25

iv. What is the mass of aluminium in 204 g of the aluminium oxide, Al_2O_3?

(a) 26 g (b) 27 g
(c) 54 g (d) 108 g

v. The reactant which is consumed earlier and gives least quantity of product is called;
(a) Reactant in excess (b) Stoichiometry
(c) Limiting reactant (d) Stoichiometric amount

vi. Which one of the following compounds contains the highest percentage by mass of nitrogen?
(a) NH_3 (b) N_2H_4
(c) NO (d) NH_4OH

vii. Vitamin A has a molecular formula of $C_{20}H_{30}O$. The number of moles of vitamin A in 500 mg of its capsule will be;
(a) 1.7 (b) 1.7×10^{-3}
(c) 1.05 (d) 3.01×10^{-3}

viii. When one mole of each of the following is completely burnt in oxygen, which will give the largest mass of CO_2?
(a) Carbon monoxide (b) Diamond
(c) Ethane (d) Methane

ix. One mole of ethanol and one mole of ethane have an equal;
(a)Mass (b)Number of atoms
(c)Number of electrons (d)Number of molecules

x. How many moles of oxygen are needed for the complete combustion of two moles of butane, C_4H_{10}?

$$2C_4H_{10(g)} + 13O_{2(g)} \longrightarrow 8CO_{2(g)} + 10H_2O_{(l)}$$

(a) 12 mol (b) 13 mol
(c) 4 mol (d) 10 mol

2. Short questions

i. Analysis of a compound used in photography indicated the following chemical composition:
65.45% C, 5.45 % H, and 29.09 % O. Its molar mass is 110 g/mol. Determine its molecular formula.

ii. How many moles of HCl will be produced when 125g of $AlCl_3$ are reacted with excess of water?

$$2AlCl_{3(s)} + 3H_2O_{(l)} \longrightarrow Al_2O_{3(s)} + 6HCl_{(aq)}$$

iii. How many moles of oxygen are needed to produce 1.0g of calcium nitrate?

$$Ca_{(s)} + 3O_{2(g)} + N_{2(g)} \longrightarrow Ca(NO_3)_{2(s)}$$

iv. Calculate the limiting reactant when Al_2S_3 is produced by the reaction of 25g of each reactant.

$$2Al_{(s)} + 3S_{(s)} \longrightarrow Al_2S_{3(s)}$$

v. Calculate the empirical and molecular formulas of a compound from the following data.

vi. 20.2 % Sodium 37.6 % Sulphur 42.2 % Oxygen, Molar Mass: 682.8 g/mol

vii. For the reaction

$$CaCO_{3(s)} + 2HCl_{(aq)} \longrightarrow CaC1_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$$

viii. 68.1 g solid $CaCO_3$ is mixed with 51.6 g HCl. Which one will be the limiting reactant?

ix. Copper(II) sulphate is prepared by the reaction of dilute sulphuric acid on Copper(II)oxide. A student prepared 1.85g of copper(II) sulphate. If its theoretical yield is 2.5g, calculate its percentage yield.

$$CuO_{(s)} + H_2SO_{4(aq)} \longrightarrow CuSO_{4(aq)} + H_2O_{(l)}$$

x. In an experiment some amount of limestone was heated, and only 24 dm^3 of carbon dioxide was produced at room temperature and pressure. What mass of limestone was heated?

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

xi. For the reaction of $C_2H_{4(g)}$ with $O_{2(g)}$ to form $CO_{2(g)}$ and $H_2O_{(g)}$, what number of moles of CO_2 can be produced by the reaction of 0.480 mol of C_2H_4 and 1.08 mol of O_2.

xii. Which reactant will be left un-reacted?

$$C_2H_{4(g)} + 3O_{2(g)} \longrightarrow 2CO_{2(g)} + 2H_2O_{(g)}$$

xiii. Given 48 g of methane (CH_4) and excess oxygen, calculate the volume of carbon dioxide gas produced at room temperature and pressure.

xiv. Calculate the empirical formula of a compound that contains 40% carbon, 6.7% hydrogen, and 53.3% oxygen by mass.

xv. A solution is prepared by dissolving 10.0 g of sodium chloride in water to make a total volume of 500 cm^3. Calculate the concentration of the solution in g/dm^3 and mol/dm^3.

xvi. In a titration, 25.0 cm^3 of a 0.10 mol/dm^3 NaOH solution neutralized 20.0 cm^3 of an HCl solution. Calculate the concentration of the HCl solution in mol/dm^3.

xvii. A student is required to prepare a 0.5 mol/dm^3 NaCl solution for an experiment.

a. Define concentration in the context of this solution.

b. Calculate the mass of NaCl needed to prepare 250 cm^3 of the solution.

c. Convert the concentration of the prepared solution to g/dm^3.

d. Propose a step-by-step procedure to accurately prepare this solution.

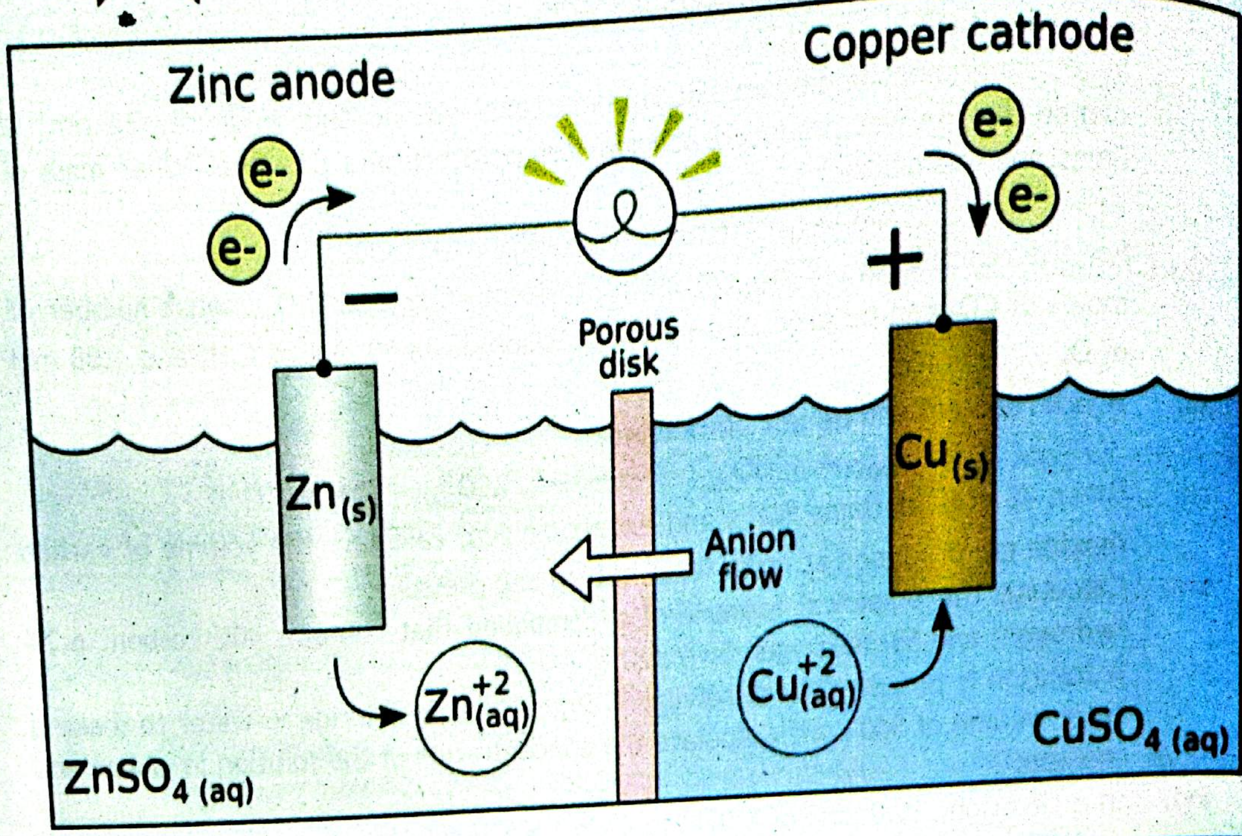
THINK TANK

1. Critically assess why the percentage yield in a reaction is rarely 100% and discuss the factors that might contribute to a lower yield.
2. A solution has a concentration of 0.5 mol/dm^3. Propose a method to double this concentration without changing the volume of the solution.
3. Calculate the percentage purity of a sample of sodium carbonate (Na_2CO_3) if 1.00 g of the sample requires 25.0 cm^3 of 0.1 mol/dm^3 hydrochloric acid for complete reaction.

$$Na_2CO_{3(s)} + 2HCl_{(aq)} \longrightarrow 2NaCl_{(aq)} + CO_{2(g)} + H_2O_{(l)}$$

4. If a solution has a concentration of 2 mol/dm^3, what is its concentration in g/dm^3 if the solute is H_2SO_4?
   Answer: 196 g/dm^3.
5. Design a method to determine the concentration of acetic acid in vinegar using titration.

UNIT 04



ELECTROCHEMISTRY

Student Learning Outcomes (SLOs)

- Define electrolysis as decomposition of ionic compounds, in molen state or aqueous solution, by passage of electric current.
- Identify and label in simple electrolytic cells, the anode (+), cathode (-), electrolyte and direction of flow of electrons in the external circuit.
- Describe the transfer of charge in external circuit, movement of ions in the electrolyte and transfer of electrons in the electrodes.
- Identify the products formed at electrodes and describe the observations made during the electrolysis of molten lead(II)chloride, concentrated aqueous sodium chloride, dilute sulphuric acid using inert electrodes (platinum or carbon/graphite).
- State that hydrogen-oxygen fuel cell uses hydrogen and oxygen to produce water as the only chemical product.

- Describe the advantages and disadvantages of using hydrogen-oxygen fuel cells in comparison with gasoline/petrol engines in vehicles.
- Identify the products formed at electrodes and describe the observations made during the electrolysis of dilute copper(II)sulphate using an inert electrode or copper electrode.
- Predict the identity of products of electrolysis of a halide compound in dilute or concentrated solution.
- Construct ionic half-equations for reaction at either electrode.
- Describe electroplating and its applications.
- Sketch a schematic diagram for a voltaic cell e.g. Daniel cell.
- Use the voltage data given for the voltaic cell to determine the order of reactivity of any two metals.

Electrochemistry is the study and application of the fundamental principles of electrochemical reactions. Electrochemical processes include electrolysis, electroplating, and voltage cells. Electrochemistry principles include understanding the role of anode and cathode, the movement of electrons in an external circuit, and the migration of ions in an electrolyte. In this chapter, we will explore electroplating and electrolysis principles. We also look at the potential advantages of a hydrogen and oxygen fuel cell over a traditional fuel engine. Finally, we will discuss the importance of the voltaic cell, the Daniel cell, and the role of metals in determining reactivity.

4.1 Electrochemical cells

Devices that convert chemical energy into electrical energy or vice versa are called electrochemical cells. Therefore, there are two types of electrochemical cells:

(1) Electrolytic Cells

(2) Galvanic Cells

An electrochemical cell that uses electrical energy to drive a chemical reaction is called an electrolytic cell. An electrochemical cell that converts chemical energy into electricity is called a galvanic cell.

4.1.1 Nature of Electrochemical Process

Electrochemical processes are oxidation-reduction reactions in which chemical energy released by a spontaneous reaction is converted to electricity or in which electrical energy is used to drive a non-spontaneous reaction. Whether an electrochemical process releases or requires energy, it always involves the transfer of electrons from one substance to another. This means that this process always involves an oxidation-reduction or a redox reaction.

Science Tidbit

A physical or chemical change that occurs by itself is called a spontaneous process. Spontaneous processes do not require a source of energy to make them happen. For instance, water flows from a higher level to a lower level. Iron placed in moist air, rusts. The flow of electrons through a conductor can be obtained from a spontaneous oxidation-reduction reaction. This is the basis for how batteries work.

On the other hand, a physical or chemical change that requires a source of energy to make it happen is called a non-spontaneous process. For example, water can be made to flow from a lower level to a higher level by using a pump.

4.1.2 Concept of Electrolytes and Electrolysis

When an ionic compound is dissolved in water, it splits up into its positive and negative ions, these ions are capable of conducting electricity. Such compounds are referred to as electrolytes.

Substances that can conduct electricity when they are in a molten state or aqueous solution and undergo chemical changes. Whereas, a substance that cannot conduct electricity when dissolved in water or in the molten state is called a non-electrolyte.

Examples of electrolytes are NaCl, KCl, HCl, NaOH, etc.
Examples of non-electrolytes are urea, glucose, sucrose, benzene etc.

4.1.3 Electrolytic Cells

An electrochemical cell in which electrical energy is used to drive a chemical reaction is called an electrolytic cell. The figure shows the sketch of an electrolytic cell.

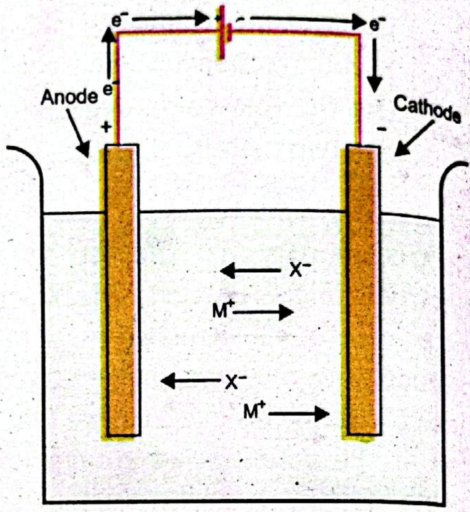


Figure 4.1: Electrolytic cell

An electrolytic cell consists of

(a) A vessel containing an electrolyte (MX)

(b) Two inert electrodes

(c) A battery

The figure shows that electrons move from anode to cathode in the outer circuit, in the solution the cations move towards the cathode and anions towards anode. At the anode, anions oxidize by losing electrons. At the cathode, cations reduce by gaining electrons. This means oxidation occurs at the anode and reduction at the cathode. The electrons released by anions at the anode move in the external circuit towards the cathode. This means the movement of ions in the electrolyte and the transfer of electrons occur at electrodes in the external circuit.

At Anode	$X^- \rightarrow X + 1e^-$
At cathode	$M^+ + 1e^- \rightarrow M$

Concept Assessment Exercise 4.1

1. Sketch an electrolytic cell for the electrolysis of fused KCl.
2. Sketch a simple representation of electrolytic cell for the electrolysis of fused sodium chloride. Indicate the direction of the flow of electrons. Identify anode and cathode.

4.2 Electrolysis

Electrolysis is the chemical process in which an electric current is passed through an electrolyte, either in its molten state or as an aqueous solution, causing a non-spontaneous redox reaction to occur. This process involves the movement of ions towards oppositely charged electrodes, where oxidation occurs at the anode and reduction occurs at the cathode. This process leads to the decomposition of the electrolyte or its components into simpler substances or elements.

4.2.1 Electrolysis of molten electrolyte

(i) Electrolysis of Molten Sodium chloride

On a large scale, sodium metal is produced by the electrolysis of fused sodium chloride. The electrolytic cell used in the process is called a Down's Cell. Down's Cell uses an iron cathode and carbon anode. During the electrolysis, the sodium ions are reduced at the cathode to liquid sodium metal. At the anode, the chloride ions are oxidized to chlorine gas.

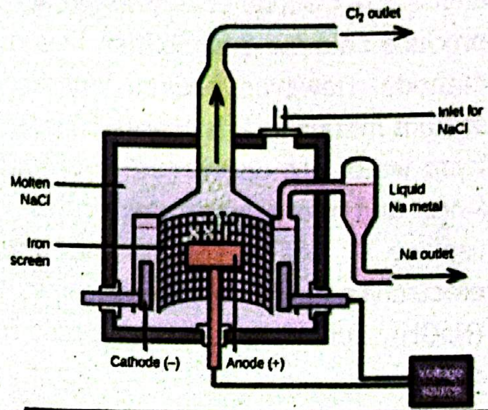


Figure 4.2: Down's Cell

At anode

$$2Cl^{-}_{(l)} \longrightarrow Cl_{2(g)} + 2e^{-} \quad \text{(oxidation half-reaction)}$$

At cathode

$$2Na^{1+}_{(l)} + 2e^{-} \longrightarrow 2Na_{(l)} \quad \text{(reduction half-reaction)}$$

(ii) Electrolysis of molten lead(II) chloride using platinum or graphite electrodes

On a large scale, lead metal is produced by the electrolysis of molten or fused lead(II) chloride. An electrolytic cell is used for this purpose. Molten lead chloride is placed in the electrolytic tank and platinum, or graphite electrodes are dipped in it. The electrolysis is conducted above 327°C, which is the melting point of lead chloride.

Molten lead chloride contains free lead ions and chloride ions. During electrolysis, chloride ions move towards the anode and lead ions towards the cathode. At the electrodes following reactions occur.

At anode

$$2Cl^{-}_{(l)} \longrightarrow Cl_{2(g)} + 2e^{-} \quad \text{(oxidation half-reaction)}$$

At cathode

$$Pb^{2+}_{(l)} + 2e^{-} \longrightarrow Pb_{(s)} \quad \text{(reduction half-reaction)}$$

Molten lead is collected at the bottom of the cathode and chlorine gas at the anode.

4.2.2 Electrolysis of concentrated aqueous solution

Electrolysis of a concentrated aqueous solution of sodium chloride called brine is used for the industrial production of sodium hydroxide. Electrolysis is carried out by using inert electrodes such as platinum, or carbon (graphite). The electrolytic cell is shown in Figure 4.3. The brine contains sodium ions and chloride ions from NaCl and hydrogen ions and hydroxide ions from water.

During electrolysis, chloride ions move towards the anode. At anode chloride ions are oxidized to produce chlorine gas. Sodium ions move towards the cathode. However, sodium ions are not reduced to sodium metals in this process. Instead, hydrogen ions from water are discharged to produce hydrogen gas. More and more water molecules keep ionizing to replace H^+ ions as soon as they are consumed. The electrolyte in the solution becomes sodium hydroxide (NaOH). Following reactions occur in the electrolytic cell.

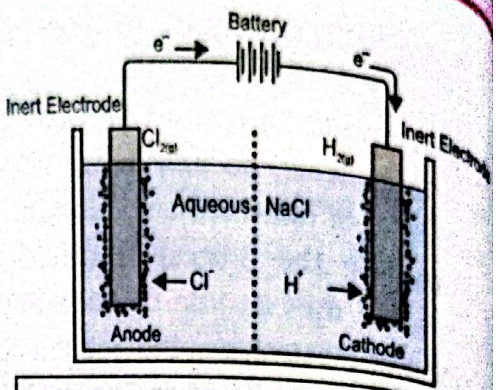


Figure 4.3: Electrolysis of Concentrated aqueous NaCl

At anode: $2Cl^-_{(aq)} \longrightarrow Cl_{2(aq)} + 2e^-$

At cathode: $2H^+_{(aq)} + 2e^- \longrightarrow H_{2(g)}$

The solution contains Na^+ and OH^- ions. Evaporation of water from this solution produces pure solid sodium hydroxide.

4.2.3 Electrolysis of dilute aqueous solution

a. Electrolysis of dilute aqueous Sodium chloride using platinum electrodes

Unlike electrolysis of concentrated aqueous sodium chloride, chloride ions are not oxidized at the anode. Instead, hydroxide ions are oxidized and oxygen gas is produced at the anode. Reaction at the cathode remains the same. And hydrogen is produced at the cathode. The following reactions take place during electrolysis.

At cathode:

$$4H^+_{(aq)} + 4e^- \longrightarrow 2H_{2(g)}$$

At anode:

$$4OH^-_{(aq)} \longrightarrow 2H_2O_{(l)} + 4e^- + O_{2(g)}$$

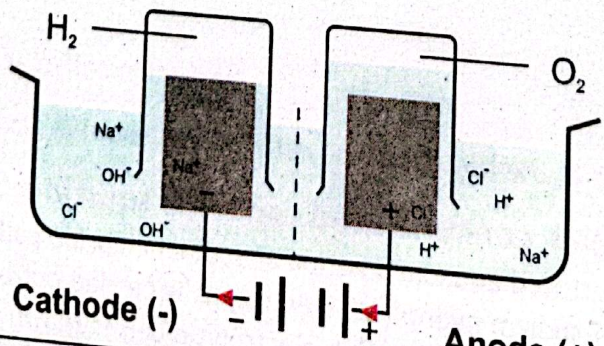


Figure 4.4: Electrolysis of dilute aqueous NaCl

b. Electrolysis of dilute sulphuric acid using platinum electrodes

In an aqueous solution, sulphuric acid ionizes to form hydrogen ions and sulphate ions. Autoionization of water gives hydrogen ions and hydroxide ions.

$$H_2SO_{4(aq)} \longrightarrow 2H^+_{(aq)} + SO_4^{2-}{}_{(aq)}$$

$$H_2O_{(l)} \rightleftharpoons 2H^+_{(aq)} + OH^-_{(aq)}$$

During electrolysis, hydrogen ions move towards the cathode and are reduced to form hydrogen. Whereas hydroxyl ions and sulphate ions move towards the anode. At the anode, hydroxyl ions are oxidized and sulphate ions remain unchanged.

At cathode

$$4H^+_{(aq)} + 4e^- \longrightarrow 2H_{2(g)}$$

At anode

$$4OH^-_{(aq)} \longrightarrow 2H_2O_{(l)} + 4e^- + O_{2(g)}$$

Therefore, in the electrolysis of dilute aqueous H_2SO_4 using a platinum electrode, hydrogen gas is produced at the cathode and oxygen gas at the anode.

c. Electrolysis of copper(II) sulphate using platinum electrodes

The aqueous solution of copper sulphate contains copper ions and sulphate ions from copper(II) sulphate and hydrogen ions and hydroxide ions from water. During electrolysis copper ions and hydrogen ions are attracted towards the cathode. At the cathode, only copper ions are reduced and hydrogen ions remain unchanged. The sulphate ions and hydroxide ions are attracted towards the anode. At the anode, only hydroxide ions are oxidized and sulphate ions remain unchanged.

At cathode

$$2Cu^{2+}_{(aq)} + 4e^- \longrightarrow 2Cu_{(s)}$$

At anode

$$4OH^-_{(aq)} \longrightarrow 2H_2O_{(l)} + O_{2(g)} + 4e^-$$

Therefore, in the electrolysis of aqueous copper(II)sulphate using a platinum electrode, copper metal is produced at the cathode and oxygen gas at the anode. The blue colour of the copper sulphate solution gradually fades away as the reaction goes on.

d. Electrolysis of copper(II) sulphate using copper electrodes

If you use copper electrodes rather than platinum, the cathode reaction remains the same but the anode reaction differs. At anode, copper atoms break away from the electrode forming Cu^{2+} ions giving up electrons to the anode. These electrons are moved towards the cathode by the power source. The following reactions occur during electrolysis.

At cathode

$$Cu^{2+}_{(aq)} + 2e^- \longrightarrow Cu_{(s)}$$

At anode

$$Cu_{(s)} \longrightarrow Cu^{2+}_{(aq)} + 2e^-$$

During electrolysis copper anode is consumed gradually and the copper cathode gains mass due to the deposition of pure copper on it.

The copper metal obtained from its ores is usually impure. It contains impurities such as zinc, iron, silver and gold. These impurities are removed by the process of electrolysis. In this process, impure copper bars act as anode and pure copper bars as cathode. $CuSO_4$ a solution containing little sulphuric acid is used as the electrolyte. (See Figure 4.5)

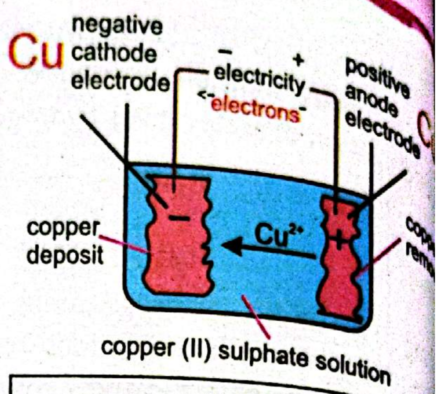


Figure 4.5: Electrolysis of copper (II) sulphate solution

On passing electricity, copper anode dissolves forming Cu^{+2} ions. Cations move towards the cathode at which only Cu^{+2} ions are reduced. Thus copper deposits at the cathode. The less electropositive metals, silver and gold fall to bottom of the cell. Copper obtained in this process is 99.5% pure. The following reac occurs in this process.

At anode: $Cu_{(s)} \longrightarrow Cu^{2+}_{(aq)} + 2e^-$

At cathode: $Cu^{2+}_{(aq)} + 2e^- \longrightarrow Cu_{(s)}$

4.3 Electrolysis of halid compound

During the electrolysis of a halide compound (a compound containing halogen ions chloride, bromide, or iodide), the products depend on whether the solution is dilut concentrated. Here's a simple explanation:

1. Electrolysis of Dilute Halide Solution

At the Anode (positive electrode): Oxygen gas is usually produced because water br down into oxygen and hydrogen ions. This happens because the water molecules compete halide ions for discharge.

At the Cathode (negative electrode): Hydrogen gas is produced as water molecules reduced to form hydrogen gas and hydroxide ions.

Example:

If you electrolyse a dilute sodium chloride (NaCl) solution, the products are:

Anode: Oxygen gas (O_2)

Cathode: Hydrogen gas (H_2)

2. Electrolysis of Concentrated Halide Solution

At the Anode: The halogen (chlorine, bromine, or iodine) is produced because there are m halide ions, so they are discharged instead of water.

At the Cathode: Hydrogen gas is still produced because water is reduced.

Example:

If you electrolyse concentrated sodium chloride (NaCl) solution, the products are:

Anode: Chlorine gas (Cl_2)

Cathode: Hydrogen gas (H_2)

Key Rule to Remember:

Dilute Solution: Oxygen at the anode.

Concentrated Solution: Halogen at the anode.

The cathode always produces hydrogen gas in both cases.

4.4 Electroplating (deposition using the same electrode)

The **electrolytic** process used to deposit one metal on another metal is called **electroplating**. An object can be electroplated by making it cathode in an electrolytic tank containing ions of the plating metal. The plating metal is made anode. On passing electricity through the electrolytic tanks, a thin layer of anode metal is deposited on the surface of the object.

4.4.1 Applications of Electroplating

Steel objects are often protected from corrosion by electroplating with zinc, tin and chromium.

Zinc Plating

Zinc plating on steel is done by using zinc metal as anode. A solution of potassium zinc cyanide $K_2[Zn(CN)_4]$ containing little sodium cyanide is used as an electrolyte. The steel object is made of cathode. During the electrolysis zinc at the anode enters the solution as Zn^{+2} ions, which are deposited at the cathode. The electrolyte ionizes as follows.

$$K_2[Zn(CN)_4]_{(aq)} \rightleftharpoons 2K^{+1}_{(aq)} + [Zn(CN)_4]^{-2}_{(aq)}$$

$$[Zn(CN)_4]^{-2}_{(aq)} \rightleftharpoons Zn^{+2}_{(aq)} + 4CN^{-1}_{(aq)}$$

Following reactions occur at the electrodes:

At anode: $Zn_{(s)} \longrightarrow Zn^{+2}_{(aq)} + 2e^-$

At cathode: $Zn^{+2}_{(aq)} + 2e^- \longrightarrow Zn_{(s)}$

Sodium cyanide prevents the hydrolysis of electrolytes.

Awareness against pollution

Cyanide ions are extremely toxic. Therefore, a solution containing cyanide ions must not be dropped into rivers and streams. This is responsible for killing fish and other animals.

Society, Technology and Science

Tin-plated steel is used to make cans. Food and beverages industries use tinplated steel cans, this is because the components of food beverages and preservatives contain organic acids or their salts. They may form toxic substances by reacting with iron. These acids and salts are corrosive. Tin plating is non-poisonous and prevents corrosion.

Tin Plating

Food cans are generally tin-plated. Tin plating on steel is done by using tin as an anode and a solution of stannous sulphate, ($SnSO_4$) as electrolyte. A few drops of dil. H_2SO_4 are added to the electrolyte to prevent its hydrolysis. The electrolyte ionizes as follows.

$$SnSO_{4\,(aq)} \rightleftharpoons Sn^{+2}_{(aq)} + SO_4^{-2}_{(aq)}$$

During the electrolysis following reactions occur:

At anode: $Sn_{(s)} \longrightarrow Sn^{+2}_{(aq)} + 2e^-$

At cathode: $Sn^{+2}_{(aq)} + 2e^- \longrightarrow Sn_{(s)}$

Chromium Plating

Since chromium metal does not adhere strongly to the steel therefore steel is first plated with copper or nickel and then with chromium. For electroplating chromium, chromium metal is used as an anode and chromium sulphate, $Cr_2(SO_4)_3$ as an electrolyte. A few drops of dil. H_2SO_4 are added to the electrolyte to prevent its hydrolysis.

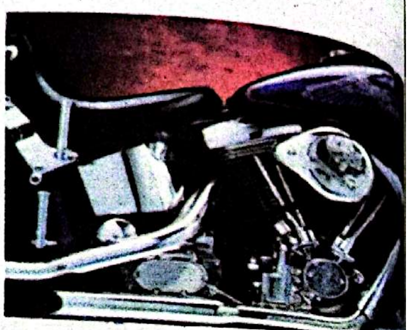


Figure 4.6: Motor Bike

The electrolyte ionizes as follows:

$$Cr_2(SO_4)_{3\,(aq)} \rightleftharpoons 2Cr^{+3}_{(aq)} + 3SO_4^{-2}{}_{(aq)}$$

Do you agree that the following reactions will occur at the electrodes?

At anode: $Cr_{(s)} \rightleftharpoons Cr^{+3}_{(aq)} + 3e^-$

At cathode: $Cr^{+3}_{(aq)} + 3e^- \rightleftharpoons Cr_{(s)}$

Chromium-plated steel is used to make automobile parts (see Figure 4.5).

4.5 Galvanic Cells (Daniel Cells)

The cell which involves a spontaneous redox reaction to generate electricity is called a galvanic or voltaic cell. The name Voltaic is given to this cell because Alessandro Volta discovered the first such cell. The English chemist Fredrick Daniel constructed the first voltaic cell using zinc (Zn) and copper (Cu) electrodes. Therefore this cell is named Daniel Cell. A galvanic or Daniel cell is shown in Figure 4.7.

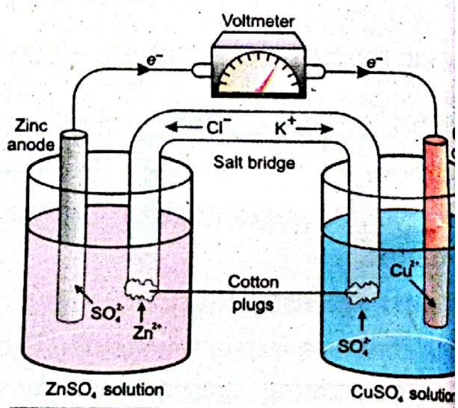


Figure 4.7: Galvanic Cell

A galvanic cell consists of the following parts:

(1) A zinc bar dipped into a 1M $ZnSO_4$ solution.

(2) A copper bar dipped into a 1M $CuSO_4$ solution.

(3) A salt bridge is an inverted U tube containing an inert electrolyte such as KCl. Its ions do not react with the electrodes or the ions the solution. It makes the electrical contact between the solutions through which i can move.

(4) A voltmeter to measure current.

Each compartment of the cell is called a half-cell. Thus a Daniel cell consists of two half-cells joined in series. When the circuit is complete, electrons begin to flow from the Zn rod through the external wires to the Cu rod. Thus Zn half-cell acts as an anode and the Cu half-cell as a cathode. Note that a half cell consists of a metal rod dipped in the solution of its salt.

Concept Assessment Exercise 4.2

Sketch a voltaic cell labeling the cathode, the anode and the direction of flow of the electrons. Use the following chemicals:

Silver, Zinc, Silver Nitrate and zinc sulphate ($ZnSO_4$).

(Hint: Zn is more active than Ag)

4.5.1 Reactions in a Daniel Cell

In Daniel's cell, electrons flow from the Zn rod, through the external wire to the Cu rod. This is because Zn has more tendency to undergo oxidation than Cu. Zn atoms from the rod go into the solution as Zn^{+2} ions leaving electrons on the rod. These electrons flow in the external circuit. Thus oxidation half reaction occurs at the anode compartment. Cu^{+2} ions in copper sulphate solution capture electrons from the Cu electrode and are reduced. Reduction half reduction occurs at the cathode compartment. Such oxidation and reduction reactions are called half-cell reactions.

At Anode (Oxidation half reaction):

$$Zn_{(s)} \longrightarrow Zn^{+2}_{(aq)} + 2e^-$$

At Cathode (Reduction half-reaction):

$$Cu^{+2}_{(aq)} + 2e^- \longrightarrow Cu_{(s)}$$

4.6 Electrochemical Series

The tendency of a metal to become oxidized or reduced, when placed in its salt solution is called electrode potential (E^o). Electrode potential is the measure of the potential of a reaction that can occur at the electrode. It is measured in volts. The electrode potential of an electrode is determined experimentally by using a standard hydrogen electrode. The International Union of Pure and Applied Chemistry (IUPAC) has recommended the representation of electrode potential as reduction potentials. A table showing the arrangement of metals based on increasing reduction potentials is called an electrochemical series.

A metal higher in the series has a lower value of reduction potential than the metal below it in the series. So, it has a higher tendency to lose electrons and is more active than the metals below it. In a voltaic cell electrode with the lower value of reduction potential acts as anode and the electrode having a higher reduction potential act as a cathode.

Table 1: Electrochemical Series

Reduction Half-reaction	E^0 (Volts)
$Li^+ + \bar{e} \rightleftharpoons Li$	-3.05
$K^+ + \bar{e} \rightleftharpoons K$	-2. 92
$Ba^{2+} + 2\bar{e} \rightleftharpoons Ba$	-2.90
$Ca^{2+} + 2\bar{e} \rightleftharpoons Ca$	-2.76
$Na^{1+} + 1\bar{e} \rightleftharpoons Na$	-2.71
$Mg^{2+} + 2\bar{e} \rightleftharpoons Mg$	-2.38
$Al^{3+} + 3\bar{e} \rightleftharpoons Al$	-1.67
$Mn^{2+} + 2\bar{e} \rightleftharpoons Mn$	-1.03
$2H_2O + 2\bar{e} \rightleftharpoons H_2 + 2OH^-$	-0.83
$Zn^{2+} + 2\bar{e} \rightleftharpoons Zn$	-0.76
$Cr^{3+} + 3\bar{e} \rightleftharpoons Cr$	-0.74
$Fe^{2+} + 2\bar{e} \rightleftharpoons Fe$	-0.44
$PbSO_4 + 2\bar{e} \rightleftharpoons Pb + SO_4^{2-}$	-0.36
$Ni^{2+} + 2\bar{e} \rightleftharpoons Ni$	-0.25
$Sn^{2+} + 2\bar{e} \rightleftharpoons Sn$	-0.14
$Pb^{2+} + 2\bar{e} \rightleftharpoons Pb$	-0.13
$Fe^{3+} + 3\bar{e} \rightleftharpoons Fe$	-0.04
$2H^+ + 2\bar{e} \rightleftharpoons H_2$	0.00
$AgCl + \bar{e} \rightleftharpoons Ag + Cl^-$	+0.22
$Hg_2Cl_2 + 2\bar{e} \rightleftharpoons 2Hg + 2Cl^-$	+0.27
$Cu^{2+} + 2\bar{e} \rightleftharpoons Cu$	+0.34
$Cu^+ + 1\bar{e} \rightleftharpoons Cu$	+0.52
$I_{2(aq)} + 2\bar{e} \rightleftharpoons 2I^-$	+0.54
$Fe^{3+} + \bar{e} \rightleftharpoons Fe^{2+}$	+0.77
$Ag^+ + \bar{e} \rightleftharpoons Ag$	+0.80
$Br_{2(aq)} + 2\bar{e} \rightleftharpoons 2Br^-$	+1.09
$O_2 + 4H^+ + 4\bar{e} \rightleftharpoons 2H_2O$	+1.23

$MnO_2 + 4H^+ + 2\bar{e} \rightleftharpoons Mn^{2+} + 2H_2O$	+1.28
$Cr_2O_7^{2-} + 14H^+ + 6\bar{e} \rightleftharpoons 2Cr^{3+} + 7H_2O$	+1.33
$Cl_{2(g)} + 2\bar{e} \rightleftharpoons 2Cl^-$	+1.36
$2ClO_3^{-1} + 12H^+ + 10\bar{e} \rightleftharpoons Cl_2 + 6H_2O$	+1.47
$8H^+ + MnO_4^- + 5\bar{e} \rightleftharpoons Mn^{2+} + 4H_2O$	+1.49
$PbO_2 + SO_4^{-2} + 4H^+ + 4\bar{e} \rightleftharpoons PbSO_4 + 2H_2O$	+1.69
$H_2O_2 + 2H^+ + 2\bar{e} \rightleftharpoons 2H_2O$	+1.7
$S_2O_3^{-2} + 2\bar{e} \rightleftharpoons 2SO_4^{-2}$	+2.00
$F_2 + 2\bar{e} \rightleftharpoons 2F^-$	+2.87

Example:

Electrochemical series helps us predict which substances will form at the electrodes during electrolysis.

At the Cathode (Negative Electrode):

At the cathode positive ions (cations) gain electrons (reduction happens).The ion lower in the electrochemical series (less reactive) is more likely to get reduced. Example: If the solution contains sodium ions (Na^+) and hydrogen ions (H^+), hydrogen gas (H_2) forms because hydrogen is lower in the series than sodium.

At the Anode (Positive Electrode):

At the anode negative ions (anions) lose electrons (oxidation happens). Halide ions (Cl^-, Br^-, I^-) are discharged before hydroxide (OH^-) unless halides are absent. For example: In a concentraded solution of sodium chloride, chloride ions (Cl^-) are discharged, producing chlorine gas (Cl_2) because chlorine is lower in the series than water.

However in the electrolysis of dilute aqueous NaCl, OH^- ions are discharged instead of Cl^- ions, even though Cl^- ions are lower in the electrochemical series This is due to the following reasons.

Concentration Effect:

The discharge of ions during electrolysis is influenced not only by their position in the electrochemical series but also by their concentration. In dilute aqueous NaCl, the concentration of Cl^- ions is relatively low compared OH^- ions, which are present in larger amounts due to the ionization of water.

Overpotential of Chlorine Gas:

The overpotential (extra voltage required) for the oxidation of Cl^- ions to chlorine gas is higher than that for the oxidation of OH^- ions to oxygen gas. This makes it energetically less favourable to discharge Cl^- ions.

Concept Assessment Exercise 4.3

1. Which of the following metals is more likely to undergo reduction?

$Al^{3+}_{(aq)} + 3e^- \rightleftharpoons Al_{(s)}$ $E^\circ = -1.66\ V$

$Fe^{3+}_{(aq)} + 3e^- \rightleftharpoons Fe_{(s)}$ $E^\circ = -0.44\ V$

2. Arrange the following metals in order of increasing ability to get reduce.

$Na^{+}_{(aq)} + e^- \rightleftharpoons Na_{(s)}$ $E^\circ = -2.71V$

$Zn^{2+}_{(aq)} + 2e^- \rightleftharpoons Zn_{(s)}$ $E^\circ = -0.76V$

$Cu^{2+}_{(aq)} + 2e^- \rightleftharpoons Cu_{(s)}$ $E^\circ = +0.34V$

3. Identify the half-cell in which oxidation occurs and the half-cell in which reduction occurs in the given voltaic cell (Figure 4.8).

Following reactions occur in the cell.

At Anode $Zn_{(s)} \longrightarrow Zn^{2+}_{(aq)} + 2e^-$

At cathode $2H^{+}_{(aq)} + 2e^- \longrightarrow H_{2(g)}$

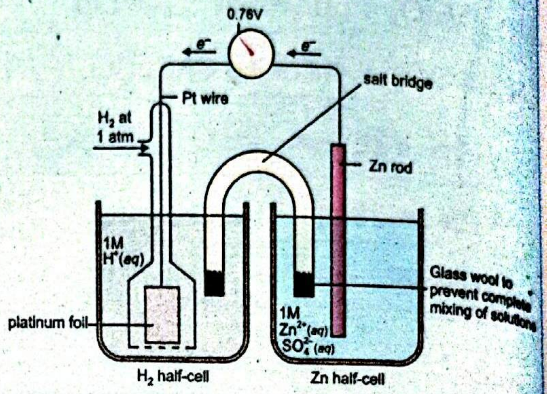


Figure 4.8: Voltaic Cell

4.7 Battery-A Source of Electrical Energy

A battery is a galvanic cell, or a group of galvanic cells joined in series. It generate electric current by a redox reaction. When connected in a circuit its anode is oxidised b releasing electrons. These electrons through the external circuit begin to flow towards th cathode. At the cathode, these electrons reduce the oxidizing agent present in th electrolyte. Examples of batteries are dry cells, storage cells, mercury batteries etc.

Fuel Cell

A fuel cell is a special type of galvanic cell which is based upon the reaction between oxyge and a gaseous fuel hydrogen. When hydrogen burns in air, an exothermic reaction occurs an a lot of chemical energy is released in the form of heat and light. In this reaction, hydrogen oxidized to water.

$$2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(g)} + \text{heat}$$

The energy released from the reaction of hydrogen with oxygen to form water is converted to electrical energy. A hydrogen-oxygen fuel cell has three compartments separated from one another by porous carbon electrodes. These electrodes contain platinum as a catalyst. The middle compartment contains a hot aqueous solution of KOH. Hydrogen gas is passed through the anode compartment and oxygen is passed through the cathode compartment.

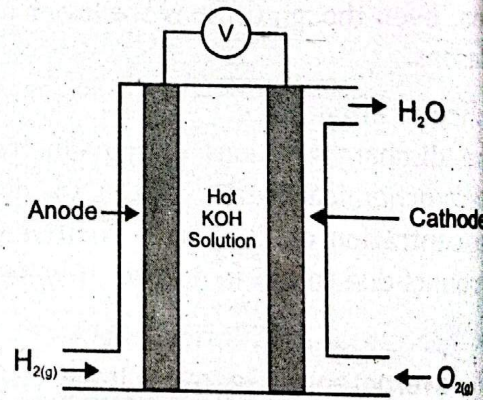


Figure 4.9: Fuel Cell

At the anode, hydrogen is oxidized to water and at the cathode oxygen is reduced to hydroxide ions.

Anode reaction = $2H_{2(g)} + 4OH^-_{(aq)} \longrightarrow 4H_2O_{(l)} + 4e^-$

Cathode reaction = $O_{2(g)} + 2H_2O_{(l)} + 4e^- \longrightarrow 4OH^-_{(aq)}$

Net cell reaction = $2H_{2(g)} + O_{2(g)} \longrightarrow 2H_2O_{(l)}$

The electrons released in the oxidation of hydrogen flow through the circuit towards the cathode. A hydrogen-oxygen cell delivers 0.9 V. The fuel cell operates at high temperatures so the water formed evaporates and may be condensed.

The fuel cells of this kind have been used by the American space program. The water condensed in spacecraft is consumed by the astronauts.

4.7.1 Advantages and disadvantages of fuel cells

Hydrogen-oxygen fuel cells are highly efficient since they convert fuel directly into electricity with very little waste. Fuel cells are a source of clean energy, as they do not produce harmful pollutants. They emit water vapour only. Moreover, fuel cells are highly reliable, as they have no moving parts. They also have a long life span with little maintenance. Hydrogen - oxygen used in fuel cells is obtained from renewable energy sources.

Unlike fuel cells, gasoline-powered combustion engines in vehicles emit pollutants, including carbon dioxide, oxides of nitrogen and sulphur, which cause pollution and create smog. These pollutants cause respiratory problems and other health issues. Moreover, gasoline is obtained from non-renewable sources of energy.

Fuel cells have a few disadvantages. Hydrogen is highly inflammable and explosive in nature. It requires careful handling for storage and use. So, it cannot be transported easily from one place to another. Hydrogen used in fuel cells is produced by electrolysis of water which is very expensive.

KEY POINTS

- An electrochemical cell in which electrical energy is used to drive a chemical reaction is called an electrolytic cell.
- Oxidation always occurs at the anode. Reduction always occurs at the cathode.
- An electrochemical cell in which a spontaneous oxidation-reduction reaction generates electricity is called a galvanic or voltaic cell.
- In a galvanic cell oxidation half-reaction occurs in the anode compartment and reduction half-reaction occurs in the cathode compartment.
- A battery is a galvanic cell, or a group of galvanic cells joined in series.
- Electrolysis of brine is used for the industrial production of sodium hydroxide.
- Electrolytic process used to deposit one metal on another metal is called electroplating.
- A fuel cell is a special type of galvanic cell which is based upon the reaction between oxygen and gaseous fuel hydrogen.
- A table showing the arrangement of metals based on increasing reduction potentials is called an electrochemical series.

References:

- B.Earl and LDR Wilford, Further Advanced Chemistry.
- B.Earl and LDR Wilford, Introduction to Advanced Chemistry.

EXERCISE

1. Multiple Choice Questions (MCQs)

i. Which of the following statements is not correct about the galvanic cell?
   (a) Cations are reduced at the cathode (b) Anions are oxidized at the anode
   (c) Electrons flow from cathode to anode (c) Oxidation occurs at the anode

ii. Which of the following is not true about the Daniel cell
   (a) Half-cell of an active metal acts as a cathode.
   (b) Half-cell contains an element in contact with its ions in aqueous solution.
   (c) A salt bridge connects the two half-cells.
   (d) A spontaneous oxidation-reduction reaction generates electricity.

iii. Which of the following does not involve an electrolytic process?
   (a) Refining of copper
   (b) Manufacture of sodium from NaCl
   (c) Electroplating of steel
   (d) Reduction of metal oxide by a reducing agent.

iv. Galvanizing is
   (a) Coating with Sn (b) Coating with Zn
   (c) Coating with Cr (d) Coating with Cu

v. Which of the following is true for the Nelson cell?
   (a) Sodium metal is produced at the anode
   (b) Chlorine gas is produced at anode
   (c) Hydrogen gas is produced at the anode
   (d) Sodium ions are not reduced at the cathode

vi. Electroplating involves:
   a) Using an electrolyte to oxidize a metal.
   b) Coating a metal object with a thin layer of metal through electrolysis.
   c) Melting a metal object to form a thin coating.
   d) Using heat to form a layer of metal on another metal object

vii. In a voltaic cell, the salt bridge serves the function of:
   a) Preventing electrons from flowing in the external circuit.
   b) Maintaining electrical neutrality by allowing ion movement.
   c) Storing excess energy from the cell.
   d) Generating additional voltage for the cell.

viii. If the voltage data shows metal A has a higher standard reduction potential than metal B, it can be concluded that:
   a) Metal A is more reactive than metal B.
   b) Metal B is more reactive than metal A.
   c) Metal A and metal B have the same reactivity.
   d) Metal A is less likely to gain electrons than metal B

2. Short questions

i. What is a fuel cell?
ii. Write chemical reactions that occur in Nelson's cell.
iii. Why tin-plated steel is used to make food cans?
iv. Explain one example from daily life which involves an oxidation-reduction reaction.
v. Define electrochemical series.
vi. Why does chlorine gas form at the anode during the electrolysis of molten lead(II) chloride?
vii. How do hydrogen-oxygen fuel cells benefit the environment compared to gasoline engines
viii. Sketch a Daniel cell with labelled components and indicate the direction of electron flow.

3. Long questions

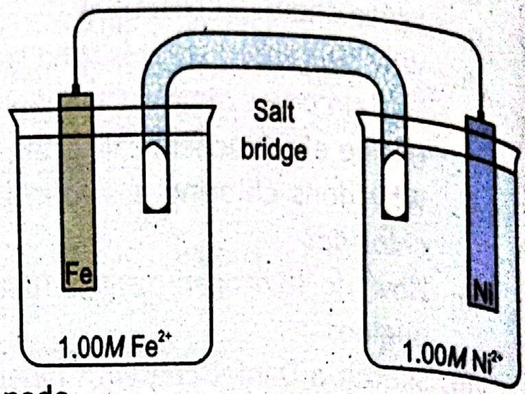
i. Define oxidation and reduction in terms of loss or gain of oxygen or hydrogen.
ii. Sketch a Daniel Cell, labelling the cathode, anode, and the direction of flow of the electrons.
iii. Describe the method of recovering metal from lead(II) chloride.
iv. Construct ionic half-equations for reaction at electrodes in the electrolysis of copper(II) sulphate in the presence of copper electrodes.
v. Electrolysis has a major role in electrochemical industries.
   (a) Sketch an electrolytic cell, label the anode and cathode and indicate the direction of electron transfer.
   (b) Describe the nature of the electrochemical process.
   (c) Distinguish between electrolytic and voltaic cells.
vi. For each of the following electrolytes, write electrode half-reactions in each case that would occur during their electrolysis.
   a. Copper(II) sulphate solution using copper electrodes
   b. Copper(II) chloride using carbon electrodes
vii. Predict the products of electrolysis for a dilute solution of potassium iodide
viii. Why does chlorine gas form at the anode during the electrolysis of molten lead(II) chloride?
ix. What changes in observations might you expect when comparing electrolysis in molten lead(II) chloride and concentrated aqueous sodium chloride?
x. How would you set up an experiment to demonstrate the production of different substances at the anode and cathode during the electrolysis of dilute copper(II) sulfate using copper electrodes?
xi. Compare and contrast the products formed at the electrodes during the electrolysis of concentrated aqueous sodium chloride and dilute sulphuric acid using inert electrodes.
xii. Assess the environmental impact of using hydrogen-oxygen fuel cells compared to gasoline engines in vehicles. Provide arguments for and against each technology.
xiii. Compare the ionic half-equations for the electrolysis of a dilute solution and a concentrated solution of sodium chloride. How do the products differ?

THINK TANK

1. The following redox reaction occurs in the voltaic cell illustrated below:

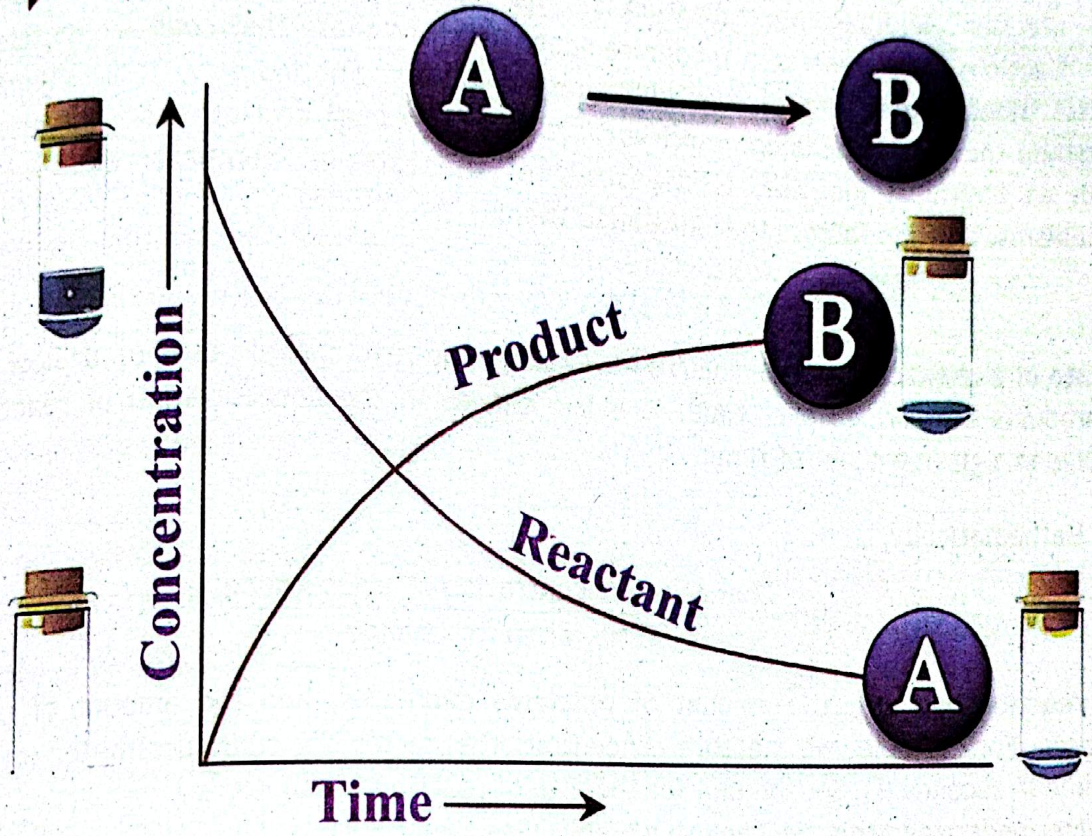
$$Ni^{+2}_{(aq)} + Fe_{(s)} \longrightarrow Fe^{+2}_{(aq)} + Ni^{+}_{(s)}$$

Select the anode, and cathode and indicate the direction of flow of electrons.



2. When molten sodium bromide is electrolyzed, reddish-brown fumes are seen at the anode. Answer the following questions.
   (i) Name the reddish-brown fumes seen at anode
   (ii) What difference would you expect to observe if you used molten sodium iodide?
   (iii) Write the electrode reactions in both cases.
   (iv) What difference would expect to observe if you used a dilute aqueous solution of potassium bromide? Also, write electrode reactions.
3. State what is formed at electrodes during the electrolysis of the following substances using carbon electrodes. Do not write reactions.
   (i) dilute aqueous solution of potassium chloride
   (ii) copper(II) chloride
   (iii) molten lead(II) bromide

UNIT 05



REACTION KINETICS

Student Learning Outcomes (SLOs)

- Describe collision theory in terms of number of particles per unit volume, frequency of collisions of particles, kinetic energy of particles, and activation energy.
- State that catalyst increases the rate of reaction, provides alternate pathway with lower activation energy, and remains unchanged at the end of a reaction.
- Describe the physical parameters that may be affected by the rate of reaction including change in mass, temperature, and formation of gas.
- Interpret data, including graphs, for investigating rate of reaction.
- Explain the effect on rate of reaction of changing concentration of a reactant, pressure of gases, surface area of solids, temperature, and presence of catalyst (including enzymes) using collision theory.
- Justify the importance of chemical kinetics in food industry to determine ideal harvesting and transportation times for produce.

Chemical reactions are processes in which mass and energy are constantly changing. These reactions can take place at a range of speeds, from very fast to very slow. Fermentation is known to be a slow reaction, taking several weeks to make enough products, and digestion is a slow reaction. Acid-base neutralization is a fast reaction, taking only a few microseconds. Other reactions take place at a moderate speed, such as those that contract muscles, send impulses along nerves and capture photographic images. For industry, it is important to understand the conditions under which a reaction will be most cost-effective. Kinetics, also known as chemical kinetics, is the study of the rate of chemical reactions, their mechanisms, and the factors that influence them.

5.1 Rates of Reactions

The rate of a chemical reaction tells us how quickly the reactants are used up or how quickly the products are formed over time. It is the change in the concentration of reactants or products in a given amount of time.

Mathematically,

$$\text{Rate} = \frac{\text{Change in concentration of a substance}}{\text{Time taken for change}}$$

As a reaction happens, the amount of reactants decreases, and the amount of products increases. For example, we measure concentration in moles per cubic decimeter (mol dm^{-3}) and time in seconds (s). So, the unit for the rate of reaction is mol dm^{-3}s^{-}.
To better understand this, we can use a graph. (See figure 5.1)

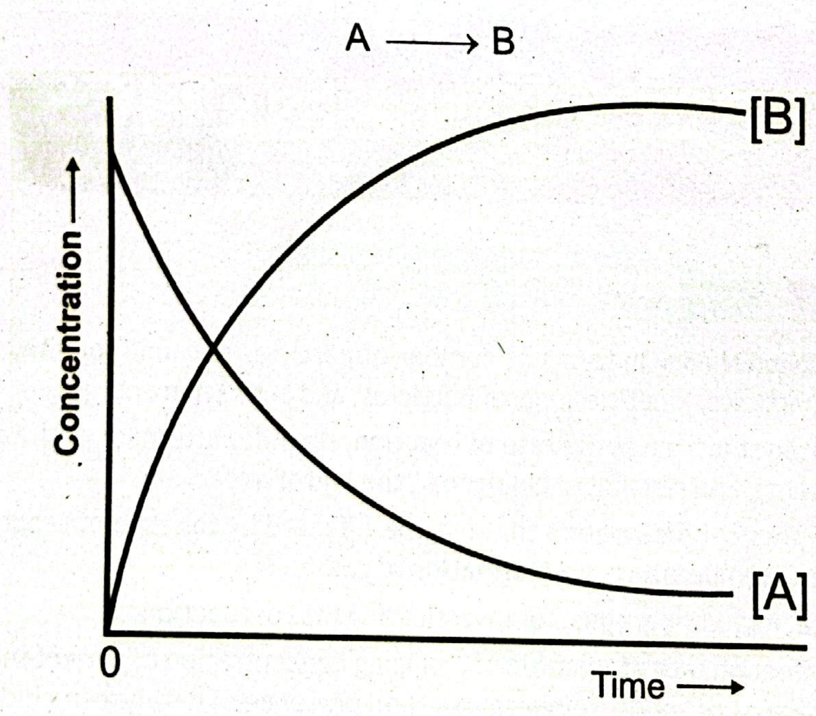


Figure 5.1: Graphical Representation of the rate of a chemical reaction

A graph with two curves—one for reactants showing decreasing concentration and one for products showing increasing concentration over time. At the beginning of the reaction, the slope of the reactant curve is steep, showing that the reactants are being used up quickly. At the same time, the product curve is steep, showing that products are being formed quickly.

1. As time goes on, the curves become less steep. This means the reaction slows down because there are fewer reactant particles to react.

2. Eventually, the curves become flat. This means the reaction has stopped because all the reactants are used up or the system has reached equilibrium.

This shows that the rate of reaction is not constant. It changes as the reaction progresses.

Average Rate of Reaction

$$\text{Average rate} = \frac{\text{Total change in concentration}}{\text{Total time taken}}$$

Consider a general reaction

$$A \longrightarrow B$$

The rate of reaction can be expressed in terms of the rate of disappearance of reactant A or the rate of appearance of product B.

$$\text{Rate of reaction} = -\frac{d[A]}{dt}$$

$$\text{Rate of reaction} = +\frac{d[B]}{dt}$$

Where, d [A] and d [B] are the changes in the concentration of A and B respectively. The negative sign indicates a decrease in the concentration of the reactant A whereas the positive sign indicates the increase in the concentration of product B.

When we talk about the rate of a chemical reaction, we're interested in how quickly or slowly a chemical reaction happens. This is often measured by how fast the reactants are used up or how quickly the products are formed.

Suppose you are carrying out a chemical reaction where substance A reacts with another substance B to produce substance C.

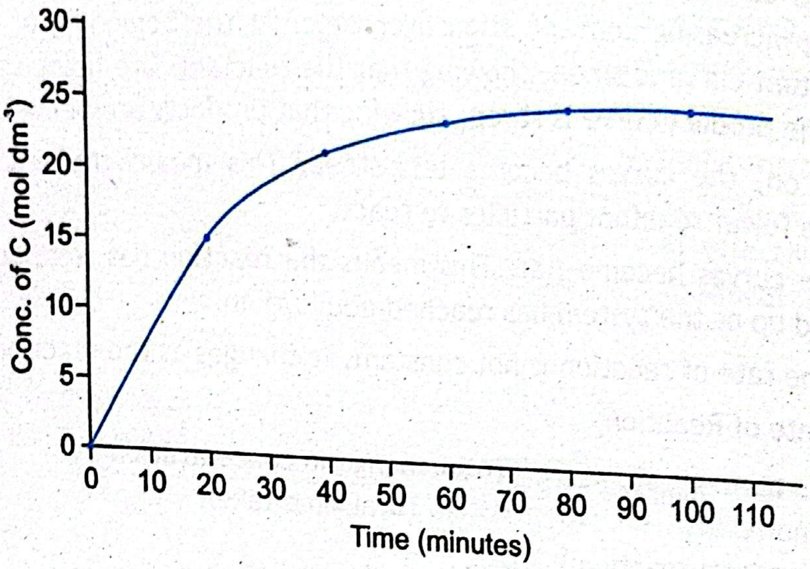
Interpreting Data

Suppose a student is carrying out a chemical reaction where substance A reacts with another substance B to produce substance C. He followed the rate of reaction by determining the concentration of C produced at regular intervals. The following data was obtained.

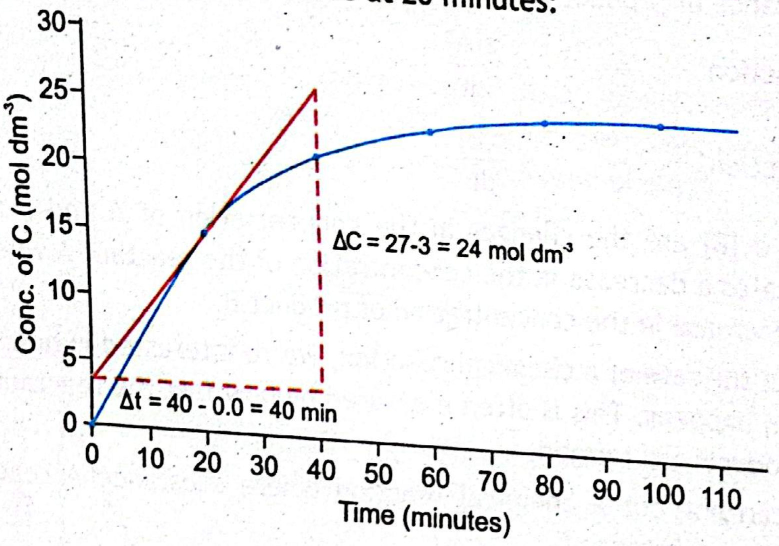
$$A + B \longrightarrow C$$

Time (minutes)	Concentration of C (mol dm^{-3})
0.0	0.00
20	15
40	21
60	23
80	25
100	25

The rate of reaction can be found by plotting a graph of concentration of C against time.



From this graph you can determine the rate of reaction at any moment by determining the gradient at that moment. Suppose you want to calculate the rate of reaction at 20 minutes. For this purpose, draw a tangent to the curve at 20 minutes:



$$\text{Rate of reaction (or gradient)} = \frac{\Delta C}{\Delta t}$$

$$\text{Rate of reaction (or gradient)} = \frac{24 \text{ mol dm}^{-3}}{40 \times 60\text{s}}$$

$$= 0.01 \text{ mol dm}^{-3}\text{s}^{-1}.$$

Thus, the rate of reaction at 20min = 0.01 mol dm^{-3}s^{-1}

$$\text{Average rate of reaction} = \frac{\text{total amount of C produced}}{\text{Total time taken}}$$

$$\text{Average rate of reaction} = \frac{25 \text{ mol dm}^{-3}}{100 \times 60\text{s}}$$

$$= 0.0042 \text{ mol dm}^{-3}\text{s}^{-1}.$$

Conclusion

From this experiment, you can see that the reaction rate isn't constant. The amount of substance C formed increases more quickly at first and then slows down. This is a common pattern in chemical reactions, where the rate can change as reactants are consumed.

5.2 Collision Theory and Activation Energy

In a chemical reaction, bonds between atoms are broken and new bonds are formed. Collision theory helps us understand how these reactions happen. For a reaction to occur, the atoms or molecules must collide with each other. However, not all collisions lead to a reaction. The success of a collision depends on two things:

1. **Energy**

The colliding particles must have enough energy to overcome the repulsion between their outer electrons.

2. **Orientation**

The particles must be aligned in a way that allows the necessary atoms to come together and form new bonds.

The smallest amount of energy needed for a reaction to happen is called activation energy. If the energy of the colliding particles is less than this activation energy, the reaction will not occur.

Reactions happen faster when more particles have enough energy to collide effectively. If the activation energy is high, fewer particles will have enough energy, and the reaction will be slower. If the activation energy is low, more particles can collide effectively, and the reaction will happen faster.

For example, when hydrogen (H_2) and chlorine (Cl_2) react to form hydrogen chloride (HCl), the molecules need enough energy to break their bonds and form new ones. When an effective collision occurs, the particles form a temporary, high-energy state called the activated complex (or transition state). This complex quickly breaks down to form the final products. (Figure 5.2)

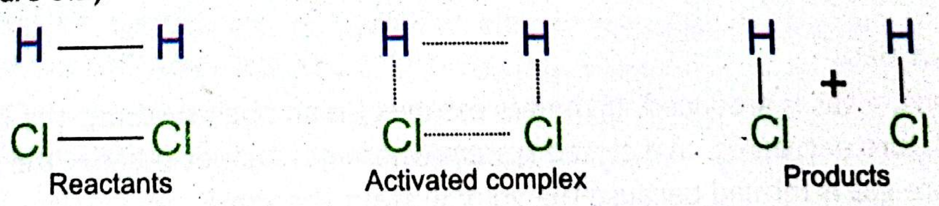


Figure 5.2: Effective Collision of Molecules

You can think of activation energy like a hill. The reacting molecules need to climb this hill (using energy) before they can roll down the other side and form products. If the molecules don't have enough energy to reach the top, they roll back and remain unchanged.

5.3 Catalysts and their Role in Reaction Kinetics

In industries, reactions are often carried out at high temperatures to produce products quickly. However, high temperatures can be dangerous and may damage certain chemicals. An alternative way to speed up reactions is to use a catalyst.

A catalyst is a substance that speeds up a chemical reaction without being used up itself. It works by providing an easier pathway for the reaction to happen, which has a lower activation energy. With a lower activation energy, more particles can collide effectively, and the reaction happens faster.

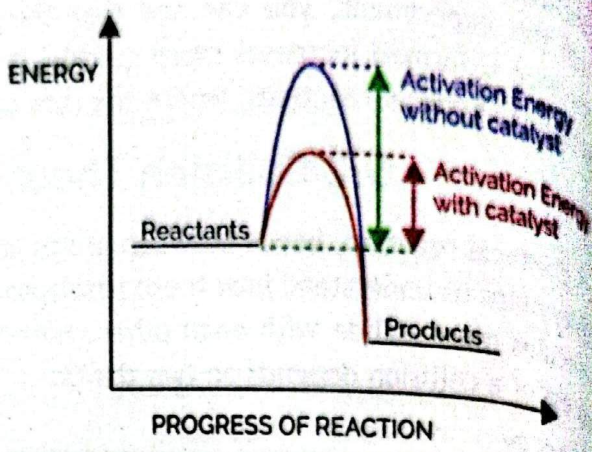


Figure 5.3: Effect of a catalyst on the reaction Kinetics

It's important to note that a catalyst doesn't change the overall energy of the reaction or its outcome. It only makes the reaction happen faster. Catalysts cannot make reaction occur if it is not already possible based on the reaction's energy changes.

Concept Assessment Exercise 5.1

1. How does the presence of a catalyst alter the activation energy of a reaction?
2. Why is it important for a catalyst to remain unchanged at the end of a reaction?

5.3.1 Physical Parameters that Affect the Rate of Reaction

1. Change in Mass

During a chemical reaction, the mass of the reactants decreases because they are used up, while the mass of the products increases as they are formed.

2. Formation of Gas

In some reactions, a gas is produced. If the gas escapes (in an open system), the total mass of the reaction mixture decreases. In a closed system where gas cannot escape, the pressure increases as more gas is formed because the volume stays the same.

3. Temperature

When the temperature of a reaction increases, the particles move faster, causing them to collide more often. This increase in collision frequency results in a faster reaction rate.

5.3.2 Factors Affecting Rate of Reactions

Several factors influence how fast a reaction happens by changing the number of successful collisions between particles. Some of the important factors are:

1. Concentration of Reactants

The more reactant particles there are in a given space, the more likely they are to collide. This means that increasing the concentration of reactants makes the reaction happen faster.

- For example, acid rain damages marble more quickly when the acid is stronger.
- Two antacid tablets neutralize stomach acid faster than one tablet because there are more reacting particles.
- Hydrogen and chlorine gases react twice as fast if their concentrations are doubled.

2. Surface Area

When solid reactants have more surface area exposed, the reaction happens faster. This is because there are more opportunities for particles to collide.

- Powdered zinc reacts with dilute HCl faster than a solid chunk of zinc because the powder has more exposed surface area.
- Similarly, powdered aluminium reacts quickly with NaOH, while aluminium foil reacts more slowly.

3. Temperature

Raising the temperature increases the speed of particles, leading to more frequent and energetic collisions. However, for a collision to cause a reaction, the particles must:

- Have enough energy (called activation energy).
- Be oriented correctly when they collide.

At normal temperatures, only a small number of particles have enough energy to react. A graph called the Maxwell-Boltzmann curve shows how energy is distributed among particles. Most particles have medium energy, while only a few have the activation energy needed for a reaction. When the temperature increases, more particles gain enough energy to overcome the activation energy barrier, leading to faster reactions.

The curve shows the distribution of available energy between the molecules of a gas at constant temperature (Figures 5.4 and 5.5). It clearly shows that most of the molecules do not have the necessary activation energy. When temperature increases (say from T_1 to T_2), the energy of the molecules also increases. Thus, the proportion of molecules having required activation energy increases.

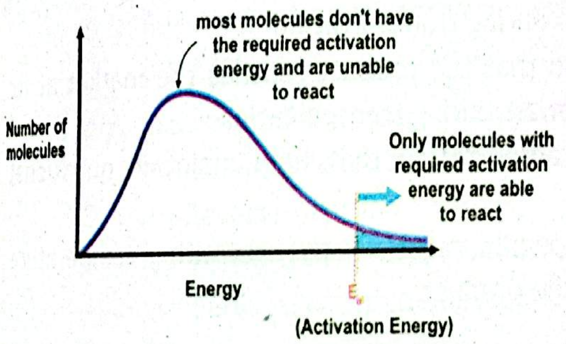


Figure 5.4: Maxwell Boltzmann curve of kinetic energy

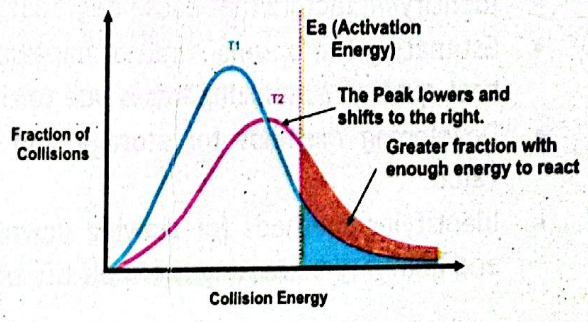


Figure 5.5: Maxwell Boltzmann curve of kinetic energy at 2 temperature

Hence an increase in kinetic energy of reactant molecules increases the collision frequency i.e. the number of effective collisions and hence the reaction rate.

1. Pressure of gases

Pressure increases the concentration of gases for a given volume. There will be mo collisions, which will increase in reaction rate. For instance, a mixture of H_2 molecules and molecules will react twice as quickly when the partial pressure of one of the H_2 molecules doubled compared to the partial pressure of the other.

2. Catalyst

A detailed account of the influence of catalyst on reaction rates is given in section 5.3

Concept Assessment Exercise 5.2

1. In what way does increasing the surface area of a solid reactant affect the rate o reaction?
2. How does temperature affect the rate of reaction?
3. Discuss the effect of changing the concentration of a reactant on the rate o reaction.

5.3.4 Enzymes

Most of the chemical reactions that occur in living organisms are regulated by molecules cal enzymes. These are biochemical catalysts i.e., substances that increase the rate of chemi reactions within living things. Enzymes like catalysts are not consumed during chemi reactions. Virtually all reactions in living cells are catalyzed by enzymes. An enzyme i specialized protein that catalyzes specific biochemical reactions. Each enzyme catalyzes o one reaction. Most of the enzymes are found inside the cells. However, some are foun extracellular fluids such as saliva, gastric juice, etc. Enzymes may speed up reactions b factor of 10^{30}. Enzymes have specific shapes. They hold the reactant molecules in the r orientation necessary for successful collisions. This causes an increase in reaction rates.

5.4 Role of Chemical Kinetics in the Food Industry

When it comes to the food industry, chemical kinetics plays an important role. Some of key roles include:

- Identifying the optimal time to harvest and transport product, so that it has the b taste, texture, and nutritional content.
- Identifying factors that cause degradation during transportation.
- Estimating the optimal time of harvest so that the product reaches the market at best quality. Minimizing losses due to ripeness during transportation
- Developing methods for storage and transportation that help maintain nutritio value.
- Identifying methods for slowing down specific reactions by controlling temperatu and humidity increasing the shelf life of the product.

KEY POINTS

- The rate of a chemical reaction is a change in the concentration of the reactant or product in a given time.
- The rate of reaction between two specific time intervals is called the average rate of reaction.
- The rate of a chemical reaction depends upon the activation energy for the reaction.
- The minimum amount of kinetic energy that the interacting particles must have is known as activation energy.
- A substance that accelerates the chemical reaction but does not change its chemical structure at the end is called a catalyst
- Reaction rates are influenced by the catalyst, which changes the mechanism of the reaction by decreasing the energy of activation.
- Enzymes are catalysts in living organisms.

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- Bonderand Pardue, Chemistry and Experimental Science 2/e
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- Graham Hill and John Holman, Chemistry in Context
- John M. Deman, Principles of Food Chemistry

EXERCISE

1. Multiple Choice Questions (MCQs)

i. The rate of a reaction ________ as the reaction proceeds.
   (a) Increases (b) Decreases
   (c) Remains the same (d) May increase or decrease.

ii) The activation energy for a reaction can be;
   (a) Increased by increasing temperature
   (b) Increased by decreasing temperature
   (c) Decreased by increasing concentration of reactants
   (d) None of these

(iii) Reactions with high activation energy are usually;
   (a) Fast (b) Slow (c) Exothermic (d) Reversible

(iv) In a reversible reaction catalyst lowers the activation energy of the;
   (a) Forward reaction
   (b) Reverse reaction
   (c) Forward as well as reverse reaction
   (d) Forward reaction but increases for the reverse reaction

(v) Which of the following is NOT a factor affecting the rate of reaction according to collision theory?
a) Number of particles per unit volume
b) Activation energy
c) Presence of a catalyst
d) Molar mass of reactants

(vi) How does a catalyst increase the rate of reaction?
a) By decreasing the number of particles per unit volume
b) By increasing the activation energy
c) By providing an alternate pathway with higher activation energy
d) By providing an alternate pathway with lower activation energy

(vii) Which physical parameter is NOT typically affected by the rate of reaction?
a) Change in mass
b) Temperature
c) Formation of gas
d) Colour of the reactants

(viii) Which factor can affect the rate of reaction involving gases?
a) Change in solubility
b) Change in pressure
c) Change in volume
d) Change in viscosity

(ix) Increasing the surface area of solids generally:
a) Decreases the rate of reaction
b) Increases the rate of reaction
c) Has no effect on the rate of reaction
d) Makes the reaction irreversible

(x) How does temperature affect the rate of reaction according to collision theory?
a) Higher temperature decreases the frequency of collisions
b) Higher temperature increases the activation energy
c) Higher temperature decreases the kinetic energy of particles
d) Higher temperature increases the frequency of collisions and kinetic energy of particles

2. Short Questions

i. Draw energy diagrams that represent the activation energy and show the effect of a catalyst.

ii. What is the effect of a catalyst on the following?
a) The rate of reaction
b) The energy of activation

i. Why powdered Zn reacts faster with acid than a piece of Zn? Give reason.

ii. List physical parameters which are affected by reaction rates.

iii. Explain collision theory and its key components.

iv. Discuss the effect of changing the concentration of a reactant on the rate of reaction.

v. Describe how graphs are used to interpret the rate of reaction.

vi. Why is activation energy important in determining the rate of reaction?

vii. If you increase the temperature of a reaction, how does this affect the kinetic energy of the particles?

viii. Why do only a fraction of collisions lead to a reaction according to collision theory?
ix. Evaluate how increasing activation energy affects the rate of reaction.
x. Suggest a way to identify if a catalyst has been effective in a reaction.
xi. Assess the impact of catalysts on industrial chemical processes.
xii. Evaluate the impact of adding an enzyme to a biochemical reaction.
xiii. Analyse how temperature control during transportation can affect the quality of the product.

3. Long Questions

i. Examine the graph depicting
   a. the concentration of reactants over time.
   b. the effect of temperature on the rate of reaction.
   c. the effect of the catalyst on reaction rate.
ii. An increase in surface area increases the reaction rate. Evaluate this statement in the light of collision theory to support your answer.
iii. Interpret the role of a catalyst in a chemical reaction.
iv. Discuss the impact of temperature on the rate of reaction.
v. Justify the role of chemical kinetics in the food industry.
vi. Propose a hypothesis for how temperature and surface area affect the reaction rate. Design a set of experiments to test your hypothesis, detailing the methods and measurements.
vii. You are investigating a new catalyst for a reaction that produces a valuable pharmaceutical product.
viii. Explain the role of the catalyst in the reaction mechanism, including its effect on activation energy.
ix. Design an experiment to compare the reaction rates with and without the catalyst.
x. A chemical reaction between substances A and B follows collision theory. You are tasked with maximizing the reaction rate. Describe how you would modify the number of particles per unit volume, temperature, and activation energy to achieve this goal.
xi. Compare and contrast the effects of temperature and concentration on the rate of reaction.
xii. Discuss the significance of activation energy in chemical reactions and its relationship to reaction rates.

THINK TANK

1. Analyse a scenario where a catalyst is not effective in increasing the rate of reaction.
2. Evaluate the role of chemical kinetics in optimizing food production processes in the food industry.
3. Predict the effect of doubling the surface area of a solid reactant on the rate of reaction, providing reasoning based on collision theory.
4. Explain why the formation of gas is often associated with an increase in the rate of reaction.

UNIT 06

SALTS

Student Learning Outcomes (SLOs)

- Explain that salts are ionic compounds formed due to electrostatic attraction between oppositely ions (in which the positive ions come from bases and negative ions come from acids.
- Explain why at STP salts are solids with high melting points.
- Describe that under normal conditions, ionic compounds are usually solids with lattice structures.
- Explain why the molten and aqueous solutions of salts are good conductors of electricity by making reference to the idea of mobile ions.
- Describe the general solubility rules for salts. these are; a. Sodium, nitrate, potassium and ammonium salts are soluble, b. Chlorides are soluble except lead and silver, c. Carbonates are insoluble except sodium, potassium, and ammonium, d. hydroxides are insoluble except sodium, potassium, ammonium, and calcium(partially).
- Describe the preparation , separation and purification of soluble salts by reactions of acids with alkali(titration), excess metal, excess insoluble base, excess insoluble carbonate.

6.1 Salts

Salts are ionic compounds formed through the electrostatic attraction between oppositely charged ions. These ions originate from acids and bases. In a typical reaction, a base provides the positive ions, also known as cations, while an acid supplies the negative ions or anions. When these ions combine, they create a neutral compound, a salt. This process is fundamental to many chemical reactions and is a key concept in understanding the behaviour of acids and bases.

For example, in the reaction between hydrochloric acid (HCl) and sodium hydroxide (NaOH), the sodium ions (Na^+) from the base combine with the chloride ions (Cl^-) from the acid to form sodium chloride (NaCl), which is a common table salt. Here, the Na^+ cations from the base and the Cl^- anions from the acid come together due to an electrostatic attractive force between their opposite charges, resulting in the formation of the salt NaCl.

This principle of ionic bonding in salts is crucial in chemistry, as it explains the formation and properties of a wide range of compounds found in nature and used in various applications.

6.2 Physical State and Melting Points

6.2.1 Solids at STP

At Standard Temperature and Pressure (STP), salts are usually solids. This is due to the strong electrostatic forces of attraction between the oppositely charged ions, which form a tightly bound lattice structure. These forces require significant energy to overcome, resulting in high melting points.

6.2.2 Lattice Structure of Ionic Compounds

Under normal conditions, ionic compounds are usually solids with a well-defined lattice structure. This property is due to the nature of the ionic bonds that hold the ions together. Ionic bonds are formed by electrostatic attraction between positively charged ions (cations) and negatively charged ions (anions). These ions are arranged in a repeating three-dimensional pattern called a crystal lattice. This arrangement maximizes the electrostatic attractions and minimizes the repulsions between ions, leading to a stable structure.

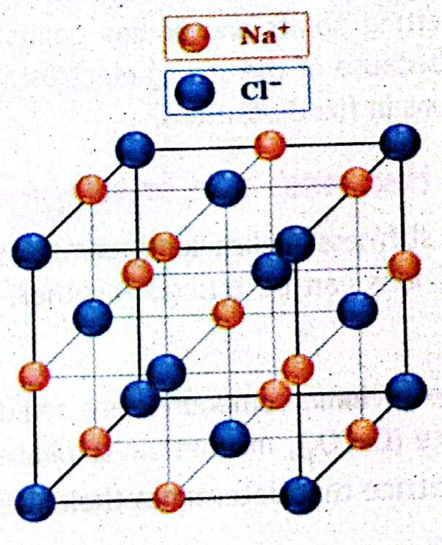


Figure 6.1: Crystal Structure of NaCl

6.2.3 Electrical Conductivity

Molten and aqueous solutions of salts are good conductors of electricity because of the presence of free-moving ions.

When salts are in their solid state, their ions are held together in a rigid lattice structure by strong ionic bonds. In this state, the ions are not free to move, so solid salts do not conduct electricity. Upon melting, the rigid lattice breaks down due to the high temperature. The ions become free to move in the molten state. These free-moving positive (cations) and negative (anions) ions can carry electrical charge, allowing the molten salt to conduct electricity.

Similarly, when salts dissolve in water, they dissociate into their constituent ions due to the polar nature of water molecules. For example, sodium chloride (NaCl) dissociates into Na^+ and Cl^- ions. These free ions are now surrounded by water molecules but can move freely within the solution. When an electric potential is applied, cations migrate toward the cathode (negative electrode), and anions migrate toward the anode (positive electrode), completing the circuit and allowing electrical conductivity.

In both molten and aqueous states, the ionic lattice is disrupted, liberating the ions. Free-moving ions under the influence of an electric field enable the conduction of electricity.

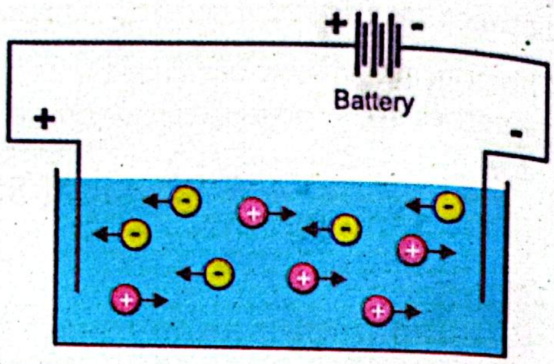


Figure 6.2: Electrical Conductivity

6.2.4 High melting points and boiling points

The strong electrostatic forces of the lattice require significant energy to break, resulting in high melting points and boiling points. Ionic compounds are solid at STP with high melting points because of the strong electrostatic forces of attraction between their ions, which hold these ions in fixed positions.

6.2.5 Hardness and brittleness

Lattice stiffness makes ionic compounds hard. However, when a voltage is applied, like-charged ions can be pushed together, causing repulsion and brittleness and a tendency to break.

Examples of ionic compounds are sodium chloride (NaCl), potassium bromide (KBr), calcium carbonate ($CaCO_3$), magnesium sulphate ($MgSO_4$), etc. Each of these compounds forms a clear crystal lattice that determines their structure and many of their physical properties.

6.3 Preparation, Separation, and Purification of Soluble Salts

Soluble salts can be prepared through various methods, depending on the nature of the reactants involved. Here, we'll describe four common methods: reaction of acids with alkali (titration), excess metal, excess insoluble base, and excess insoluble carbonate.

6.3.1 Preparation by Titration (Acid and Alkali)

Activity 6.1

Preparation of sodium chloride (NaCl) from hydrochloric acid (HCl) and sodium hydroxide (NaOH) by titration.

$$HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

Materials required

- Dilute solutions of sodium hydroxide and hydrochloric acid.
- Phenolphthalein indicator
- Burette
- Pipette
- Conical flask
- Funnel
- Evaporating disc
- Burette stand, tripod stand, and heating source.

Procedure

- Measure exactly 25 cm^3 of HCl solution using a pipette and transfer it to a conical flask.
- Add a few drops of phenolphthalein as an indicator to the acid.
- Fill a burette with NaOH solution using a funnel.
- Slowly add the NaOH from the burette to the HCl in the conical flask, swirling the flask continuously until the indicator changes colour from colourless to light pink indicating neutralization is complete.

Separation

- Once the endpoint is reached, indicating that the acid and alkali have completely reacted, note the volume of NaOH used.

Crystallization

- Evaporate the water from the resulting NaCl solution gently to obtain a hot saturated solution.
- Allow the solution to cool and crystallize, then filter to collect the crystals.

6.3.2 Preparation with Excess Metal

Example: Zinc sulphate ($ZnSO_4$) from sulphuric acid (H_2SO_4) and zinc (Zn)

Activity 6.2:

Preparation of zinc sulphate

Reaction

$$Zn_{(s)} + H_2SO_{4(aq)} \longrightarrow ZnSO_{4(aq)} + H_2O_{(l)}$$

Materials required

- Zinc metal
- Dilute sulphuric acid
- Beaker and glass rod
- Filter funnel and filter paper
- Evaporating disc
- Tripod stand, wire gauze and heating source

Procedure

- Measure 25 cm^3 dilute sulphuric acid into a beaker.
- Add excess zinc metal to dilute sulphuric acid in a beaker. You will observe bubbles of hydrogen are produced.
- The reaction produces zinc sulphate and hydrogen gas.
- If all the zinc disappears, add more until there is some left un-reacted, indicating the acid has been fully reacted.

Separation

- Filter the mixture to remove unreacted excess zinc.

Crystallization

Evaporate the filtrate to obtain a hot saturated solution. Allow the solution to cool and crystallize, then filter to collect the crystals.

6.3.3 Preparation with Excess Insoluble Base

Example: Copper(II) sulphate ($CuSO_4$) from sulphuric acid (H_2SO_4) and copper(II) oxide (CuO)

Activity 6.3:

Preparation of copper(II) sulphate

Reaction: $CuO_{(s)} + H_2SO_{4(aq)} \longrightarrow CuSO_{4(aq)} + H_2O_{(l)}$

Materials required

- Copper(II) oxide
- Dilute sulphuric acid
- Beaker and glass rod
- Filter funnel and filter paper
- Evaporating disc
- Tripod stand, wire gauze and heating source

Procedure

- Measure 25 cm^3 dilute sulphuric acid into a beaker.
- Add excess copper(II) oxide to dilute sulfuric acid in a beaker.
- The reaction produces copper(II) sulphate and water.
- Continue adding CuO until no more dissolves, indicating all the acid has reacted.

Separation

- Filter the mixture to remove unreacted CuO.

Crystallization

- Evaporate the filtrate to obtain a hot saturated solution. Allow the solution to cool and crystallize, then filter to collect the crystals.

6.3.4 Preparation with Excess Insoluble Carbonate

Activity 6.4:

Calcium chloride ($CaCl_2$) from hydrochloric acid (HCl) and calcium carbonate ($CaCO_3$)

Reaction: $CaCO_{3(s)} + 2HCl_{(aq)} \longrightarrow CaCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$

Materials required

- Calcium carbonate (limestone)
- Dilute hydrochloric acid
- Beaker and glass rod
- Filter funnel and filter paper
- Evaporating disc
- Tripod stand, wire gauze and heating source

Procedure

- Measure 25 cm^3 dilute hydrochloric acid into a beaker.
- Add excess calcium carbonate to dilute hydrochloric acid in a beaker.
- The reaction produces calcium chloride, carbon dioxide, and water.
- You will observe carbon dioxide has evolved with effervescence.
- Continue adding $CaCO_3$ until no more effervescence (bubbles) is observed, indicating all the acid has reacted.

Separation

- Filter the mixture to remove unreacted $CaCO_3$.

Crystallization

- Evaporate the filtrate to obtain a hot saturated solution. Allow the solution to cool and crystallize, then filter to collect the crystals.

6.4 Soluble and insoluble salts

Soluble salts are salts that dissolve in water at room temperature, and insoluble salts are salts that do not dissolve in water at room temperature.

General rules for the solubility of salts help predict the solubility of various ionic compounds in water. These rules are necessary to understand the reactions of aqueous solutions. Here is a detailed description of the solubility rules:

1. All sodium, potassium and ammonium salts are soluble in water. This includes common compounds such as sodium chloride (NaCl), sodium sulphate (Na_2SO_4), potassium chloride (KCl), potassium bromide(KBr), ammonium chloride(NH_4Cl), ammonium sulphate $(NH_4)_2SO_4$ etc
2. All nitrate salts are soluble in water. This rule applies to all nitrate compounds such as potassium nitrate (KNO_3), calcium nitrate $Ca(NO_3)_2$ etc
3. Most chloride (Cl^-) salts are soluble in water, except lead (II) chloride ($PbCl_2$) and silver chloride (AgCl) are insoluble in water.
4. Most carbonate salts (CO_3^{2-}) are insoluble in water. Except sodium, potassium, and ammonium carbonates which are soluble. Examples of insoluble carbonates include calcium carbonate($CaCO_3$), magnesium carbonate($MgCO_3$), etc
5. Most common sulphates are soluble, except lead(II) sulphate, barium sulphate and calcium sulphate.

Concept Assessment Exercise 6.1

Which of the following salts are insoluble,
Silver chloride, barium sulphate, sodium nitrate, ammonium carbonate, and lead nitrate.

KEY POINTS

- Salts are ionic compounds formed through the electrostatic attraction between oppositely charged ions.
- Under normal conditions, ionic compounds are usually solids with a well-defined lattice structure.
- Lattice stiffness makes ionic compounds hard.
- In the solid state, ionic compounds do not conduct electricity because the ions are fixed in the lattice.
- Soluble salts are salts that dissolve in water at room temperature.
- All nitrate salts are soluble in water.

EXERCISE

1. Multiple Choice Questions (MCQs)

i. Which of the following salts is soluble in water?
   a. Silver chloride (AgCl)
   b. Lead carbonate ($PbCO_3$)
   c. Sodium nitrate ($NaNO_3$)
   d. Lead chloride ($PbCl_2$)

ii. What type of ions do bases provide for salt formation?
   a. Negative ions
   b. Positive ions
   c. Neutral molecules
   d. Complex ions

iii. What is the primary reason salts have high melting points?
   a. Weak van der Waals forces
   b. Strong electrostatic forces
   c. Hydrogen bonding
   d. Covalent bonding

iv. In what state are salts generally good conductors of electricity?
   a. Solid
   b. Gas
   c. Molten
   d. Powdered

v. Which of the following is a general solubility rule for chlorides?
   a. All chlorides are insoluble.
   b. All chlorides are soluble.
   c. Chlorides are soluble except lead and silver chlorides.
   d. Chlorides are soluble except sodium and potassium chlorides.

vi. What happens to the ions in a salt when it is dissolved in water?
   a. They form a gas.
   b. They become fixed in place.
   c. They become mobile.
   d. They form a solid.

vii. Which of the following methods is used to prepare a salt by titration?
   a. Acid + Metal
   b. Acid + Insoluble Base
   c. Acid + Insoluble Carbonate
   d. Acid + Alkali

viii. Which of these salts is insoluble in water?
a. Potassium carbonate (K_2CO_3)
b. Ammonium nitrate (NH_4NO_3)
c. Calcium Cloride ($CaCl_2$)
d. Lead chloride ($PbCl_2$)

ix. What is formed when an acid reacts with an excess of an insoluble base?
a. Salt and hydrogen
b. Salt and water
c. Salt and carbon dioxide
d. Salt and oxygen

x. Which ion is commonly found in soluble nitrates?
a. NH_4^+
b. NO_3^-
c. Cl^-
d. CO_3^{2-}

2. Short Answer Questions

i. Define what a salt is in terms of ions.
ii. Why do salts generally have high melting points?
iii. Describe the lattice structure of an ionic compound.
iv. How do salts conduct electricity when molten or in solution?
v. List three salts that are generally soluble in water.
vi. What happens to the ions in an ionic compound when it dissolves in water?
vii. Do you think that most carbonates are soluble in water?
viii. How can you prepare a soluble salt using an excess of an insoluble base?
ix. Which salts are typically soluble according to the general solubility rules?

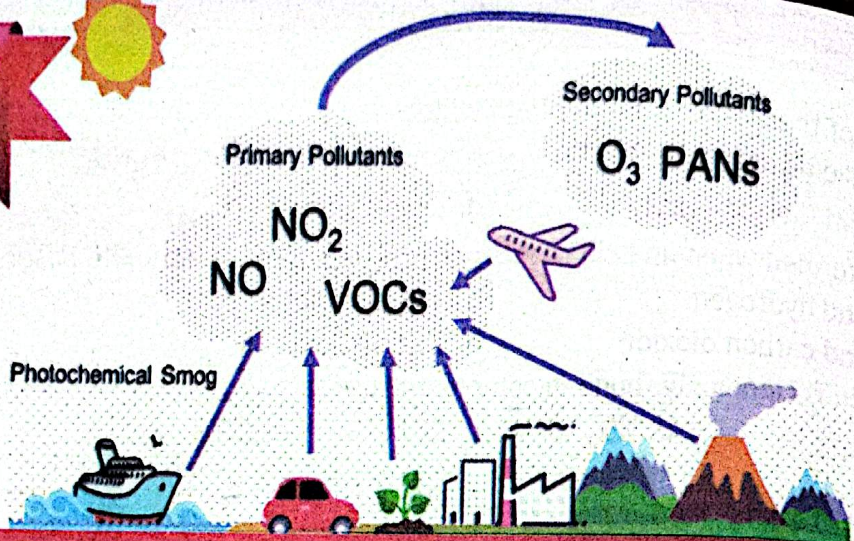
3. Long Answer Questions

i. Explain the process of preparing a soluble salt using titration. Include a detailed description of the steps involved.
ii. Discuss the properties of salts that make them solid at STP and have high melting points.
iii. Describe the solubility rules for salts and explain the exceptions for chlorides, carbonates, and hydroxides.
iv. Explain why ionic compounds have lattice structures and how this influences their physical properties.
v. Describe the preparation, separation, and purification of salts using an excess of an insoluble carbonate, providing an example reaction.

THINK TANK

1. Design an experiment to make magnesium sulphate crystals with suitable reactants.
2. Design an experiment to make potassium sulphate crystals using titration method.
3. Name two types of salts that are always soluble.
4. How could you prepare pure dry sample of copper(II) sulphate from copper(II) carbonate.
5. What would you add to dilute sulphuric acid to make copper(II) sulphate?

UNIT 07



NITROGEN, SULPHUR AND METALS

Student Learning Outcomes (SLOs)

- Recognize that atmospheric oxides of nitrogen(NO and NO_2) can react with unburned hydrocarbons to form peroxyacetyl nitrate, PAN, which is a component of photochemical smog.
- Describe the role of NO and NO_2 in the formation of acid rain both directly and in their catalytic role in the oxidation of atmospheric sulphur dioxide.
- State the symbol equation for the production of ammonia in the Haber process, $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$
- State the sources of hydrogen (methane) and nitrogen(air) in Haber process.
- State that typical conditions in the Haber process as 450°C, 20000kPa/ 200 atm and an iron catalyst.
- State the symbol equation for the conversion of sulphur dioxide to sulphur trioxide in the contact process, $2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$
- State the sources of the sulphur dioxide (burning sulphur or roasting sulphide ores) and oxygen (air0 in the Contact process.
- State the typical conditions for the conversion of sulphur dioxide to sulphur trioxide in the Contact process as 450°C, 200kPa/atm and vanadium(V) oxide catalyst.
- Describe atmospheric oxides as oxides that react with acids and bases to produce a salt and water.
- Classify oxides as acidic, including SO_2 and CO_2, basic, including CuO and CaO, or amphoteric , limited to Al_2O_3 and ZnO,related to metallic and mon-metallic character.
- Identify the general chemical properties of metals, limited to their reactions with dilute acids, cold water, steam and oxygen.
- Arrange metals in order of reactivity given relevant information.

Nitrogen and sulphur oxides play important roles in the environment and industrial processes. For instance, in the atmosphere, oxides such as nitric oxide (NO) and nitrogen dioxide (NO_2) react with unburned hydrocarbons, resulting in the formation of peroxy acetyl nitrate, or PAN, which is a major component of photochemical smog. Nitrogen oxides also play a role in acid rain, both directly and by catalyzing the oxidation of SO_2 to SO_3. On the industrial level, nitrogen is important for the production of ammonia in Haber processes, while sulphur dioxide is essential for the production of sulphuric acid. Understanding the chemistry of nitrogen and sulphur oxides, including their behaviour, and their industrial applications is important in both the environment and chemical engineering.

7.1 Photochemical Smog

Photochemical smog occurs when sunlight reacts with specific chemicals in the air. One of the most important step in photochemical smog formation is the reaction of nitrogen oxides (NO and NO_2) in the atmosphere with unburned (unburned) hydrocarbons in the presence of sunlight. This reaction leads to the formation of various secondary pollutants, including peroxyacetyl nitrate (PAN).

The chemical reactions involved in the formation of PAN:

1. Formation of Nitrogen Dioxide (NO_2)

Nitric oxide (NO) is emitted from vehicles, industrial processes, and other combustion sources. NO reacts with oxygen (O_2) in the atmosphere to form nitrogen dioxide (NO_2):

$$2NO_{(g)} + O_{2(g)} \xrightarrow{\text{UV Radiations}} 2NO_{2(g)}$$

2. Photolysis of Nitrogen Dioxide (NO_2)

NO_2 absorbs sunlight (particularly UV light) and undergoes photodissociation to form nitric oxide (NO) and a free oxygen atom (O):

$$NO_{2(g)} \xrightarrow{\text{UV Radiations}} NO_{(g)} + [O]_{(g)}$$

3. Formation of Ozone (O_3)

Nascent [O] or atomic oxygen is highly reactive and reacts with atmospheric O_2 to form O_3.

$$O_{2(g)} + [O]_{(g)} \xrightarrow{\text{UV Radiations}} O_{3(g)}$$

4. Reaction of Hydrocarbons

Unburned hydrocarbons (often referred to as volatile organic compounds or VOCs) in the atmosphere can react with nascent oxygen in the presence of UV light to form a variety of intermediate organic radicals.

$$\text{Hydrocarbons}_{(g)} + [O]_{(g)} \longrightarrow RCO^{\cdot}_{(g)}$$

5. Formation of Peroxyacyl Radicals:

These organic radicals react with molecular oxygen (O_2) to form peroxy acyl radicals ($RC(O)O_2$).

$$RCO^{\bullet}_{(g)} + O_{2(g)} \longrightarrow RC(O)O_2^{\bullet}{}_{(g)}$$

Peroxy acyl Radical

6. Formation of PAN:

The peroxy acyl radicals ($RC(O)O_2^{\bullet}$) react with NO_2 to form peroxyacetyl nitrate (PAN):

$$RC(O)O_2^{\bullet}{}_{(g)} + NO_{2(g)} \longrightarrow RC(O)O_2NO_{2(g)}$$

Peroxyacetyl Nitrate (PAN)

PAN is a stable molecule at lower temperatures and can travel long distances in the atmosphere. It acts as a reservoir for NOx and organic radicals, releasing them under conditions of higher temperatures and sunlight, thereby contributing to the formation and persistence of photochemical smog.

7.2 Acid rain

The acidity of rainwater increases in polluted areas during thunderstorms e.g SO_2 Sulphur dioxide from power plants during the combustion of fossil fuels and NO_2 form automobiles Exhaust fumes dissolve in rainwater producing acids. The pH of rainwater can be much lower due to the production of H_2SO_4 and HNO_3. By lightning during the thunderstorm. The rain may have a pH as low as 2. Acid Rain is defined as rain having a pH less than 5.

7.2.1 Role of nitric oxide and nitrogen dioxide in the formation of acid rain

Nitric oxide (NO) and nitrogen dioxide (NO_2) play important roles in the formation of acid rain through both direct and catalytic processes. Here's an overview of their involvement:

7.2.2 Direct Role in Acid Rain Formation

Formation of Nitric Acid (HNO_3)

Nitric oxide (NO) is initially produced during combustion processes, such as those occurring in vehicle engines and industrial activities. NO is relatively stable but can be oxidized to form NO_2:

$$2NO_{(g)} + O_{2(g)} \longrightarrow 2NO_{2(g)}$$

Formation of Nitric Acid: NO_2 can further react with hydroxyl radicals (OH) and water in the atmosphere to form nitric acid (HNO_3), a major component of acid rain:

$$4NO_{2(g)} + 2H_2O_{(l)} + O_{2(g)} \longrightarrow 4HNO_{3(aq)}$$

Catalytic role in the oxidation of sulphur dioxide (SO_2)

Sulphur dioxide (SO_2) is another significant precursor of acid rain, primarily originating from the burning of fossil fuels containing sulphur. The conversion of SO_2 to sulphuric acid (H_2SO_4) can be catalysed by NO_2.

$$SO_{2(g)} + NO_{2(g)} \longrightarrow SO_{3(g)} + NO_{(g)}$$

Formation of Sulphuric Acid (H_2SO_4)

SO_3 readily reacts with water vapour to form sulphuric acid (H_2SO_4)

$$SO_{3(g)} + H_2O_{(l)} \longrightarrow H_2SO_{4(aq)}$$

Regeneration of NO_2

The NO produced in the oxidation of SO_2 can be re-oxidized to NO_2 by reacting with molecular oxygen (O_2), continuing the catalytic cycle:

$$2NO_{(g)} + O_{2(g)} \longrightarrow 2NO_{2(g)}$$

This cycle allows a small amount of NO_2 to catalyse the conversion of a large amount of SO_2 to sulphuric acid.

7.3.3 Overall Impact on Acid Rain

NO_2 acts as a catalyst in the oxidation of SO_2 to sulphuric acid, thereby increasing the concentration of another strong acid in the atmosphere.

7.3 Contact Process

Contact Process for the Manufacture of Sulphuric Acid

Sulphuric acid is a most important industrial chemical used for making a large number of compounds e.g. fertilizer, plastic, explosives, paints, leather, tanning, textiles, metallurgy etc. Sulphuric acid is used in almost all industries which is why it is called the King of Chemicals.

Sources:

This process is based on the catalytic oxidation of SO_2 and SO_3 in the presence of atmospheric oxygen. Sulphur dioxide is produced by burning sulphur or roasting sulphide ores.

$$2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)} + 45.2 \text{ kcals}$$

This reaction is reversible and exothermic. Therefore the optimum conditions for the reaction are:

1) **Concentration:** A controlled amount of air is passed.

2) **Temperature:** The temperature of the reaction should be kept at 450°C

3) **Pressure:** Pressure is usually kept at 200kPa / 2 atm

4) **Catalyst:** Vanadium pentaoxide is an efficient catalyst

Different Steps involved in the contact process

i) Burner: Sulphur is burnt in a Sulphur burner, SO_2 gas produced and vapours of th gas are cooled by passing through a pipe cooler made up of iron.

$$S_{(s)} + O_{2(g)} \longrightarrow SO_{2(g)}$$

ii) The gases then pass through a coke filter which filters the traces of suspende matter.

iii) The purified gases then pass through the heat exchanger and are cooled to 25°C

iv) From heat exchange gases go to catalytic chambers called converters. Where SO_3 formed

$$2SO_{2(g)} + O_{2(g)} \underset{450°C,2atm}{\overset{V_2O_5}{\rightleftharpoons}} SO_{3(g)} + \text{Heat}$$

SO_3 is cooled and passed through an absorption tower, steam, water and dil. sulphuric ac runs into the tower and oleum $H_2S_2O_7$ or fusing H_2SO_4 is obtained and stored in the oleu tower. The oleum tower is made up of brick-lined steel packed with quartz and fed with 98 H_2SO_4.

$$H_2SO_{4(l)} + SO_{3(g)} \longrightarrow H_2S_2O_{7(l)} \text{ (Oleum)}$$

By adding the appropriate amount of water oleum to concentrated H_2SO_4

$$H_2S_2O_{7(l)} + H_2O_{(l)} \longrightarrow 2H_2SO_{4(l)}$$

The acid obtained from this method is extremely pure.

Any concentration of H_2SO_4 can be obtained in this method.

Flow chart of the contact process

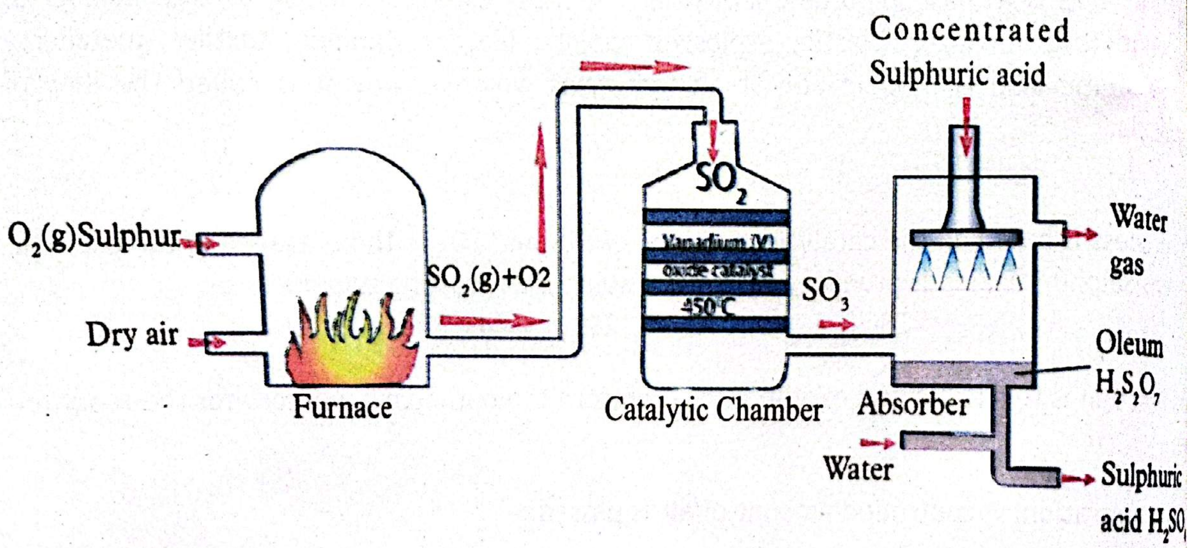


Figure 7.1: Contact Process

7.4 Haber Process:

Ammonia NH_3 is commercially produced by the Haber process.

Ammonia can be liquefied and its Boiling point is -33.35°C. It can be solidified as white ice crystals. Most of the commercial ammonia is prepared by fixing atmospheric nitrogen.

Sources of reactants: Hydrogen is obtained by the decomposition of methane and nitrogen is obtained from air.

Optimum Condition for Haber process

i) **Concentration of Reactant:** A mixture of 1 volume of nitrogen and 3 volume of hydrogen.

ii) **Catalytic Chamber:** These two gases are compressed to 200 - 500 atm. pressure by special pumps injected into the heated reaction vessel and then passed over a catalyst consisting of a mixture of Fe/Mo (Molybdenum) at 450°C

iii) **Refrigerated Brine:** The gases coming out of the catalytic chamber contain 10-12%. Ammonia is removed periodically and then passed through refrigerated brine (concentrated solution of NaCl) to liquefy Ammonia. The residual or unreacted gases are recycled. Excess of nitrogen is used to favour the reaction to the right.

$$N_{2(g)} + 3H_{2(g)} \xrightleftharpoons[450^\circ C,\,200atm]{Fe/Mo} 2NH_{3(g)}$$

Haber process is the cheapest method for manufacturing Ammonia. The reaction between nitrogen and hydrogen is an exothermic and reversible process and is accompanied by a decrease in the volume of the product.

Favourable conditions according to the le-Chatellier's Principal

1) High pressure (200 atm) due to a decrease in the volume of the product.

2) The temperature must be kept as low as possible. In the presence of a catalyst, the optimum temperature is 450°C

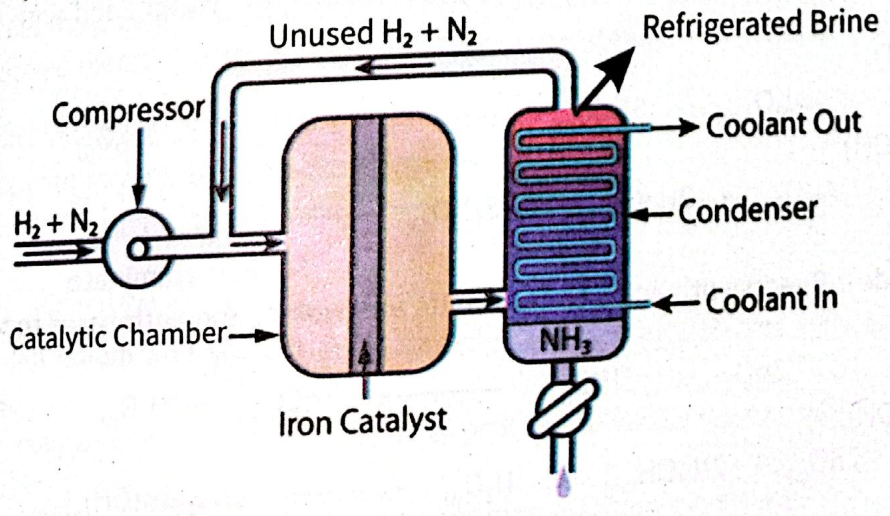


Figure 7.2: Haber Process

7.5 Oxides

Binary compounds of elements with oxygen are called oxides. For example, CaO, CO_2, SO_3, Na_2O, CuO, Al_2O_3 etc.
Oxides can be classified as acidic, basic, or amphoteric based on their chemical properties and their relationship with metallic and non-metallic elements.

1. Acidic Oxides

Acidic oxides typically form acids when they react with water. They are oxides of non-metals. Examples include:

SO_2 (Sulphur dioxide): Reacts with water to form sulphurous acid (H_2SO_3).

$$SO_{2(g)} + H_2O_{(l)} \longrightarrow H_2SO_{3(aq)}$$

CO_2 (Carbon Dioxide): Reacts with water to form carbonic acid (H_2CO_3).

$$CO_{2(g)} + H_2O_{(l)} \longrightarrow H_2CO_{3(aq)}$$

2. Basic Oxides

Basic oxides form bases when they react with water. They are oxides of metals. Examples include:

Na_2O (sodium oxide): Reacts with acids to form salts and water, indicating its basic nature.

$$Na_2O_{(s)} + 2HCl_{(aq)} \longrightarrow 2NaCl_{(aq)} + H_2O_{(l)}$$

CaO (Calcium Oxide): Reacts with water to form calcium hydroxide ($Ca(OH)_2$), a strong base. It reacts with acids to form salt.

$$CaO_{(s)} + H_2O_{(l)} \longrightarrow Ca(OH)_{2(aq)}$$

$$CaO_{(s)} + 2HCl_{(aq)} \longrightarrow CaCl_{2(aq)} + H_2O_{(l)}$$

3. Amphoteric Oxides

Amphoteric oxides can react both with acids and bases, displaying both acidic and basic properties. These are oxides of some metals. Examples include:

Al_2O_3 (Aluminum Oxide): Reacts with acids to form salts and water, and with bases to form aluminates.

With acid (HCl):

$$Al_2O_{3(s)} + 6HCl_{(aq)} \longrightarrow 2AlCl_{3(aq)} + 3H_2O_{(l)}$$

With base (NaOH):

$$Al_2O_{3(s)} + 2NaOH_{(aq)} + 3H_2O_{(l)} \longrightarrow 2NaAl(OH)_{4(aq)}$$

Sodium aluminate

ZnO (Zinc Oxide): Reacts with acids to form salts and water, and with bases to form zincates.

With acid (HCl):

$$ZnO_{(s)} + 2HCl_{(aq)} \longrightarrow ZnCl_{2(aq)} + H_2O_{(l)}$$

With base (NaOH):

$$ZnO_{(s)} + 2NaOH_{(aq)} + H_2O_{(l)} \longrightarrow Na_2[Zn(OH)_4]_{(aq)}$$

Sodium zincate

7.5 General characteristics of metals

Metals exhibit various chemical properties based on their reactions with different substances, including dilute acids, cold water, steam, and oxygen.

Reactions with Dilute Acids

Metals react with dilute acids to form a salt and hydrogen gas.

$$\text{Metal} + \text{Dilute Acid} \longrightarrow \text{Salt} + \text{Hydrogen Gas}$$

Example with Hydrochloric Acid

$$Mg_{(s)} + 2HCl_{(aq)} \longrightarrow MgCl_{2(aq)} + H_{2(g)}$$

Metals like potassium and sodium react explosively.
Metals like magnesium, zinc and iron react steadily, producing bubbles of hydrogen.
Metals such as copper, silver and gold do not react with dilute acids.

Reactions with Cold Water

Reactive metals react with cold water to form a metal hydroxide and hydrogen gas.

$$\text{Metal} + \text{Water} \longrightarrow \text{Metal Hydroxide} + \text{Hydrogen Gas}$$

Example

$$2Na_{(s)} + 2H_2O_{(l)} \longrightarrow 2NaOH_{(aq)} + H_{2(g)}$$

Metals like potassium, sodium and calcium react vigorously, sometimes explosively.
Metals like magnesium react slowly with cold water, but faster with hot water.
Where as Metals like zinc and iron do not react significantly with cold water.

Reactions with Steam

Metals react with steam to form a metal oxide and hydrogen gas.

$$\text{Metal} + \text{Steam} \longrightarrow \text{Metal Oxide} + \text{Hydrogen Gas}$$

Example

$$Fe_{(s)} + H_2O_{(l)} \longrightarrow Fe_3O_{4(s)} + 4H_{2(g)}$$

Metals such as potassium and sodium are typically not tested with steam due to violent reactions.
Metals such as magnesium, zinc and iron react readily.
But less reactive metals like copper do not react with steam.

Reactions with Oxygen

Metals react with oxygen to form metal oxides.

$$\text{Metal} + \text{Oxygen} \longrightarrow \text{Metal Oxide}$$

Example

$$2Mg_{(s)} + O_{2(g)} \longrightarrow 2MgO_{(s)}$$

Metals like potassium and sodium react rapidly, forming oxides and sometimes peroxides or superoxides.
Metals like magnesium, aluminium form a protective oxide layer, which prevents further reaction.
Metals such as copper oxidize slowly, often forming a patina over time.
Metals like gold, platinum do not react with oxygen under normal conditions.

7.5.1 Reactivity series

Metals can be arranged into a reactivity series based on their observed reactions with acids, cold water, and steam. Metals can be grouped into four groups.

1. Highly Reactive Metals

These metals react vigorously with cold water, steam, and acids, releasing hydrogen gas.

Examples: Potassium (K), Sodium (Na), Calcium (Ca)

- **With cold water:** Form hydroxides and hydrogen gas.

$$2K_{(s)} + 2H_2O_{(l)} \longrightarrow 2KOH_{(aq)} + H_{2(g)}$$

- **With acids:** Form salts and hydrogen gas.

$$2K_{(s)} + 2HCl_{(aq)} \longrightarrow 2KCl_{(aq)} + H_{2(g)}$$

2. Moderately Reactive Metals

These metals react:

- Slowly or not at all with cold water.
- React with steam to form oxides and hydrogen gas.
- React with acids to form salts and hydrogen gas.

Examples: Magnesium (Mg), Aluminium (Al), Zinc (Zn), Iron (Fe)

- **With cold water:** Limited or no reaction (e.g., Mg reacts very slowly).
- **With steam:** Form oxides and hydrogen gas.

$$Mg_{(s)} + H_2O_{(g)} \longrightarrow MgO_{(s)} + H_{2(g)}$$

- **With acids:** React more slowly compared to highly reactive metals.

$$Mg_{(s)} + 2HCl_{(aq)} \longrightarrow MgCl_{2(aq)} + H_{2(g)}$$

3. Less Reactive Metals

These metals:

- Do not react with cold water or steam.
- React slowly or not at all with acids.

Examples: Lead (Pb), Copper (Cu), Silver (Ag)

- **With cold water:** No reaction.
- **With steam:** No reaction.
- **With acids:** Lead reacts slowly with strong acids, while copper and silver do not react.

4. Unreactive Metals

These metals are least reactive and do not react with cold water, steam, or acids under normal conditions.

Examples: Gold (Au), Platinum (Pt)

Reactivity Series (Simplified Order)

Potassium > Sodium > Calcium > Magnesium > Aluminium > Zinc > Iron > Lead > Copper > Silver > Gold

This arrangement reflects their decreasing reactivity with acids, cold water, and steam.

Activity 7.1:

Exploring Metal Reactivity

Objective: Students will explore the reactivity of different metals by conducting simple experiments and then arrange the metals in order of their reactivity, from most reactive to least reactive.

Materials Required:

- Small strips or pieces of various metals (e.g., Magnesium, Zinc, Iron, Copper)
- 4 Test tubes or small beakers
- Dilute hydrochloric acid (HCl) solution (safely diluted for the grade level)
- Sandpaper (to clean metal surfaces)
- Water
- Safety goggles and gloves
- Activity worksheet

Procedure:

Introduction to Metals and Reactivity:

Introduce the concept of a reactivity series.

1. **Cleaning the Metals:**
   Give each student or group of students a small piece of each metal and a piece of sandpaper. Ask them to clean the surface of the metal to remove any oxide layer, making it shiny.
2. **Setting Up the Experiment:**
   - Label each test tube or beaker with the name of the metal.
   - Place one piece of metal into each test tube.
   - Add enough dilute hydrochloric acid to each test tube to cover the metal.
3. **Observation:**
   - Ask students to observe what happens to the metals when they come into contact with the acid.
   - Encourage students to record their observations on the activity worksheet. They should note any bubbles (indicating a reaction), the speed of the reaction, and any other changes.
4. **Arranging the Metals:**
   - Based on their observations, students will arrange the metals from most reactive to least reactive on their worksheet.
   - Guide them to understand that metals that reacted vigorously (produced a lot of bubbles quickly) are more reactive, while those that reacted slowly or not at all are less reactive.
5. **Discussion:**
   Discuss the results in the class. Ask students why they think some metals reacted more than others and how this relates to the metal's position in the reactivity series.
6. **Safety Considerations:**
   - Ensure that all students wear safety goggles and gloves during the experiment.
   - Remind students to handle the acid with care, even though it is dilute.
   - Supervise students closely during the activity.

Concept Assessment Exercise 7.1

1. If you were to conduct this experiment with a new metal, what steps would you take to predict its reactivity before starting the experiment?
2. Compare the reactions of magnesium and copper in hydrochloric acid. What does the difference in their reactions tell you about their positions in the reactivity series?
3. Some students observed that a metal did not react with hydrochloric acid. How could you confirm whether this result is due to the metal's low reactivity or an experimental error?
4. Design an experiment to test the reactivity of metals using a different acid, such as sulphuric acid. What changes would you make to the procedure, and what results would you expect?

KEY POINTS

- PAN is a stable molecule at lower temperatures and can travel long distances in the atmosphere.
- Nitric oxide (NO) and nitrogen dioxide (NO_2) play important roles in the formation of acid rain through both direct and catalytic processes.
- Nitrogen dioxide and Sulphur dioxide are significant precursors of acid rain.
- Binary compounds of elements with oxygen are called oxides.
- Acidic oxides typically form acids when they react with water. They are the oxides of non-metals.
- Basic oxides form bases when they react with water. They are the oxides of metals.
- Amphoteric oxides can react with acids and bases, displaying both acidic and basic properties.
- Metals react with dilute acids to form a salt and hydrogen gas.
- Reactive metals react with cold water to form a metal hydroxide and hydrogen gas.

EXERCISE

1. Multiple Choice Questions (MCQs)

i. What is a key component of photochemical smog formed by the reaction of NO and NO_2 with unburned hydrocarbons?

a) Sulfuric acid b) Peroxyacetyl nitrate (PAN)
c) Carbon monoxide d) Ozone

ii. Which of the following is the balanced equation for the production of ammonia in the Haber process?

a) $N_{2(g)} + H_{2(g)} \rightleftharpoons NH_{3(g)}$ b) $N_{2(g)} + 2H_{2(g)} \rightleftharpoons 2NH_{3(g)}$
c) $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$ d) $2N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$

iii. What are the sources of hydrogen and nitrogen in the Haber process?

a) Water and air b) Methane and air
c) Methane and water d) Water and methane

iv. Which catalyst is used in the Haber process?
   a) Platinum
   b) Vanadium(V) oxide
   c) Iron
   d) Nickel
v. At what temperature is the Haber process typically conducted?
   a) 300°C
   b) 450°C
   c) 600°C
   d) 200°C
vi. What is the symbol equation for the conversion of sulphur dioxide to sulphur trioxide in the Contact process?
   a) $SO_{2(g)} + O_{2(g)} \rightleftharpoons SO_{3(g)}$
   b) $2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$
   c) $SO_{2(g)} + 2O_{2(g)} \rightleftharpoons 2SO_{3(g)}$
   d) $2SO_{2(g)} + O_{2(g)} \rightleftharpoons SO_{3(g)}$
vii. Which catalyst is used in the Contact process for the conversion of SO_2 to SO_3?
   a) Iron
   b) Vanadium(V) oxide
   c) Platinum
   d) Nickel
viii. What are the sources of sulphur dioxide in the Contact process?
   a) Burning sulphur or roasting sulphide ores
   b) Burning methane
   c) Electrolysis of water
   d) Combustion of natural gas
ix. How do atmospheric oxides react with acids and bases?
   a) Forming a salt and water
   b) Forming an acid and a gas
   c) Forming a base and hydrogen
   d) Forming a salt and hydrogen
x. Which of the following oxides is amphoteric?
   a) SO_2
   b) CO_2
   c) CuO
   d) Al_2O_3

2. Short Answer Questions

i. What is peroxyacetyl nitrate (PAN) and how is it formed?
ii. Describe the role of NO and NO_2 in the formation of acid rain.
iii. Write the balanced equation for the production of ammonia in the Haber process.
iv. What are the typical conditions (temperature, pressure, catalyst) for the Haber process?
v. How is sulphur dioxide produced for the Contact process?
vi. State the balanced chemical equation for the conversion of sulphur dioxide to sulphur trioxide.
vii. Describe the role of vanadium(V) oxide in the Contact process.
viii. What are acidic oxides? Give two examples.
ix. What are basic oxides? Give two examples.
x. What is meant by amphoteric oxides? Provide examples.
xi. Evaluate the environmental impact of acidic oxides like SO_2 and CO_2.
xii. Evaluate the significance of controlling the emission of oxides like NO_2 and SO_2 in industrial processes.

3. Long Answer Questions

i. Explain the environmental impact of nitrogen oxides in the atmosphere, particularly focusing on photochemical smog and acid rain.

ii. Discuss the Haber process, including the chemical reaction, sources of reactants, conditions required, and its significance in the production of ammonia.

iii. Describe the Contact process for sulphuric acid production, detailing the chemical reactions involved, the sources of reactants, and the industrial conditions used.

iv. Compare and contrast acidic, basic, and amphoteric oxides with suitable examples for each type.

v. How do industrial processes like the Haber and Contact processes contribute to environmental pollution, and what measures can be taken to minimize their impact?

vi. Compare the roles of NO and NO_2 in the formation of acid rain. How do their chemical behaviours contribute to both direct acid formation and the oxidation of sulphur dioxide?

vii. Analyse the classification of oxides. Why are oxides like SO_2 considered acidic, while oxides like CuO are considered basic? Discuss how the metallic or non-metallic character of the element influences this classification.

THINK TANK

1. Explain why gold and platinum are often used in jewellery despite their high cost.
2. If a new metal was discovered and found to react with steam but not cold water, where would you place it in the reactivity series? Justify your placement.
3. Give the expected reactivity series from the following data for the following three metals. Justify your placement.

Metal A

a. Reaction with Cold Water: Reacts slowly, producing hydrogen gas.
b. Reaction with Steam: Reacts vigorously, producing hydrogen gas and white oxide.
c. Reaction with Dilute Acid: Reacts quickly, producing hydrogen gas.

Metal B

a. Reaction with Cold Water: No reaction.
b. Reaction with Steam: No reaction.
c. Reaction with Dilute Acid: Reacts slowly, producing hydrogen gas.

Metal C

a. Reaction with Cold Water: No reaction.
b. Reaction with Steam: No reaction.
c. Reaction with Dilute Acid: No reaction.

4. How can the knowledge of basic oxides, such as CaO, be applied to neutralize acidic pollutants in industrial wastewater treatment?
5. Evaluate the choice of 450°C and 200 atm for the Haber process.
6. Evaluate the environmental impact of acidic oxides.
7. Evaluate the significance of controlling the emission of oxides like NO_2 and SO_2 in industrial processes.

UNIT 08

ORGANIC CHEMISTRY

Student Learning Outcomes (SLOs)

- Name and draw the structural and displayed formulae of unbranched alkanes, alkenes, alcohols, and carboxylic acids. (include but-1-ene and but-2-ene, propan-1-ol, propan-2-ol, butan-1-ol and butan-2-ol).
- State the type of compound present given the chemical name ending in -ane, -ene,-yne, -ol, or -oic acid or from a molecular, structural or displayed formula,
- Name and draw the displayed formulae of the unbranched esters which can be made from unbranched alcohols and carboxylic acids, each containing upto four carbon atoms.

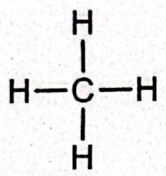
Organic chemistry is the study of carbon-based compounds, which are fundamental to life and have diverse applications in various industries. Understanding the structures, properties, and reactions of organic molecules is crucial for fields such as medicine, materials science, and environmental science.

8.1 Structural Formula

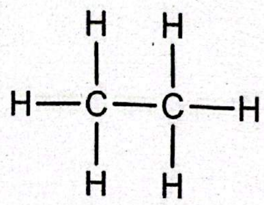
A structural formula shows how different atoms are joined up or arranged in a molecule or compound. You can represent structural formulas in two ways. You can draw it as a displayed structural formula or as a condensed structural formula.

A displayed formula is a full structural formula that shows all the bonds between the atoms in a molecule as individual lines. The bonds are represented by lines. The strength of the bond is indicated by the number of lines. Single bonds are represented by one line. Double bonds are represented by two lines. In some molecules, three lines are possible. These formulas are very useful because they show as much information as possible about the molecule.

Methane is the simplest alkane. Other examples of alkanes are ethane, propane, butane etc. The displayed formulas of methane and ethane:



Methane



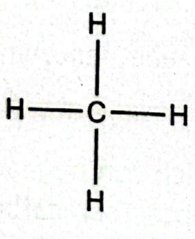
Ethane

Note that displayed formulas are always drawn with the molecule straightened out and flattened. They, however, show exactly how all the atoms are joined together in a condensed structural formula.

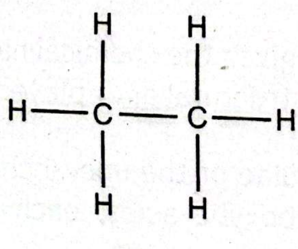
However, they are very large and time-consuming to draw. Condensed structural formulas try to solve this problem by omitting some of the bonds and grouping some of the atoms together.

8.1.1 The normal way to draw a structural formula

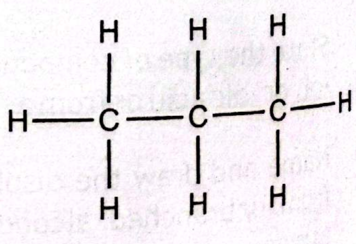
Except for the smallest molecules, drawing a fully displayed formula is very time-consuming. You can simplify the formula by listing the main chain carbon atoms and the hydrogen atoms attached to them in the sequence they appear, for example, CH_3 or CH_2 instead of showing all the carbon-hydrogen bonds. So, the structural formula for methane could be written as CH_4, and that of ethane as CH_3-CH_3 or as CH_3CH_3.



Methane



Ethane



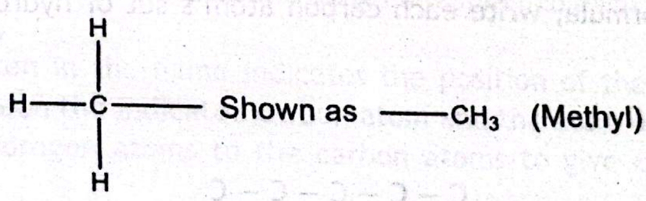
Propane

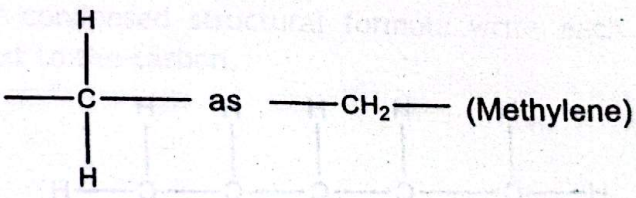
The condensed structural formulas of these alkanes are

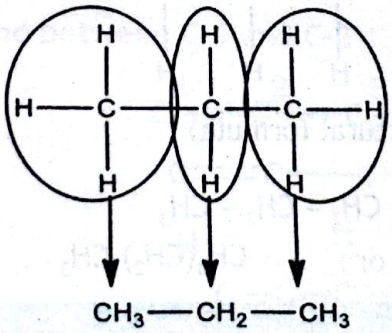
$$CH_4 \quad , \quad CH_3CH_3 \quad , \quad CH_3CH_2CH_3$$

A condensed or normal structural formula uses established abbreviations for various groups of chains. In the displayed formula, we list the main chain carbon atoms and the hydrogen atoms attached to them in the sequence in which they appear in the naming system. It means that a condensed or normal formula is a simplified version that omits some or all of the bonds. It involves grouping atoms that are connected to the same carbon atom.

For instance,







Or $CH_3CH_2CH_3$

Table 8.1 Shows the condensed structural formulas of alkane.

Table 8.1: Condensed or normal structural formulas of some alkanes

Name	Molecular Formula	Structural Formula
Butane	C_4H_{10}	$CH_3CH_2CH_2CH_3$
Pentane	C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$
Hexane	C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$
Heptane	C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
Octane	C_8H_{18}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
Nonane	C_9H_{20}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$
Decane	$C_{10}H_{22}$	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

Example 8.1

Give the displaced and normal structural formula for pentane.

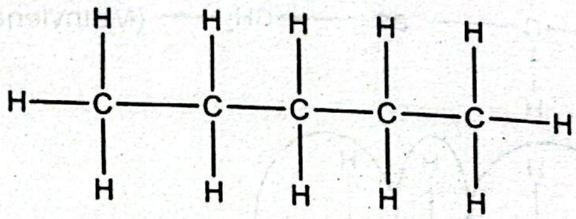
Problem Solving Strategy

i) The stem pent -means five carbon atoms.
ii) The ending -ane indicates an alkane.
iii) Write a string or chain of five carbon atoms.
iv) Attach hydrogen atoms to the carbons to give each carbon atom four bonds. This requires three hydrogen atoms on each end of carbon and two each on others.
v) For the structural formula, write each carbon atom's set of hydrogen atoms next to the carbon.

Solution

C – C – C – C – C

Displayed formula



Normal Structural formula (Condensed Structural formula)

$CH_3 - CH_2 - CH_2 - CH_2 - CH_3$

Or $CH_3CH_2CH_2CH_2CH_3$ or $CH_3(CH_2)_3CH_3$

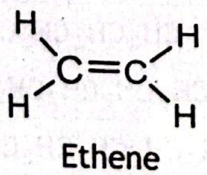
Concept Assessment Exercise 8.1

Give the displayed and structural formulas for

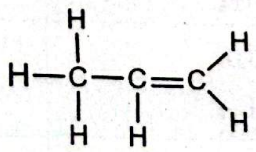
(a) Butane (b) Hexane

8.1.2 Structural formulae for alkenes

Alkenes have one or more double bonds between carbon atoms. They have the general formula C_nH_{2n}. When two carbon atoms share two pairs of electrons, they form a double covalent bond between the carbon atoms. Doubly bonded carbon atoms form a single bond with two other atoms.



Ethene



Propene

Example 8.2

Draw structural and condensed formulas for:

(a) But-1-ene
(b) But-2-ene

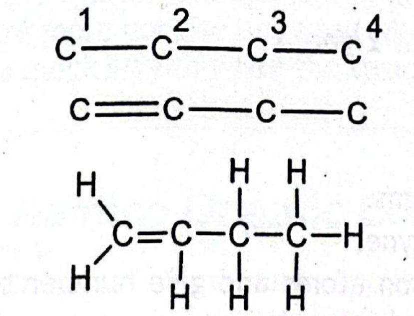
Problem Solving Strategy

(i) But- means four carbon atoms.
(ii) Ending -ene indicates an alkene.
(iii) Write a string of four carbon atoms and assign a number to each carbon atom from one side.
(iv) The Number written in the name indicates the position of the double bond. Make a double bond between the indicated carbon atom and the atom next to it.
(v) Attach enough hydrogen atoms to the carbon atoms to give each carbon atom four bonds.
(vi) For the normal or condensed structural formula write each carbon atom's set of hydrogen atoms next to the carbon.

Solution

(a) But-1-ene

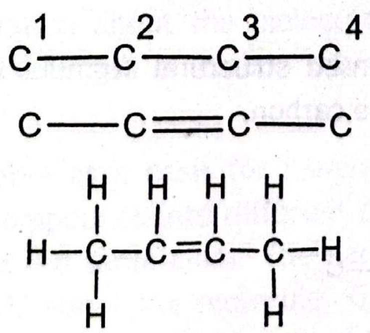
Indicates double bond between C-1 and C-2



$CH_2 = CH - CH_2 - CH_3$

(b) But-2-ene

Indicates double between C-2 and C-3



$CH_3 - CH = CH - CH_3$

Concept Assessment Exercise 8.2

Draw structural and displayed formulas for the following compounds.

(a) Pent-1-ene (b) Pent-2-ene

8.1.3 Structural formulae for alkynes

Hydrocarbons which have at least one triple bond between carbon atoms are called alkynes. Those with one triple bond have the general formula C_nH_{2n-2}.

Ethyne, also called acetylene is the simplest member of the alkyne family. In ethyne, the two carbon atoms share three pairs of electrons. This means the carbon atoms are joined by a triple bond. How many hydrogen atoms can share electrons with each triply-bonded carbon atom?

The structure of ethyne is

$$H-C\equiv C-H$$

Example 8.3

Draw structural and condensed formulas for:

Draw structural formulas for

(a) But-1-yne (b) But-2-yne

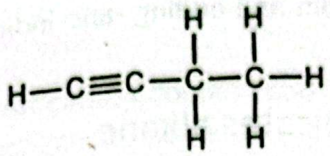
Problem Solving Strategy

(i) But- means four carbon atoms.
(ii) Ending-yne indicates an alkyne.
(iii) Write a string of four carbon atoms and give number to each carbon atom form one side.
(iv) The Number written in the names indicates the position of the triple bond. Make a triple bond between this Carbon atom and next to it.
(v) Attach the required number of hydrogen atoms to the carbon atoms to give each carbon atom four bonds.
(vi) For the normal or condensed structural formula write each carbon atom's set of hydrogen atoms next to the carbon.

Solution

(i) $C^1-C^2-C^3-C^4$

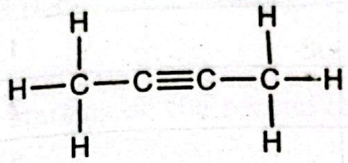
$C^1\equiv C^2-C^3-C^4$



$H - C \equiv C - CH_2 - CH_3$

(ii) $C^1 - C^2 - C^3 - C^4$

$C^1 - C^2 \equiv C^3 - C^4$



$CH_3 - C \equiv C - CH_3$

Key Differences:

- **Displayed formulas** provide a clear view of how atoms are connected and can reveal structural isomers and the spatial arrangement of atoms.
- **Condensed formulas** are more concise and used when detailed bond information is not required, offering a quick way to write the structure of a compound.

8.2 Naming Organic Compounds

The IUPAC (International Union of Pure and Applied Chemistry) system provides a standardized set of rules for naming organic molecules based on their structure, which helps chemists and researchers accurately identify and differentiate compounds regardless of language or region. This systematic approach avoids the confusion that can arise from the use of common or trivial names, which may vary widely and lack specificity. Additionally, IUPAC names convey important information about the molecular structure, such as the type and position of functional groups, the length of carbon chains, and the presence of double or triple bonds.

Recall that functional groups serve as a basis for naming organic compounds. A functional group serve to classify organic compounds into different classes. All the compounds with the same functional group belong to the same class. The name has two parts. Each part of the name tells you something specific about the molecule. One part tells you how many carbon atoms are there in the longest chain, This part is called the stem. The other part tells you about the functional group. This part is called a suffix. It is indicated by the ending in the name. The suffix is placed after the stem. (see Table 8.2)

For example, stem meth means one carbon atom and ending -ane indicates an alkane, So one carbon alkane is named as methane, CH_4

Methane

→ The suffix, indicates alkane

→ Stem, indicates the number of carbon atom

Table 8.2: Shows stem names

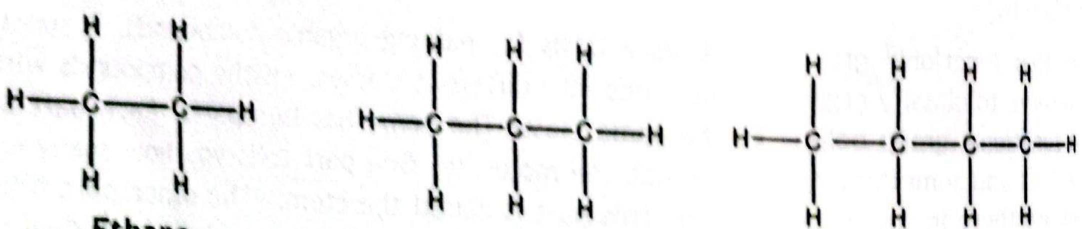
Stem	Number of c-atoms
Meth	1
Eth	2
Prop	3
But	4
Pent	5
Hex	6
Hept	7
Oct	8
Non	9
Dec	10

8.2.1 Naming Alkanes

Alkanes are hydrocarbons in which all the carbon atoms are joined to each other with single covalent bonds. Their names are coded with the ending "-ane". Adding stem before ane gives the name of alkane. For example;

One carbon alkane is methane, CH_4, Two carbon alkane is ethane, CH_3CH_3

Three carbon alkanes are propane, $CH_3CH_2CH_3$ and so on. What is the name of an alkane containing 4 carbon atoms?



Ethane Propane Butane

8.2.2 Naming Alkenes

Alkenes contain carbon-carbon double bond. This is shown in their name by the ending "ene". For example 2-carbon chain containing a carbon-carbon double bond is named ethene, $CH_2{=}CH_2$, 3-carbon chaining alkene is named propene, $CH_3CH_2{=}CH_2$. What will be the name of alkene containing 4-carbon atoms?

With larger chains, the position of double bond is indicated by numbering the chain. Numbering is started from the end nearest to the double bond, noting which carbon the double bond starts from. For example a 4-carbon chain with a double bond starting on carbon number 1 is named as;

$$^{1}CH_2{=}^{2}CH^{3}CH_2{}^{4}CH_3$$

But-1-ene

If the double bond is starting on the second carbon, then the alkene is named;

$$^{1}CH_3{}^{2}CH{=}^{3}CH^{4}CH_3$$

But-2-ene

NOTE: How do you know from which end of the longest chain numbering is done? For this, you should remember the rule that numbering is started from the end which gives the smaller number to the name.

8.2.3 Naming Alkynes

Alkynes contain a carbon-carbon triple bond. This is shown in their name by the ending "yne". For example, 2-carbon chain containing a carbon-carbon triple bond is named ethyne,

$$H-C\equiv C-H$$

3-carbon chaining alkyne is named propyne, $CH_3C{\equiv}CH$. What will be the name of the alkene containing 4-carbon atoms?

With larger chains, the position of the triple bond is indicated by numbering the chain. Numbering is started from the end nearest to the triple bond, noting which carbon the triple bond starts from. For example, a 4-carbon chain with a double bond starting on carbon number 1 is named;

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

But-1-yne

If the triple bond is starting on the second carbon, then the alkene is named;

$$^{1}CH_3{}^{2}C\equiv{}^{3}C^{4}CH_3$$

But-2-yne

Concept Assessment Exercise 8.3

1. Write the name and structural formula of an alkane containing 5-carbon atoms.
2. Write the name and structural formula of an alkene containing 6-carbon atoms with double bond starting on the third carbon.
3. Which name is correct for the following compound

   $CH_3CH_2CH = CHCH_3$

   Pent-2-ene or Pent-3-ene
4. Write the structural formula of an alkyne containing 6-carbon atoms with a triple bond starting on the second carbon.

8.2.3 Naming Alcohols

Alcohols are characterized by the presence of the hydroxyl group(-OH) attached to hydrocarbon chain. This is shown by the ending "ol" in their names. While naming alcohols the "e" of alkane containing the same number of carbon atoms is replaced by the suffix "ol". For example; one carbon alkane is methane, so the name of one carbon alcohol is methanol.

$$\text{Alkane} \xrightarrow{e\ to\ ol} \text{Alkanol}$$

$$\text{Methane} \xrightarrow{e\ to\ ol} \text{Methanol}$$

$$\text{Ethane} \xrightarrow{e\ to\ ol} \text{Ethanol}$$

CH_3OH	CH_3CH_2OH
Methanol	Ethanol
$^3CH_3{}^2CH_2{}^1CH_2OH$	$^1CH_3{}^2CHCH_3$ (with OH on C-2)
Propan-1-ol	Propan-2-ol

Concept Assessment Exercise 8.4

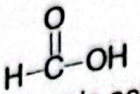
1. Write the name, display and structural formula of an alcohol-containing 4-carbon chain with -OH group attached to a second carbon atom.
2. Write the structural formulas of the following alcohols.

   (a) Butan-1-ol (b) Butan-2-ol

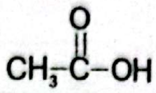
Hint: Write a string of relevant numbers of carbon atoms and number them from one side. Attach OH group on the indicated C-atom and then complete the structure by H-atoms.

8.2.4 Naming Carboxylic Acids

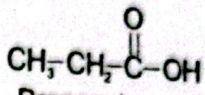
The carboxylic acids are characterized by the presence of carboxylic group -COOH attached to a hydrocarbon chain. This is shown by ending **-oic acid** in their names. While naming carboxylic acids the ending **"e"** of the name of the corresponding alkane containing the same number of carbon atoms is replaced by **'oic acid'**. For example;



Methanoic acid
[Formic acid]



Ethanoic acid
[Acetic acid]



Propanoic acid
[Propionoic acid]

Name shown in square brackets are common names of these compounds.

The position of carbonyl carbon ($\overset{O}{\overset{\|}{-C-}}$) is not mentioned in the name, because it is always numbered carbon 1 i.e. numbering always starts from the carbonyl carbon atom in naming carboxylic acids.

Concept Assessment Exercise 8.5

1. Write the name, displayed and structural formulae of a carboxylic acid containing 4-carbon atoms.
2. Identify the class of each of the following compounds from their names. Also, write their displayed structural formulas and condensed structural formulas
   Pent-2-ol, Pentanoic acid, Pent-2-ene, Pentane

8.3 Esters

Esters are organic compounds that are derived from carboxylic acids and alcohols. Carboxylic acids contain -COOH group(carboxylic group) and can be represented by the general formula RCOOH. When OH of the carboxyl group is simply replaced by OR′ group from an alcohol an ester is formed. It has a general formula RCOOR′. The reaction is carried out in the presence of a few drops of dilute sulphuric acid as a catalyst. This reaction is known as esterification reaction. Esters possess a fruity odour. Both R and R′ may be the same or different.

$$RCOOH \quad + \quad ROH \quad \rightarrow \quad RCOOR \quad + \quad H_2O$$

$$CH_3COOH \quad + \quad CH_3OH \quad \rightarrow \quad CH_3COOCH_3 \quad + \quad H_2O$$

Ethanoic acid   Methanol   Methyl Ethanoate   Water

Their names have two parts, which reflect these two molecules. The first part indicates the attached alkyl group from alcohol and the second one is the name of carboxylic acid, the **-ic** acid is replaced with **-ate**. For example, methyl ethanoate gets its name from the methyl group of the parent methyl alcohol, while ethanoate is obtained by replacing the **-ic** acid of parent ethanoic acid with **-ate**.

Concept Assessment Exercise 8.6

Complete the following reactions and write the names of the reactants and the products.

(i) $CH_3CH_2COOH + CH_3OH \longrightarrow$

(ii) $CH_3CH_2COOH + CH_3CH_2CH_2OH \longrightarrow$

(iii) $CH_3COOH + CH_3CH_2OH \longrightarrow$

KEY POINTS

- Hydrocarbons are compounds containing carbon and hydrogen only. **Hydrocarbons whose carbon-carbon bonds are all single bonds are called alkanes.**
- Alkenes have at least one carbon-carbon double bond between carbon atoms.
- Alkynes have at least one carbon-carbon triple bond between carbon atoms.
- The class of organic compounds which have a hydroxyl functional group attached to a hydrocarbon chain are called alcohol Alcohols are named by changing the ending 'e' of the parent alkane by 'ol'.
- The family compounds which have -COOH functional group attached to the carbon chain are called carboxylic acids of organic.
- Esters are organic compounds that are derived from carboxylic acids and alcohols.

EXERCISE

1. Multiple Choice Questions (MCQs):

i. Which of the following correctly represents the formula for but-2-ene?

a) $CH_3CH{=}CHCH_3$ b) $CH_2{=}CHCH_2CH_3$

c) $CH_3CH_2CH{=}CH_2$ d) $CH_3C{\equiv}CHCH_3$

ii. Given the molecular formula $C_4H_{10}O$, which compound is most likely to be represented by this formula?

a) Butanoic acid b) Butan-1-ol

c) But-2-ene d) Butanal

iii. Which of the following is the correct IUPAC name for the compound with the formula $CH_3CH_2CH_2COOH$?

a) Butanoic acid b) Propanoic acid

c) Butanal d) Butanol

iv. Identify the statement which is true regarding the propan-1-ol and propan-2-ol.

a) Both have identical condensed structural formula.

b) They have the same molecular formula.

c) They are different compounds with the same structural formula.

d) Propan-1-ol is a carboxylic acid, and propan-2-ol is an ester.

v. Name the compound that can be formed by the esterification of methanol and propanoic acid.
   a) Methyl propanoate   b) Propyl methanoate
   c) Ethyl propanoate   d) Propyl ethanoate

vi. Which of the following molecules contains an -OH functional group?
   a) Butane   b) Ethene
   c) Butan-1-ol   d) But-2-yne

vii. If a compound ends in "**-oic acid**", what functional group must it contain?
   a) $-OH$ b) $-COOH$
   c) $-C{=}O$ d) $-C{\equiv}C-$

viii. Which formula corresponds to an ester that could be formed from butan-1-ol and ethanoic acid?
   a) $CH_3CH_2CH_2CH_2COOCH_3$ b) $CH_3COOCH_2CH_2CH_2CH_3$
   c) $CH_3CH_2CH_2CH_2CH_2COOH$ d) $CH_3CH_2COOCH_3$

ix. Which structural formula represents butan-1-ol?
   a) $CH_3CH_2CH_2CH_2OH$ b) $CH_3CH_2CH_2CH_2COOH$
   c) $CH_3CH_2CH{=}CH_2$ d) $CH_3CH{=}CHCH_3$

x. Identify the compound based on the following information: It has the formula C_3H_8O and the name ends with "-ol".
   a) Propanoate   b) Propan-2-ol
   c) Propane   d) Propanoic acid

xi. Which of the following names is incorrect for the given formula?
   a) But-2-ene: $CH_3CH_2CH{=}CH_2$ b) But-1-ene: $CH_2{=}CHCH_2CH_3$
   c) Butane: $CH_3CH_2CH_2CH_3$ d) Butan-2-ol: $CH_3CH(OH)CH_2CH_3$

2. Short Answer Questions

i. Define the term displayed structural formula in organic chemistry.
ii. Explain the difference between an alkane and an alkene.
iii. How can you distinguish between an alcohol and a carboxylic acid by their structural formulae?
iv. Write the name for $CH_3-CH_2-CH_2-CH_2-CH_2-OH$.
v. Describe the process of esterification.
vi. Given the condensed structural formula $CH_3CH_2CH_3$, what is the displayed structural formula?
vii. Give displayed structural formulae for (i) Ethanol (ii) Ethanoic acid
viii. Identify the type of organic compounds from the given names. And give the normal structural of each compound.
   a. Propyne
   b. Propanoic acid
   c. Propan-2-ol
   d. Methyl propaoate
ix. Identify the type of compound given the name "but-2-ene".

x. Draw the structural formula of but-1-ene ... plain the difference between them.

xi. Draw the displayed formula of ethyl butanoate.

xii. Given the displayed formula $CH_3COOCH_2CH_3$, identify the alcohol and carboxylic acid used to form the ester.

xiii. From the displayed formula $CH_3-C\equiv C-CH_3$, identify the compound and its type.

xiv. Design the synthesis pathway for converting butan-1-ol into but-1-ene.

3. Long Questions:

i. Discuss the significance of functional groups in organic chemistry and provide examples.

ii. How can you differentiate alkenes, alcohols, and carboxylic acids by looking at their structural formulae?

iii. Explain the reaction between an alcohol and a carboxylic acid to form an ester.

iv. Explain the chemical reaction process for forming esters from alcohols and carboxylic acids. Draw the structural and displayed formulas of the ester formed from ethanol and propanoic acid.

v. Given the esters methyl methanoate, ethyl ethanoate, and butyl butanoate, Give the starting materials required to produce these esters.

vi. Explain the significance of the suffixes -ane, -ene, -yne, -ol, and -oic acid in naming organic compounds. Provide examples of each with their molecular and displayed formulas.

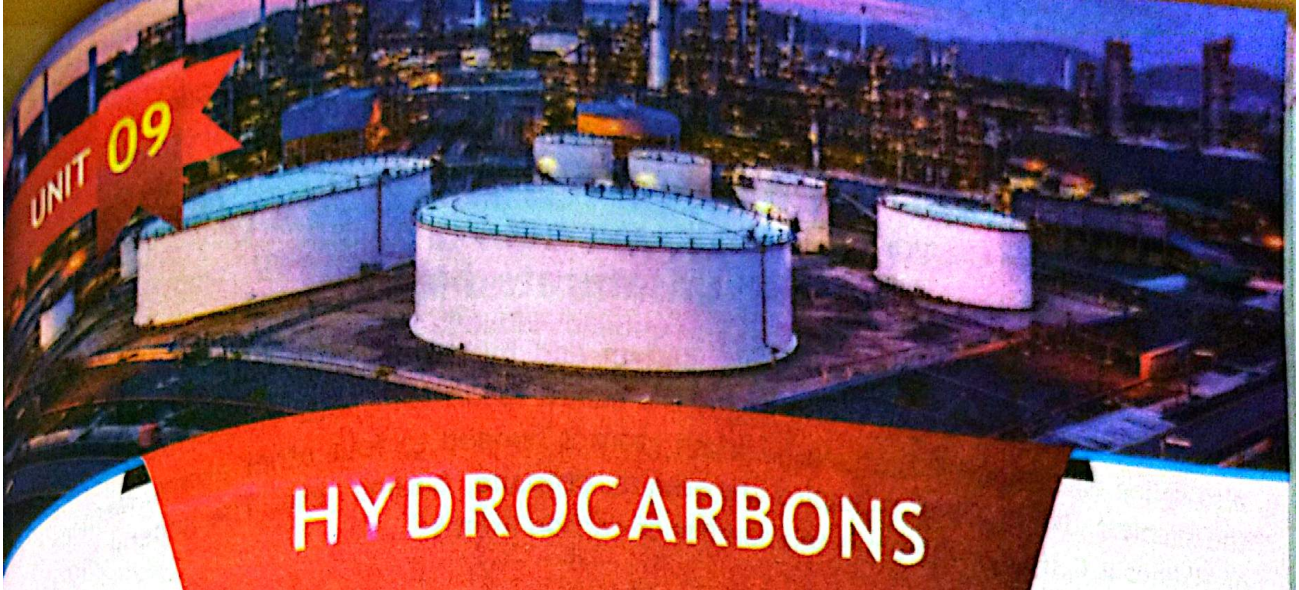
vii. Compare the functional groups of esters and carboxylic acids. Use specific examples to illustrate your answer.

viii. Develop a table that helps you to determine the type of organic compound based on its structural formula (having two carbon atoms) and functional groups.

THINK TANK

1. Develop a flowchart or decision tree that helps students determine the type of organic compound based on its molecular formula and functional groups.
2. Given the molecular formula $C_3H_6O_2$, draw all possible structural formulas and identify the type of compound.

UNIT 09



HYDROCARBONS

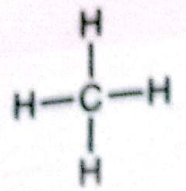
Student Learning Outcomes (SLOs)

- State that the bonding in alkene includes a double carbon-carbon covalent bond and that alkenes are unsaturated hydrocarbons.
- Describe the manufacture of alkenes by the cracking of large alkane molecules using a high temperature and a catalyst.
- Describe the reasons for the cracking of large alkane molecules.
- Describe the test to distinguish between saturated and unsaturated hydrocarbon by their reaction with aqueous bromine and $KMnO_4$.
- Describe the properties of alkenes in term of addition reactions with, a) bromine or aqueous bromine, b) hydrogen in the presence of nickel catalyst, c) steam in the presence of an acid catalyst and draw the structural or displayed formulae of the products.
- Describe, using symbol equations, preparation of alkenes by elimination reaction in halogenoalkanes and alcohols.
- Identify alkynes as hydrocarbons containing triple carbon-carbon covalent bond and that alkynes are unsaturated hydrocarbons.
- Describe the use of ethyne as fuel for welding and in artificially ripening fruits.
- Describe separation of petroleum into useful fractions by fractional distillation.
- Describe how the properties of fractions obtained from petroleum change from bottom o the top of the fractionating column, limited to: a. decreasing the chain length b. higher volatility c. lower boiling point d. lower viscosity.
- Name the uses of the fractions as: a. refinery gas fraction for gas used in heating and cooking b. gasoline/petrol fraction for fuels used in cars, c. naphtha fraction as a chemical feedstock, d. kerosene/paraffin fraction for jet fuel. e diesel oil/gas oil fraction for fuel used in diesel engines, f. fuel oil fraction for fuel used in ships and home heating systems, g. lubricating oil fraction for lubricants, waxes and polishes, h. bitumen fraction for making roads.
- Name fossil fuels; coal, natural gas and petroleum.
- Name methane as main constituent of natural gas.
- State that petroleum is a mixture of hydrocarbons, compounds containing hydrogen and carbon only.

Hydrocarbons are organic compounds composed solely of carbon (C) and hydrogen (H). Carbon atoms attach to each other to form the backbone of the compound. Hydrogen atoms attach to the carbon atoms in a variety of ways. Hydrocarbons make up the major component of petroleum and natural gas (methane). They are raw materials for plastics, fibers, explosives, and many industrial chemicals.

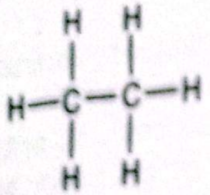
9.1 Saturated and Unsaturated Hydrocarbons

Hydrocarbons are compounds containing carbon and hydrogen only. **Hydrocarbons whose carbon-carbon bonds are all single bonds are called saturated.** Saturated hydrocarbons are also called alkanes. In alkanes, each carbon atom is bonded to four other atoms. Methane is the simplest alkane. Other examples are ethane, propane, butane, etc. The general formula of alkanes is C_nH_{2n+2}, where n is the number of carbon atoms.

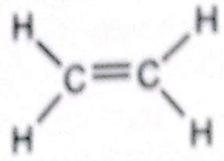


Methane

Hydrocarbons containing carbon-carbon multiple bonds are called unsaturated. Which of the following are unsaturated hydrocarbons?



Ethane



Ethene

Ethyne

Unsaturated hydrocarbons are further divided into:

(i) **Alkenes**

(ii) **Alkynes**

Unsaturated hydrocarbons containing at least one carbon-carbon double bond are called alkenes. They have the general formula (C_nH_{2n}), for example, ethene. Unsaturated hydrocarbons that have at least one carbon-carbon triple bond are called alkynes. They have a general formula C_nH_{2n-2}, for example, ethyne.

Concept Assessment Exercise 9.1

Choose saturated and unsaturated compounds from the following.

(i) $CH_3-CH_2-CH_3$ (ii) $CH_3-C\equiv CH$

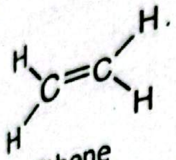
(iii) $CH_3-CH=CH_2$ (iv) $CH_2=CH-CH=CH_2$

9.2 ALKENES

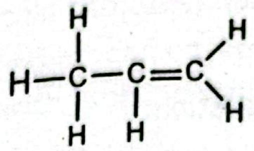
Alkenes have one or more double bonds between carbon atoms. They have the general formula C_nH_{2n}. When two carbon atoms share two pairs of electrons, they form a double bond between the carbon atoms. How many electrons are left on each carbon atom? Doubly bonded carbon atoms form a single bond with two other atoms.

Do you know?

Ethylene or ethene is the most important commercial organic chemical. It is used to manufacture polythene, one of the most familiar plastics. It is also converted to ethylene glycol which is used as antifreeze in automobile radiators.



Ethene



Propene

9.2.1 Preparation of Alkene

1. By the cracking of large alkanes

i. A large alkane molecule breaks up into smaller hydrocarbons when heated at high temperatures such as 450-750°C and high pressure. This process is called thermal cracking. This process produces a mixture of alkanes and alkenes. For example, when the decane is heated at high temperatures and pressure, it breaks into octane and ethene.

$$\underset{\text{Decane}}{C_{10}H_{22}} \longrightarrow \underset{\text{Octane}}{C_8H_{18}} + \underset{\text{Ethene}}{C_2H_4}$$

ii. Large alkane molecules can also be broken into smaller pieces by catalytic cracking. In catalytic cracking, alkanes are heated at 550°C in the presence of a catalyst such as zeolite. Catalytic cracking gives a higher percentage of hydrocarbons containing 5 to 10 carbon atoms.

$$\underset{\text{Dodecane}}{C_{12}H_{26}} \longrightarrow \underset{\text{Pentane}}{C_5H_{12}} + \underset{\text{Heptene}}{C_7H_{14}}$$

$$\underset{\text{Heptane}}{C_7H_{16}} \longrightarrow \underset{\text{Pentane}}{C_5H_{12}} + \underset{\text{Ethene}}{C_2H_4}$$

Cracking gives a mixture of smaller hydrocarbons containing a higher proportion of alkenes. These hydrocarbons are more volatile and possess lower boiling points, making them easier to use as better fuels. Moreover, their combustion can be controlled and they produce large amounts of heat per gram.

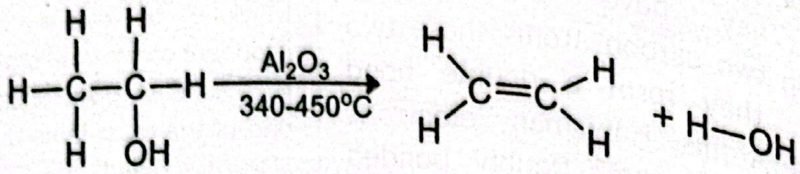
For example, the following reaction occurs when alkanes are burned.

$$C_2H_{4(g)} + 3O_{2(g)} \longrightarrow 2CO_{2(g)} + 2H_2O_{(g)} + \text{heat}$$

$$C_5H_{12(g)} + 8O_{2(g)} \longrightarrow 5CO_{2(g)} + 6H_2O_{(g)} + \text{heat}$$

2. By Dehydration of Alcohols

Dehydration means loss of water. Alcohols dehydrate when their vapour are passed over heated alumina to give alkenes.



Ethanol Ethene

Phosphoric acid (H_3PO_4) and phosphorus pentaoxide (P_4O_{10}) can also be used as the catalyst for the dehydration of alcohols.

Concentrated sulphuric acid is also used for dehydration.

$$CH_3-CH_2(OH) \xrightarrow[140\text{-}170^{\circ}C]{Conc.\ H_2SO_4} H_2C{=}CH_2 + H_2O$$

Note that in a dehydration reaction the -OH group is removed from one carbon and the H atom from the adjacent carbon atom, resulting in the formation of a double bond between such carbon atoms. Such a reaction is called an elimination reaction.

3. By dehydrohalogenation of halogenoalkanes

Dehydrohalogenation means the loss of hydrogen halide. Halogenoalkanes on heating with alcoholic potassium hydroxide undergo dehydrohalogenation.

$$CH_3-CH_2(Cl) + KOH \xrightarrow{Alcohol} CH_2{=}CH_2 + KCl + H_2O$$

Note that removal of H and halogen takes place from two adjacent carbon atoms. Is dehydrohalogenation an elimination reaction?

Science titbits

Alkenes occur widely in nature. Ripening fruits and vegetables give off ethene which helps in further ripening. So artificially ethene is used to hasten the normal ripening process. For example 1 kg of tomatoes can be ripened by exposure to 0.1mg of ethene for 24 hours. The red color of tomatoes is due to an alkene called Lycopene.

Concept Assessment Exercise 9.2

Complete the following reactions.

1. $CH_3-CH_2-CH_2(OH) \xrightarrow[170^{\circ}C]{Conc.\ H_2SO_4}$
2. $CH_3-CH_2-CH_2(Br) + KOH \xrightarrow{Alcohol}$
3. Which alkene is formed by the dehydration of the following alcohol?

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

9.2.2 Properties of Alkenes

a. Physical Properties

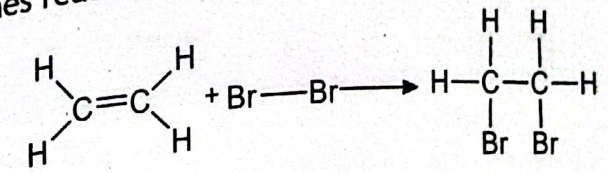
Alkenes are unsaturated hydrocarbons. The first three members i.e. ethene, propene and butene are gases while C_5-C_{15} members are liquids, and the higher members are solids. They are insoluble in water but soluble in organic solvents such as alcohol etc.

b. Chemical Properties

The two carbon atoms forming double bond is the site where other molecules can attack giving addition reaction.

1. Reaction with halogens

Chlorine and bromine are added to the double bond ($>C=C<$). One bromine atom becomes attached to one carbon and another carbon atom. Such a type of reaction is called an addition reaction. Alkenes react with bromine water in the same way.



Ethene(colourless) (Reddish-brown) 1,2-Dibrome ethane (colourless)

Bromine is a reddish-brown liquid and the product is colourless. When bromine water is added to an alkene, the red-brown colour disappears. The decolourization of bromine solution is frequently used as a simple test for the detection of unsaturation. Alkynes also give this reaction.

2. Reaction with $KMnO_4$

When an alkene is treated with a dilute alkaline aqueous solution of $KMnO_4$ (1%) addition of two hydroxyl groups occurs across the double bond. The pink colour of $KMnO_4$ the solution is discharged during the reaction. This reaction is used as a test for the presence of an unsaturated compound like alkene and is known as **Baeyer's test.** This test is used to distinguish saturated and unsaturated hydrocarbons. Saturated hydrocarbons do not give this reaction.

$$3CH_2{=}CH_2 + 2KMnO_4 + 4H_2O \longrightarrow 3CH_2(OH)\text{—}CH_2(OH) + 2MnO_2 + 2KOH$$

Ethene Ethylene Glycol

Ethylene glycol is used as an anti-freeze.

Concept Assessment Exercise 9.3

Complete the following reactions:

1. $CH_3-CH=CH_2 + Br_2 \longrightarrow$
2. $CH_3-CH=CH_2 + KMnO_4 + H_2O \longrightarrow$
3. $CH_3-CH_3 + KMnO_4 + H_2O \longrightarrow$

1. Hydrogenation of [illegible]

The addition of hydrogen molecules [illegible] multiple-bond is called hydrogenation. Hydrogenation takes place in the presence of finely divided nickel at 200 - 300 °C and high pressure. Hydrogenation can also be done in the presence of Pt or Pd at room temperature.

$$\underset{\text{Ethene}}{CH_2 = CH_2} + H_2 \xrightarrow[\text{High Pressure}]{\text{Ni, 200-300°C}} \underset{\text{Ethane}}{CH_3 - CH_3}$$

Concept Assessment Exercise 9.4

Complete the following reactions

$$CH_3 - CH = CH_2 + H_2 \xrightarrow{\text{Ni, 200-300°C}}$$

$$CH_3 - CH = CH - CH_3 + H_2 \xrightarrow{\text{Ni, 200-300°C}}$$

2. Hydration of alkenes

Alkenes produce alcohol on treatment with steam. Phosphoric acid is used as a catalyst in this reaction. Ethanol is commercially produced by this reaction.

$$\underset{\text{Ethene}}{CH_2 = CH_2} + \underset{\text{Steam}}{H\text{-}OH} \xrightarrow{H_3PO_4} \underset{\text{Ethanol}}{CH_3-CH_2-OH}$$

$$\underset{\text{Propene}}{CH_3CH = CH_2} + \underset{\text{Steam}}{H\text{-}OH} \xrightarrow{H_3PO_4} \underset{\text{Propanol}}{CH_3-CH_2-CH_2-OH}$$

9.3 ALKYNE

Hydrocarbons that have at least one triple bond between carbon atoms are called alkynes. This means alkynes are unsaturated hydrocarbons. Alkynes with one triple bond have the general formula C_nH_{2n-2}.

Ethyne, also called acetylene is the simplest member of the alkyne family. In ethyne, the two carbon atoms share three pairs of electrons. This means the carbon atoms are joined by a triple bond.

$$H - C \equiv C - H$$

Commercial Importance of Ethyne

Ethyne has great commercial importance. It is also known as acetylene and is commonly used in cutting and welding metals. When it is ignited in oxygen or air, it burns with a bluish colour producing a very hot flame called oxy-acetylene flame. Its temperature is about 3200 °C. Oxy-acetylene flame has the highest flame temperature of all other fuel gases. Welding and cutting of metals require high temperatures. Therefore, ethyne is used for this purpose.

Another advantage of ethyne is its use in the artificial ripening of fruits. Have you ever seen a packet containing solid material in your fruit boxes, especially in mango crates? This packet contains calcium carbide, which on coming in contact with moisture produces ethyne gas. This ethyne promotes ripening and also induces colour changes in fruits. However, its use can lead to exposure to harmful chemicals, that can cause respiratory issues and other health problems.

$$CaC_2 + H_2O \longrightarrow C_2H_2 + Ca(OH)_2$$

9.4 Distinguishing saturated and unsaturated hydrocarbons

To distinguish between saturated and unsaturated hydrocarbons, you can perform the **bromine water test**. This test involves adding bromine water (Br_2 in water, which is an orange-brown solution) to the hydrocarbon and observing the colour change.

Procedure

1. Add bromine water to the hydrocarbon sample.
2. Observe the colour change.

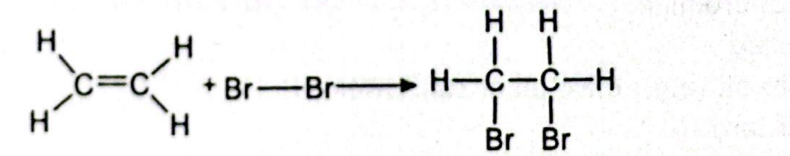
Observations

- Saturated hydrocarbons (alkanes) will not react with bromine water. The solution will remain orange-brown.
- Unsaturated hydrocarbons (alkenes and alkynes) will react with bromine water. The solution will decolourize (turn colourless) because the bromine reacts with the double or triple bonds.

Symbol Equations

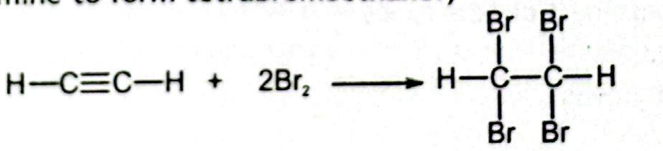
For an alkene (unsaturated hydrocarbon)

Ethene reacts with bromine to form dibromoethane.



Ethene(colourless) (Reddish-brown) 1,2-Dibrome ethane (colourless)

Ethyne reacts with bromine to form tetrabromoethane.)



Ethyne (colourless) Bromine (redish brown) 1,1,2,2-Tetrabromoethane (colourless)

For an alkane (saturated hydrocarbon)

$$C_2H_6 + Br_2 \longrightarrow \text{No reaction}$$

(Ethane does not react with bromine water, so the colour remains unchanged.)

This test is effective because the presence of a double or triple bond in unsaturated hydrocarbons allows them to react with bromine, breaking the bond and forming a dibromo compound, which is colourless.

The **Baeyer's test** is another method to distinguish between saturated and unsaturated hydrocarbons. This test involves using a cold, dilute alkaline, aqueous solution of potassium permanganate, $KMnO_4$ (1%), which is purple.

Procedure

3. Add a few drops of cold, dilute alkaline, aqueous $KMnO_4$ solution to the hydrocarbon sample.
4. Shake the mixture and observe the colour change.

Observations

- **Saturated hydrocarbons** (alkanes) do not react with $KMnO_4$, and the solution remains purple.
- **Unsaturated hydrocarbons** (alkenes) react with $KMnO_4$, causing the solution to become colourless as the permanganate ion is reduced to manganese dioxide (MnO_2), which precipitates as a brown solid.

Symbol Equations

For an alkene (unsaturated hydrocarbon):

$$3C_2H_4 + 2KMnO_4 + 4H_2O \longrightarrow 3C_2H_4(OH)_2 + 2MnO_2 + 2KOH$$

(Ethene reacts with potassium permanganate, resulting in the formation of ethane-1,2-diol, manganese dioxide, and potassium hydroxide. The solution turns brown due to MnO_2 and loses its purple colour.)

Alkynes do not react with cold 1% alkaline aqueous solution of $KMnO_4$ (Baeyer's agent).

Activity 9.1

To distinguish between saturated (butter representing saturated hydrocarbon) and unsaturated (vegetable oil representing an unsaturated hydrocarbon) hydrocarbons based on the reaction with bromine.

Materials Required

- Vegetable oil (e.g., olive oil or sunflower oil)
- Butter or lard
- Bromine water (a dilute solution of bromine in water. CAUTION: Bromine is toxic and corrosive; handle with gloves and under supervision)
- Two small glass containers or test tubes
- Droppers or pipettes
- Safety goggles and gloves
- Lab apron
- White paper or white tiles (to better observe colour change)
- Tongs or test tube holders.
- Fume hood or well-ventilated area for safety

Safety Precautions

- Ensure all students wear safety goggles, gloves, and lab aprons.
- Conduct the experiment in a well-ventilated area or fume hood.
- Explain the hazards associated with bromine water and the importance of not directly inhaling or contacting the solution.

Procedure

- Pour a small amount (about 5 mL) of vegetable oil into one glass container or test tube.
- Place a small piece of butter in another glass container or test tube.
- Label each container appropriately (e.g., "Vegetable Oil" and "Butter").
- Using a dropper, add a few drops of bromine water to each container.
- Observe and note the initial colour of the bromine water (orange-brown).

Observations

- Gently swirl each container to mix the contents:
  - **Vegetable Oil (Unsaturated Hydrocarbon):** The bromine water will react with the double bonds in the unsaturated hydrocarbons, causing the orange-brown colour to disappear or lighten. This reaction occurs because the bromine adds across the double bonds, forming a colourless dibromo compound.
  - **Butter (Saturated Hydrocarbon):** The bromine water will remain orange-brown in colour, indicating no reaction. Saturated hydrocarbons do not have double bonds, so they do not react with bromine under these conditions.

Discussion

- Ask the students to discuss their observations:
- Why did the colour of bromine water change with vegetable oil but not with butter?
- What does this indicate about the types of bonds present in vegetable oil and butter?

9.5 Fossils Fuels

Where does most of the energy used today come from?

Fossil fuels are natural energy sources. Fossil fuels are a non-renewable energy source. It is believed that they are formed from the remains of ancient organisms. They include coal, natural gas, and petroleum.

9.5.1 Coal

Coal is a material usually found in sedimentary rock deposits where rock and dead plant and animal matter are piled up in layers. It can be burned for fuel and used to generate electricity. Coal is the leading source of energy in the world. Because coal takes millions of years to develop and there is a limited amount of it, it is a non-renewable resource.

9.5.2 Natural Gas

Natural gas is a gaseous mixture of hydrocarbons that occurs naturally. The main component of natural gas is methane, but there are also small amounts of other high-alkanes such as ethane, propane, and butane, as well as trace gases such as carbon dioxide (CO_2), nitrogen (N_2), hydrogen sulfide (H_2S), and helium. Natural gas is used extensively for heating, electricity generation, and as a fuel for vehicles and spacecraft.

9.5.3 Petroleum

The name petroleum is derived from Latin words, petra meaning rock and oleum meaning oil. It is also known as crude oil. Petroleum or crude oil is a thick dark liquid composed mostly of hydrocarbons. Natural gas, usually associated with petroleum deposits, consists mostly of methane. It also contains significant amounts of ethane, propane, and butane.

Petroleum is extracted by drilling holes into the earth's crust where it is found. When a drill is made through the rocks, natural gas comes out first with great pressure. After the gas pressure subsides, crude oil is extracted by pumps.

9.6 Separating crude oil

Refining is the process of separating crude oil into usable products. These useful products contain a group of hydrocarbon molecules that have similar chain lengths, similar boiling points, and condense over a range of temperatures. These groups of hydrocarbons are called fractions. This means that each useful fraction consists of a combination of different hydrocarbons that boil at a specific temperature. Oil refining takes place in a high-temperature fractionation tower, where the temperature at the top of the tower is colder than at the bottom of the tower (see figure). Crude oil is heated under high pressure in a furnace to a temperature of 400 °C. The oil is then passed through a distillation column where vapour rises. As the hot vapour move up the tower, it condenses into different fractions according to the boiling point. Compounds with the highest boiling point condense near the bottom, compounds with the lowest boiling point at the top, and non-boiling compounds collect at the bottom (see Figure 9.1). Therefore, crude oil is divided into several fractions. Each fraction has its specific boiling range and composition. How many fractions are obtained?

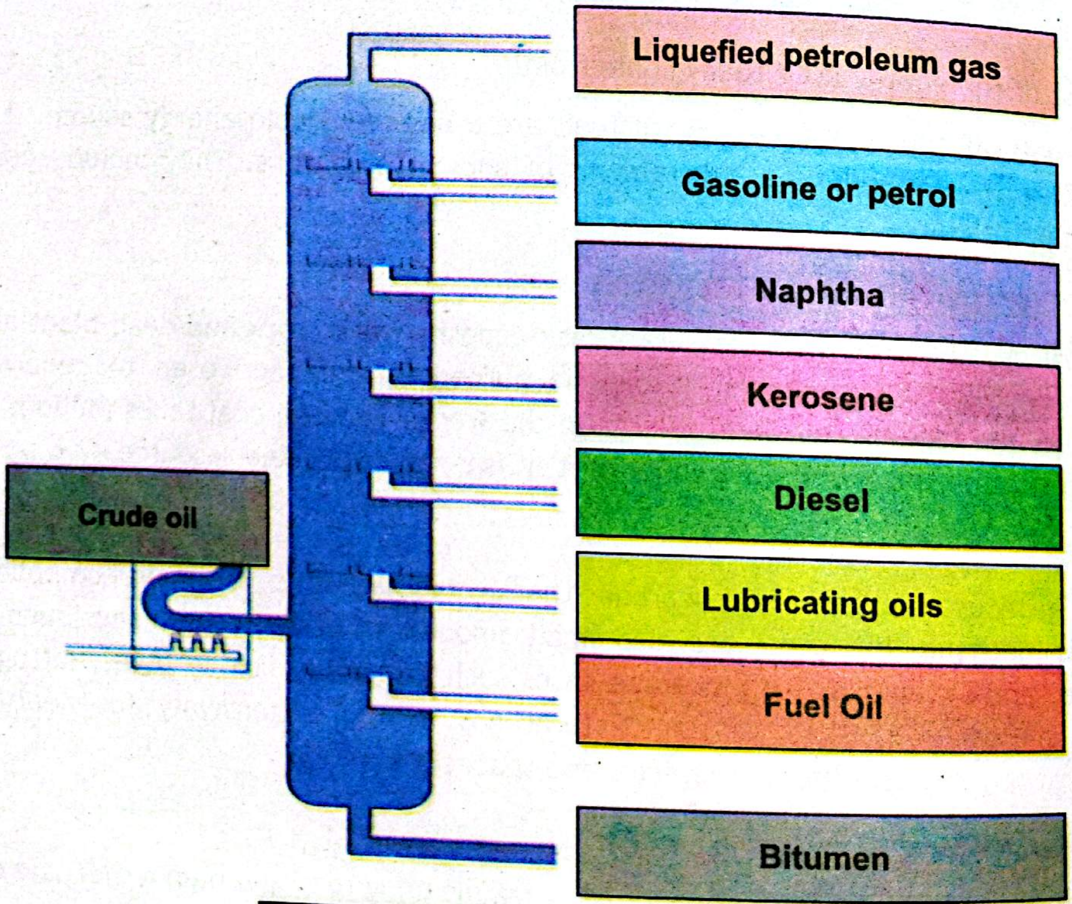


Figure 9.1: Fractional distillation of petroleum

The physical properties and uses of petroleum fractions are given in the table 9.1.

Table 9.1: Fractions of petroleum and their uses

Fraction	Number of carbon atoms per molecule	Boiling point °C	Important uses
Liquefied petroleum gas (LPG)	1-4	Below 20	Cylinder gas for cooking and heating
Petrol/ gasoline	5-10	35-70	Fuel for motor cars and vehicles
Naphtha	8-12	70-120	Chemical feedstock for making drugs, plastics and other chemicals
Kerosene/ paraffine	10-16	170-250	Fuel for jet planes, fuel for heating, lighting and cooking
Diesel/ gas oil	14-20	270-340	Fuel for diesel engines of buses, trucks and trains.
Lubricating oil	20-50	350-500	Lubricants for machines and engines, waxes and polishes
Fuel oil	50-70	500-600	Fuel for power stations, factories, ships and home heating systems
Bitumen	More than 70	More than 500	Paving roads and making roofing materials

As the length of the hydrocarbon carbon chain increases, the strength of the intermolecular force also increases. Bitumen has the longest carbon chain, highest boiling point, highest viscosity, lowest volatility, and darkest colour. As you move from bottom to top. The chain length of carbon atoms in different fractions gradually decreases. Thus, their boiling points and viscosity also decrease. However, the weakening of the strength of the intermolecular forces increases the volatility of the fractions. For example, refinery gas (LPG) has the shortest carbon chain, lowest boiling point, lowest viscosity, and highest volatility.

Concept Assessment Exercise 9.5

1. List names of fractions obtained by the fractional distillation of petroleum.
3. List one use of each petroleum fraction.
4. How is petroleum obtained?

KEY POINTS

- Hydrocarbons are compounds containing carbon and hydrogen only.
- Hydrocarbons whose carbon-carbon bonds are all single bonds are called saturated.
- Hydrocarbons containing carbon-carbon multiple bonds are called unsaturated.
- Unsaturated hydrocarbons containing at least one carbon-carbon double bond are called alkenes.
- Unsaturated hydrocarbons that have at least one carbon-carbon triple bond are called alkynes.
- In catalytic cracking alkanes are heated at 550 °C in the presence of a catalyst such as zeolite.
- Dehydration means loss of water.
- Dehydrohalogenation means loss of hydrogen halide.
- The name petroleum is derived from Latin words, petra meaning rock and oleum meaning oil. It is also known as crude oil.

EXERCISE

1. Multiple Choice Questions (MCQs)

i. What Alkenes have one or more double bonds between carbon atoms? They have the general formula C_nH_{2n}. When two carbon atoms share two pairs of electrons, they form a double bond between the carbon atoms. How many electrons are left on each carbon atom?
   a) 2 b) 3 c) 1 d) 4

ii. The type of bond present between the carbon atoms in alkynes is:
   a) Single covalent bond b) Double covalent bond
   c) Triple covalent bond d) Saturated covalent bond

iii. Alkenes are classified as:
   a) Saturated hydrocarbons b) Unsaturated hydrocarbons
   c) Aromatic hydrocarbons d) None of the above

iv. Cracking of large alkane molecules requires:
   a) Low temperature and pressure b) High temperature and catalyst
   c) Low temperature and catalyst d) High temperature and high pressure

v. Which of the following is a product of cracking large alkane molecules?
   a) Carbon dioxide b) Alkenes
   c) Water d) Hydrogen

vi. The chemical test to distinguish between alkanes and alkenes involves:
   a) Limewater b) Bromine water
   c) Litmus paper d) Universal indicator

vii. Alkynes contain which type of carbon-carbon bond?
   a) Single covalent bond b) Double covalent bond
   c) Triple covalent bond d) Saturated covalent bond

viii. Ethyne is commonly used for:
a) Cooking b) Welding
c) Fuel for cars d) Heating

ix. Fractional distillation separates petroleum into fractions based on:
a) Density b) Boiling point
c) Viscosity d) Solubility

x. Which property increases as you move from the bottom to the top of the fractionating column?
a) Volatility b) Chain length
c) Boiling point d) Viscosity

xi. The gasoline/petrol fraction from petroleum is primarily used for:
a) Jet fuel b) Heating
c) Car fuel d) Chemical feedstock

xii. Doubly bonded carbon atoms form which type of bond with two other atoms.
a) Single b) Double
c) Trible d) Non

2. Short Answer Questions

i. Describe the bonding in alkenes.
ii. What are the conditions required for the cracking of alkanes?
iii. Why is the cracking of large alkane molecules important in the petroleum industry?
iv. How can you test for the presence of an unsaturated hydrocarbon?
v. Write the symbol equation for the preparation of ethene from ethanol.
vi. What type of bond is present in alkynes?
vii. Name two uses of ethyne.
viii. What is the principle behind the fractional distillation of petroleum?
ix. How does the boiling point of fractions change from the bottom to the top of the fractionating column?
x. List two uses of the naphtha fraction obtained from petroleum
xi. How can you distinguish between propane and propene?
xii. In a refinery, large alkane molecules are cracked to produce smaller alkenes and other hydrocarbons.
   a. Explain why alkenes are considered unsaturated hydrocarbons. Write conditions for cracking.
   b. Write the symbol equation for the cracking of decane to produce ethene and octane.
   c. Why cracking of large alkanes is necessary in the petroleum industry.
   d. Propose a method to increase the efficiency of the cracking process.
xiii. Ethyne (acetylene) is a hydrocarbon, used as a fuel for welding and in artificially ripening fruits.
   a. Explain why ethyne is considered an unsaturated hydrocarbon.
   b. Explain why ethyne is an effective fuel for welding.

c. Discuss the potential health risks associated with the use of ethyne for artificially ripening fruits.

d. Propose a safer alternative method for ripening fruits that does not involve ethyne.

xiv. Explain why alkenes are considered unsaturated hydrocarbons.

xv. Write the symbol equation for the cracking of decane ($C_{10}H_{22}$).

xvi. Explain why the refinery gas fraction is more volatile than the fuel oil fraction.

3. Long Answer Questions

i. Explain the process of fractional distillation of petroleum, including how the properties of fractions change from the bottom to the top of the fractionating column.

ii. Discuss the significance of cracking in the petroleum industry and how it helps in meeting the demand for various hydrocarbons.

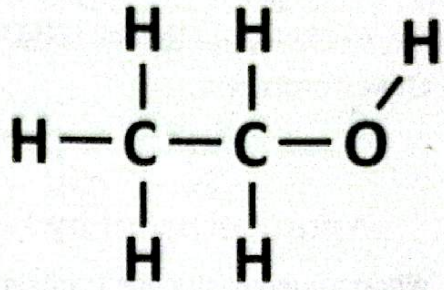
iii. Describe the preparation of alkenes by elimination reactions from halogenoalkanes and alcohols, providing balanced chemical equations for each process.

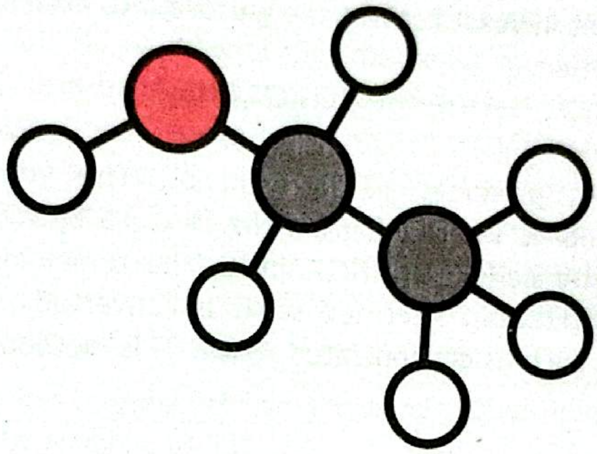
THINK TANK

1. Compare the economic benefits of producing alkenes via cracking versus extracting them directly from crude oil.
2. Describe the chemical properties of ethyne that make it suitable for welding.
3. In a laboratory, you need to distinguish between a sample of hexane and hexene. Describe the test to distinguish between them.

UNIT 10

$$H_3C-CH_2-OH$$





HYDROXY COMPOUNDS

Student Learning Outcomes (SLOs)

- Describe the manufacture of ethanol (This can be done by discussing- fermentation of aqueous glucose at 25-35°C in the presence of yeast and in the absence oxygen.- catalytic addition of steam to ethene at 300°C and 600kPa/6atm in the presence of an acid catalyst including a comparison of the advantages and disadvantages of the two methods.
- Describe the combustion of alcohols.
- Discuss the applications of alcohols as fuels, including their advantages over fossil fuels.
- Explain the role of alcohols in various industries such as pharmaceuticals, cosmetics, and fuel production.
- Discuss the impact of alcohols on daily life, including their uses as solvents and disinfectants.

An alcohol is an organic compound in chemistry that contains at least one hydroxy functional group attached to a saturated carbon atom. The class of organic compounds which have a hydroxyl functional group attached to a hydrocarbon chain are called alcohols. There are many different types of alcohols, ranging from simple,

for example, methanol (CH_3OH), and ethanol (CH_3CH_2OH), to complex alcohols like sugar, cholesterols, etc.

10.1 Manufacture of Ethanol

1. Making ethanol by fermentation

When aqueous glucose is mixed with yeast and left for several days at 25-35 °C in the absence of oxygen. Enzymes present in yeast convert the glucose into ethanol and carbon dioxide. This process is called fermentation.

$$\underset{\text{glucose}}{C_6H_{12}O_{6(aq)}} \longrightarrow \underset{\text{ethanol}}{2CH_3CH_2OH_{(aq)}} + \underset{\text{carbon dioxide}}{2CO_{2(g)}}$$

The fermentation process produces 10-15% ethanol. The yeast is killed beyond this concentration. The ethanol is separated from the mixture by fractional distillation, which gives 96% pure alcohol also called rectified spirit. The remaining 4% of water cannot be removed by fractional distillation. Rectified spirit is converted into 100% pure ethanol by using a dehydrating agent such as concentrated H_2SO_4. This method uses renewable resources and low energy levels.

2. Making ethanol by the hydration of ethene

Ethanol is produced when steam is added to ethene at 300°C and 6000kPa/6 atm. in the presence of phosphoric acid as a catalyst.

$$\underset{\text{ethene}}{CH_2{=}CH_{2(g)}} + \underset{\text{steam}}{H_2O_{(g)}} \xrightarrow[300^\circ C,\,6atm]{H_3PO_4} \underset{\text{ethanol}}{CH_3CH_2OH_{(g)}}$$

Only 4% of ethene is converted into ethanol. The ethanol produced is condensed into liquid and unreacted ethene is recycled in the process. By repeating these steps 96% ethanol is produced. This method uses non-renewable resources and high energy levels.

Table 10.1: Comparing hydration and fermentation

Hydration of ethene	Fermentation of glucose
The raw material is ethene, which comes from crude oil (non-renewable source)	The raw material is glucose, which comes from plants such as sugar cane (a renewable source)
Continuous process (efficient) - the reaction occurs as long as the reactants are constantly provided	Batch process (less efficient) - all the reactants are mixed in a reaction vessel and left for several days to react. A new reaction is set up when the first batch of reaction is over
Is a fast reaction	Is a slow reaction
Produces pure ethanol	Produces impure ethanol, so needs further processing
Requires high temperature and pressure, so needs a lot of energy	Requires moderate temperature, so less energy required

10.2 Combustion of Alcohols

Alcohols are flammable organic compounds. They burn in the air due to the presence of a hydrocarbon chain. Just like fossil fuels, all alcohols burn in the presence of oxygen to form carbon dioxide water and release energy. This feature makes it possible to use alcohol as a fuel. In countries where there is no oil industry, ethanol produced by fermentation is used as an alternative fuel to imported oil.

$$CH_3OH + 2O_2 \longrightarrow CO_2 + 2H_2O + \text{heat}$$

$$CH_3CH_2OH + 3O_2 \longrightarrow 2CO_2 + 3H_2O + \text{heat}$$

10.2.1 Application of Alcohols as Fuels

Methanol has been used as an alternative fuel for cars. However, it has a low energy content as compared to gasoline, diesel, or ethanol. So, methanol reduces the driving range of the vehicles. Ethanol, on the other hand, is a more useful fuel. It produces about two-thirds as much energy per litre as gasoline. Ethanol has a higher octane number than gasoline. Petrol blended with 10-20% ethanol is used in many countries, for example Brazil. This mixture is commonly known as gasohol. Ethanol not only increases the octane value of fuel but also cuts down the formation of carbon monoxide and other smog-causing emissions. Moreover, ethanol is a renewable energy source. Whereas, fossil fuels are non-renewable energy source. At the same time, pollution is a major disadvantage of fossil fuels.

According to recent studies conducted at Harward, USA, corn-based ethanol reduces greenhouse gas emissions by roughly 40-50%.

The disadvantage of using alcohols as fuel is that it can corrode certain materials used in engines. This is due to their much hygroscopic nature than gasoline, so, they absorb significant amounts of water from air.

10.3 Role of alcohols in the pharmaceutical industry

Alcohols have many important roles in the pharmaceutical industry. Some of these are:

- As solvent alcohols such as ethanol and isopropanol are used as solvents. Ethanol is used in the production of herbal extracts and homoeopathy in the preparation of liquid potencies.
- Alcohols are also used for sterilization and disinfection of equipment, surfaces and pharmaceutical manufacturing areas. Isopropyl alcohol or isopropanol are especially useful for disinfecting, and sterilizing, as they can kill or inhibit the growth of many microorganisms.
- Alcohols exhibit rapid antibacterial properties against vegetative bacteria, viruses, and fungi. So, they are used in medicines as an antiseptic, and disinfectant, in tropical pharmaceutical formulations such as creams or lotions.
- As a solvent alcohols diffuse active pharmaceutical ingredients through the skin, which makes them easier to administer and more effective.
- Some alcohols, such as ethanol and isopropanol are also used as antiseptic agents in making disinfectant wipes to kill or inhibit the growth of harmful microorganisms. Alcohol swabs are also used on the skin to disinfect the skin before injection or before surgery.

10.4 Role of alcohols in the cosmetic industry

Ethanol is widely used in the cosmetic industry because of its antibacterial, antiviral, antimicrobial, and antifungal qualities. It is used in hygiene products such as deodorants, skin care products, toners, perfumes, and skin lotions. Alcohols keep cosmetic ingredients together in a formulation and prevent them from separating. It also increases the adhering properties of a product.

10.5 Impact of alcohols on Everyday Life Public Health

Alcohols significantly impact daily life through their diverse applications as solvents and disinfectants. Their chemical properties make them invaluable in medical, industrial, and household contexts, contributing to health, hygiene, and convenience. Alcohols are widely used in household and industrial cleaners, paints, and inks.

Alcohol-based disinfectants are widely used and play an important role in controlling the spread of infections, especially during pandemics such as COVID-19. Alcohols' solubility and rapid drying make them easy to use in a variety of applications, improving the efficiency and effectiveness of many products. Alcohols are effective in sanitizing surfaces and hands, especially in healthcare settings.

KEY POINTS

- Enzymes present in yeast convert the glucose into ethanol and carbon dioxide in the absence of air. This process is called fermentation.
- The fermentation process produces 10- 15%.
- Ethanol is produced when steam is added to ethene at 300 °C and at 6000kPa/ 6 atm. in the presence of phosphoric acid as catalyst ethanol.
- 96% pure alcohol is also called rectified spirit.
- Ethanol is used in the production of herbal extracts and homoeopathy in the preparation of liquid potencies.
- Alcohols exhibit rapid antibacterial properties against vegetative bacteria, viruses, and fungi. Petrol blended with 10-20% ethanol is commonly known as gasohol.
- Ethanol has a higher octane number than gasoline. Ethanol has a higher octane number than gasoline.
- Ethanol not only increases the octane value of fuel but also cuts down the formation of carbon monoxide and other smog-causing emissions.
- Ethanol is widely used in the cosmetic industry because of its antibacterial, antiviral, antimicrobial, and antifungal qualities.

EXERCISE

1. Multiple Choice Questions (MCQs):

i. What is the optimal temperature range for the fermentation of glucose to produce ethanol?
   a) 0-10°C b) 25-35°C
   c) 50-60°C d) 70-80°C

ii. Which organism is used in the fermentation process to produce ethanol?
   a) Bacteria b) Yeast
   c) Algae d) Molds

iii. What is the catalyst used in the catalytic hydration of ethene to ethanol?
   a) Sulfuric acid b) Hydrochloric acid
   c) Phosphoric acid d) Nitric acid

iv. What is the primary by-product of ethanol fermentation?
   a) Methane b) Oxygen
   c) Carbon dioxide d) Water

v. Which of the following is a major advantage of using ethanol as a fuel?
   a) High cost b) Non-renewable
   c) Clean burning d) Low energy density

vi. What is the chemical formula for ethanol?
   a) CH_3OH b) C_2H_6
   c) C_2H_5OH d) C_3H_7OH

vii. Which process requires high pressure and temperature for ethanol production?
   a) Fermentation b) Catalytic hydration
   c) Distillation d) Sublimation

viii. Ethanol combustion primarily produces:
   a) CO and H_2O b) CO_2 and H_2
   c) CO_2 and H_2O d) CO and H_2

ix. What is the disadvantage of ethanol production through fermentation?
   a) High-temperature requirement b) Slow process
   c) High-pressure requirement d) Uses non-renewable resources

x. Which industry uses alcohol extensively as a solvent?
   a) Agriculture b) Pharmaceuticals
   c) Mining d) Construction

2. Short Answer Questions:

i. What is the chemical equation for the fermentation of glucose to ethanol?
ii. Name two advantages of producing ethanol via fermentation.
iii. What catalyst is used in the catalytic hydration of ethene to ethanol?
iv. List two disadvantages of the catalytic hydration method for ethanol production.
v. What are the primary products of ethanol combustion?
vi. Why is ethanol considered a renewable fuel?
vii. How is ethanol used in the pharmaceutical industry?

viii. Describe one environmental benefit of using ethanol as a fuel.
ix. What role does yeast play in ethanol production?
x. Name two industries where alcohols are used as solvents.
xi. Write the chemical equation for the fermentation of glucose.
xii. Evaluate the environmental impact of the two ethanol production methods.
xiii. Explain why alcohols are considered cleaner fuels compared to fossil fuels.
xiv. Discuss the benefits of using ethanol as a fuel in internal combustion engines compared to gasoline.
xv. Describe how ethanol is used in cosmetic products.
xvi. Explain the role of alcohols in the pharmaceutical industry.
xvii. Evaluate the environmental impact of the two ethanol production methods.

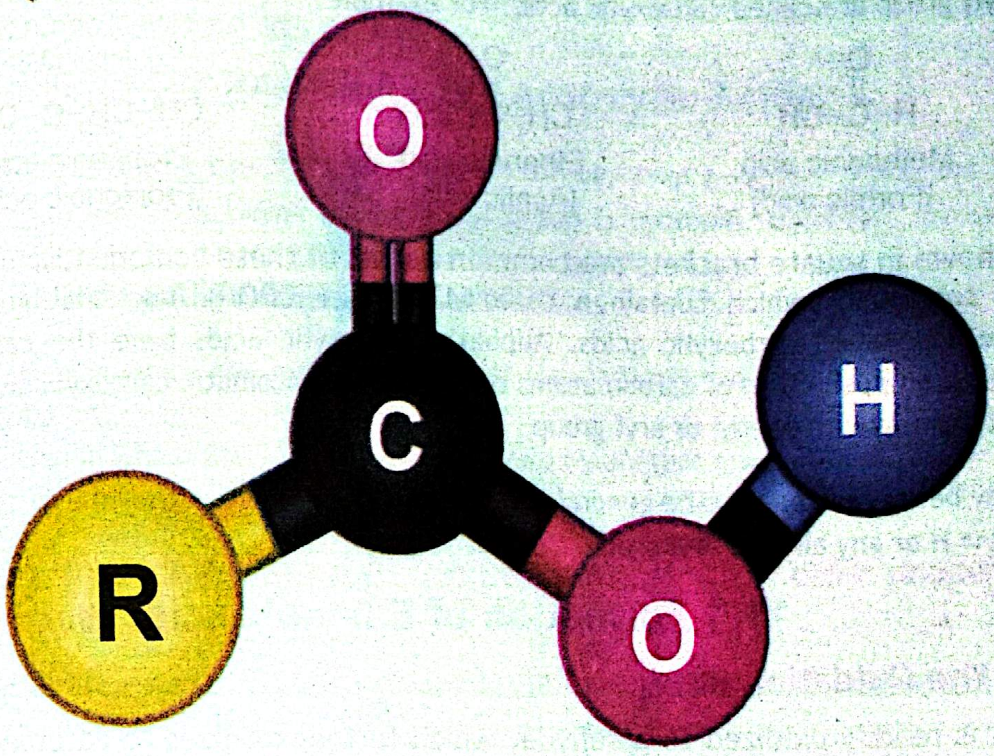
3. Long Answer Questions:

i. Compare and contrast the fermentation and catalytic hydration methods of ethanol production, including their advantages and disadvantages.
ii. Explain the combustion process of alcohols and discuss why they are considered cleaner fuels compared to fossil fuels.
iii. Discuss the role of ethanol in fuel production, highlighting its benefits and potential challenges.
iv. Describe the impact of alcohols on various industries, including pharmaceuticals, cosmetics, and household products.
v. Analyse the overall impact of alcohols on daily life, considering their use as fuels, solvents, and disinfectants, and discuss potential health and environmental implications.
vi. Compare the advantages and disadvantages of the two methods of ethanol production in terms of energy efficiency, cost, and environmental impact.
vii. Analyse the impact of replacing traditional fossil fuels with alcohol-based fuels in terms of emissions and energy efficiency.
viii. Evaluate the feasibility of switching to ethanol as a primary fuel source for transportation in your country.
ix. Evaluate the impact of widespread use of alcohol-based disinfectants on public health and the environment

THINK TANK

1. Assess the potential economic and environmental impacts of shifting from fossil fuels to alcohols as primary fuels.
2. Which raw material is better for the production of ethanol, glucose or ethane? Give reasons for your choice.
3. Evaluate the impact of the widespread use of alcohol-based disinfectants on public health and the environment.
4. Develop a strategy for promoting the use of alcohols in the cosmetics industry, emphasizing their benefits.

UNIT 11

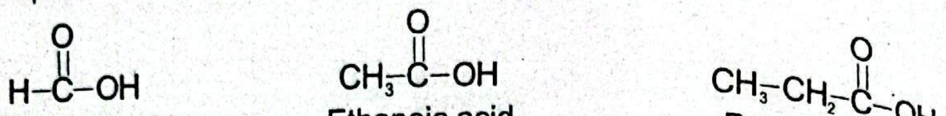


CARBOXYLIC COMPOUNDS

Student Learning Outcomes (SLOs)

- Describe the reactions of carboxylic acids with metals, bases, and carbonates including names and formulae of the salts produced.
- Describe the formation of ethanoic acid by the oxidation of ethanol with acidified aqueous potassium manganate(VII) and by bacterial oxidation during vinegar production.
- Describe the reaction of a carboxylic acid with an alcohol using an acid catalyst to form an ester.
- Describe the industrial applications of carboxylic acids and esters, including their use as solvents, flavours, fragrance, and plastics.
- Explain the role of carboxylic acids and esters in daily life, including their use in food preservation, cosmetics, and pharmaceuticals.

The organic compounds that contain carbon-oxygen double bonds (>C=O) are called carbonyl compounds. There are many types of carbonyl compounds, such as aldehydes, ketones, carboxylic acids, etc. Carbonyl compounds in which carbonyl carbon is attached to the -OH (hydroxyl) group are called carboxylic acids. For example:



Methanoic acid [Formic acid] — Ethanoic acid [Acetic acid] — Propanoic acid [Propionoic acid]

Name shown in square brackets are common names of these compounds.

Organic compounds which contain a carboxyl group (−COOH) functional group in their molecule are called carboxylic acids. Aliphatic carboxylic acids have the carboxyl group attached to an open chain of carbon atoms of alkyl group. Aromatic carboxylic acids have the carboxylic group with phenyl or aryl group.

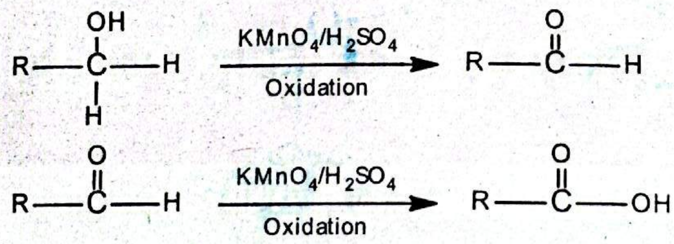
They may be represented by the general formula R—C(=O)—OH

where R = H or any alkyl or aryl group.

11.1 Formation of Ethanoic acid

1. By the Oxidation of Alcohols

Ethanol is readily oxidized to aldehyde, which further oxidizes to carboxylic acids in the presence of oxidizing agents such as potassium dichromate or potassium permanganate(VII) in an acidic medium. This process is fast but requires strong oxidizing agents.



The oxidizing agent provides nascent oxygen for the oxidation of alcohol. In the first step, oxygen an atom removes two hydrogen atoms from ethanol to form water and ethanal. In the second step, the oxygen atom oxidizes ethanal into ethanoic acid.

$$\underset{\text{Ethanol}}{CH_3CH_2OH_{(l)}} + [O]_{(g)} \longrightarrow \underset{\text{Ethanal}}{CH_3CHO_{(l)}} + H_2O_{(l)}$$

$$\underset{\text{Ethanol}}{CH_3CHO_{(l)}} + [O]_{(g)} \longrightarrow \underset{\text{Ethanoic acid}}{CH_3COOH_{(l)}}$$

2. By the Bacterial Oxidation of Ethanol

Ethanol can be converted into vinegar by the action of micro-organisms called acetobacter in an aerobic environment. The reaction is catalysed by enzymes produced by acetobacter bacteria.

$$CH_3CH_2OH_{(l)} + O_{2(g)} \longrightarrow CH_3COOH_{(aq)} + H_2O_{(l)}$$

The fermentation is complete when the ethanol is fully converted to acetic acid. This can be confirmed by tasting or by measuring the acetic acid concentration using titration.

Typical vinegar contains about 4-8% acetic acid. This process is slow but environmentally friendly, uses renewable resources.

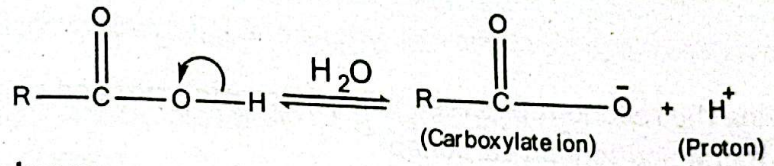
11.2 Reactions of Carboxylic Acids

The carboxyl group shows the chemistry of both the carbonyl (—C(=O)—) and the hydroxyl (–OH) groups. In most reactions, the carboxyl group is retained. However, the reactivity of these molecules is due to the presence of the carbonyl group.
Carboxylic acids undergo the following types of reactions.

i) The reaction in which the hydrogen atom of the carboxyl group (–C(=O)–O–H) is involved (salt formation).
ii) The reaction in which the –OH group is replaced by another group (–OH).
iii) The reactions involving the carboxyl group as a whole (–COOH).

1. Reaction involving H-atom of the carboxyl group (Acidic properties of Carboxylic acid)

Carboxylic acids are weaker acids than mineral acids. They produce H^+ ion when dissolved in water



(a) Reactions with bases
Carboxylic acids react with strong bases (NaOH, KOH) to form salts

$$\underset{\text{Acetic acid}}{CH_3COOH_{(aq)}} + NaOH_{(aq)} \longrightarrow \underset{\text{Sodium Acetate}}{CH_3COONa_{(aq)}} + H_2O_{(l)}$$

(b) Reaction with carbonates and bicarbonates
Carboxylic acids decompose carbonate and bicarbonates evolving carbon dioxide gas with effervescence.

$$CH_3COOH_{(aq)} + Na_2CO_{3(aq)} \longrightarrow 2CH_3COONa_{(aq)} + CO_{2\,(g)} + H_2O_{(l)}$$
$$CH_3COOH_{(aq)} + NaHCO_{3(aq)} \longrightarrow CH_3COONa_{(aq)} + CO_{2(g)} + H_2O_{(l)}$$

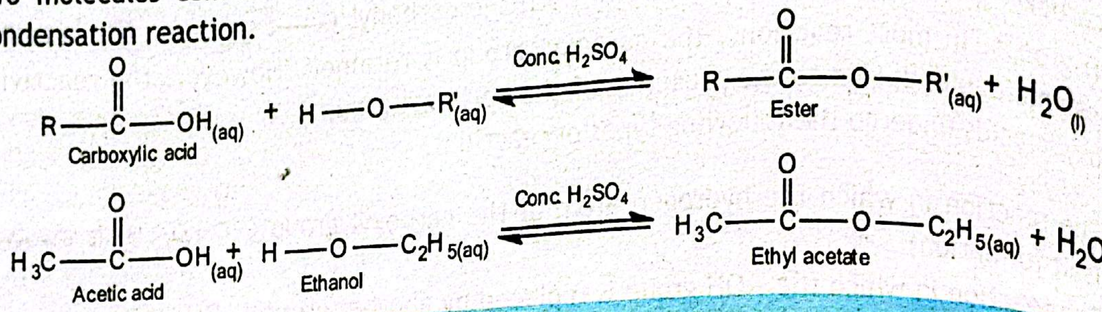
(c) Reactions with metals
Carboxylic acids react with active metals such as Na, K, Ca, Mg etc to form their salts with the evolution of hydrogen gas,

$$\underset{\text{Acetic acid}}{2CH_3COOH_{(aq)}} + 2Na_{(s)} \longrightarrow \underset{\text{Sodium Acetate}}{2CH_3COONa_{(aq)}} + H_{2\,(g)}$$

2. Reaction involving the OH group of Carboxylic acid

Reaction with Alcohol (Preparation of Esters)

When a carboxylic acid is heated with an alcohol in the presence of conc. sulphuric acid as catalyst and esters is formed and the reaction is named "Esterification reaction". Esters are usually significant for their fruity smells and act as flavouring agents. Such a reaction in which two molecules combine with the elimination of a small molecule like water is called a condensation reaction.



Concept Assessment Exercise 11.1

Complete the following reactions and write the names of reactants and products.

1. $CH_3COOH_{(aq)} + CH_3OH_{(aq)} \longrightarrow$
2. $CH_3CH_2COOH_{(aq)} + Na_{(s)} \longrightarrow$
3. $HCOOH_{(aq)} + NaHCO_{3(aq)} \longrightarrow$

Activity 11.1

Studying and analyzing the reactions between vinegar (acetic acid) and two different substances: sodium metal and sodium carbonate.

Materials Needed:

- Vinegar (acetic acid, CH_3COOH)
- Small pieces of sodium metal (Na) (Caution: Sodium metal is highly reactive and should be handled with extreme care under the supervision of a qualified instructor)
- Sodium carbonate (Na_2CO_3)
- Two small beakers or glass containers
- Droppers or pipettes
- Safety goggles and gloves

Safety Precautions

- Ensure all students wear safety goggles, gloves, and lab aprons.
- Explain the safety hazards associated with handling sodium metal and performing reactions that release gases.
- Conduct the experiment in a fume hood or a well-ventilated area.
- Sodium metal should be handled only with tweezers or tongs and kept away from water.

Introduction to Chemical Reactions

- Briefly introduce the concept of chemical reactions, reactants, and products.
- Discuss the properties of vinegar (acetic acid), sodium metal, and sodium carbonate.
- Explain that vinegar is an acid that can react with metals and carbonates to produce different products.

Procedure

- Place a small piece of sodium metal in a dry beaker.
- Using a dropper, carefully add a small amount of vinegar to the beaker with sodium metal.

Observation

- **Reaction:** The sodium metal reacts vigorously with vinegar, producing bubbles and fizzing.
- **Gas Released:** Hydrogen gas (H_2) is released, and sodium acetate (CH_3COONa) is formed in the solution.

Chemical Equation:

$$2Na_{(s)} + 2CH_3COOH_{(aq)} \longrightarrow 2CH_3COONa_{(aq)} + H_{2(g)}$$

Discussion Points:

- Why is hydrogen gas released?
- Discuss the safety concerns of handling sodium metal and why the reaction is exothermic (releases heat).

Reaction: Vinegar with Sodium Carbonate

Procedure:

- In a separate beaker, add a small amount (about a teaspoon) of sodium carbonate.
- Slowly add vinegar using a dropper until the bubbling reaction occurs.

Observation:

- **Reaction:** Vigorous bubbling and fizzing are observed as carbon dioxide gas (CO_2) is released.
- **Gas Released:** Carbon dioxide (CO_2) is released, forming water (H_2O) and sodium acetate (CH_3COONa).

Chemical Equation:

$$Na_2CO_{3(s)} + 2CH_3COOH_{(aq)} \longrightarrow 2CH_3COONa_{(aq)} + CO_{2(g)}$$

Discussion Points:

- Why does carbon dioxide gas form?
- How can we identify the gas released?

Concept Assessment Exercise 11.2

1. Describe the chemical reaction for the oxidation of ethanol to ethanoic acid using acidified potassium manganate(VII).
2. Explain the role of bacteria in the production of vinegar from ethanol.
3. Write structural formulas for the following compounds.
   1. Ethanoic acid b) Propanoic acid

11.3 Industrial Applications of Carboxylic acids and Esters

Carboxylic acids and esters have many industrial applications.

1. Methanoic acid commonly known as formic acid is used in the textile industry as an acid-reducing agent.
2. Ethanoic acid commonly known as acetic acid is used in making plastics and esters.

3. Sodium salts of fatty acids are used in making soaps and detergents.
4. Ethanoic acid is used in making medicines like aspirin.
5. Many carboxylic acids are used as industrial solvents.
6. Citric acid is a natural preservative and is used in both processed foods and drinks.
7. Many carboxylic acids are used as industrial solvents.
8. Carboxylic acids are used in the preparation of perfumes and artificial food essences.
9. Benzoic acid and sodium benzoate are used in the food industry, the pharmaceutical industry and the personal care industry. These are widely used for making jams, jellies, sauces, toothpaste, mouthwashes, lipsticks, and facial cleansers. Esters enhance the feel and performance of other ingredients in cosmetics. They hydrate, soften, and smooth the surface of skin texture so they are widely used in making lotions and creams. They also reduce the greasy feel of products.
10. Tartaric acid is used in baking powder. It reacts with carbonates in dough in the baking industry.
11. Esters are industrial solvents for dyes, glues, inks for permanent markers, and whiteboard markers.
12. Esters are used for making car spray paints, varnishes and nail polish remover.
13. Esters are used to making polymers called polyesters, which are used to make plastic bottles, canes, and textile clothing fibers.

Table 11.1: Some carboxylic esters used as flavouring agents

Structure	Name	Flavour
$CH_3COOCH_2CH_2CH(CH_3)_2$	isopentyl acetate	Banana
$CH_3COO(CH_2)_7CH_3$	octyl acetate	Orange
$CH_3(CH_2)_2COOCH_2CH_3$	ethyl butyrate	Pineapple
$CH_3(CH_2)_2COOCH_3$	methyl butyrate	Apple
$HCOOCH_2CH(CH_3)_2$	isobutyl formate	Raspberry

11.4 Everyday uses of Carboxylic acids

- Ethanoic acid solution (5%) is used as vinegar.
- Vinegar is used to make pickles, flavouring food, and dress salads.
- Lemon juice which contains ascorbic acid is used to reduce the smell of fish and flavouring food.
- Ascorbic acid is also used as vitamin-C.
- Benzoic acid and its salt sodium benzoate are used as preservatives in food and beverages to inhibit the growth of bacteria and fungi.

11.5 Everyday uses of Esters

Esters are sweet-smelling organic compounds. They are used as;

- Food flavouring compounds as they give a characteristic odour to fruits.
- As fragrance and perfumes.
- Some esters are used in the treatment of rheumatoid arthritis.
- Aspirin is an ester. It is used as a fever reducer and pain killer.

KEY POINTS

- Carbonyl compounds in which carbonyl carbon is attached to the –OH (hydroxyl) group are called carboxylic acids
- Ethanol can be converted into vinegar by the action of micro-organisms called acetobacter in an aerobic environment.
- vinegar contains about 4-8% acetic acid
- Carboxylic acids react with bases (NaOH, KOH) to form salts
- Carboxylic acids decompose carbonate and bicarbonates evolving carbon dioxide gas with effervescence.
- When a carboxylic acid is heated with an alcohol in the presence of conc. sulphuric acid as catalyst and ester is formed.
- Carboxylic acids are used in the preparation of perfumes and artificial food essences.
- Esters are sweet-smelling organic compounds.

EXERCISE

1. Multiple Choice Questions (MCQs)

i. What is the product of the reaction between ethanoic acid and sodium carbonate?
   a) Sodium propanoate b) Sodium hydroxide
   c) Sodium chloride d) Sodium acetate

ii. Which catalyst is used in the esterification reaction between a carboxylic acid and an alcohol?
   a) Potassium manganate(VII) b) Sulfuric acid
   c) Sodium hydroxide d) Hydrochloric acid

iii. What is the main component of vinegar?
   a) Ethanol b) Methanol
   c) Propanoic acid d) Ethanoic acid

iv. What gas is produced when a carboxylic acid reacts with a metal?
   a) Oxygen b) Carbon dioxide
   c) Hydrogen d) Nitrogen

v. Which compound is formed by the bacterial oxidation of ethanol?
   a) Methanoic acid b) Propanoic acid
   c) Ethanoic acid d) Butanoic acid

vi. What type of bond is formed between a carboxylic acid and an alcohol during esterification?
   a) Ionic bond b) Hydrogen bond
   c) Covalent bond d) Metallic bond

vii. Which of the following is an example of a carboxylic acid?
   a) Ethanol b) Ethanoic acid
   c) Ethyl acetate d) Methanol

viii. In the oxidation of ethanol to ethanoic acid, what is the role of potassium manganate(VII)?
a) Reducing agent
b) Oxidizing agent
c) Catalyst
d) Inhibitor

ix. What is produced when ethanoic acid reacts with sodium hydroxide?
a) Sodium chloride
b) Sodium ethanoate
c) Sodium oxide
d) Sodium bicarbonate

2. Short Answer Questions

i. Write the balanced chemical equation for the reaction between ethanoic acid and sodium.
ii. Describe how ethanoic acid can be formed from ethanol using an oxidizing agent.
iii. What is the role of sulfuric acid in the esterification process?
iv. Name the salt formed when ethanoic acid reacts with sodium carbonate.
v. How is ethanoic acid used in the food industry?
vi. Explain the industrial use of ethyl acetate.
vii. Write the chemical equation for the esterification reaction between methanol and ethanoic acid.
viii. What happens when a carboxylic acid reacts with a base? Provide a general reaction.
ix. Describe the bacterial oxidation process used in vinegar production.
x. What are the products of the reaction between a carboxylic acid and a metal?

3. Long Answer Questions

i. Explain why esters are commonly used in the fragrance industry.
ii. Discuss the industrial importance of carboxylic acids and esters.
iii. Compare the efficiency of chemical and bacterial oxidation methods in the production of ethanoic acid.
iv. Analyze the importance of esterification reactions in the pharmaceutical industry.
v. Compare the reactivity of carboxylic acids with metals, bases, and carbonates. Which reaction releases a gas, and why is this significant in practical applications?
vi. Describe how carboxylic acids are used in the food industry, particularly in food preservation.
vii. Explain the use of esters in the cosmetics industry and pharmaceutical industry.
viii. Evaluate the impact of carboxylic acids and esters on daily life.

THINK TANK

1. Explain why carbon dioxide is produced when ethanoic acid reacts with sodium carbonate.
2. Write the balanced chemical equation for the esterification reaction between methanoic acid and propanol.
3. Discuss the environmental and economic implications of producing ethanoic acid via the chemical method (using potassium manganate(VII)) compared to the biological method.

UNIT 12

POLYMERS

Student Learning Outcomes (SLOs)

- Define polymers as large molecules built up from many smaller molecules called monomers.
- Identify the repeating units and/or linkages in addition polymers and condensation polymers.
- Deduce the structure or repeat unit of an addition polymer from a given alkene and vice versa.
- Deduce the structure or repeating unit of a condensation polymer from given monomer and vice versa, limited to; a. Polyamides from dicarboxylic acid and a diamide, b. Polyester from a dicarboxylic acid and a diol.
- Describe the differences between addition and condensation polymerisation.
- State that plastics are made from polymers.
- Describe how the properties of plastics have implications for their disposal.
- Describe the environmental challenges caused by plastics, limited to: a. Disposal in landfill sites, b. Accumulation in oceans, c. Formation of toxic gases from burning..
- Describe the structure of: a. Nylon, a polyamide, b. PET, a polyester. The full name for PET, polyethylene tetraphthalate in not required.
- State that PET can be converted back into monomers and re-polymerised.
- Outline the importance of polymers in the textile industry.(Examples for polymers being used may be given along with their specific properties).

12.1 Polymers

Polymers are large molecules built from many smaller repeating units called monomers. These monomers bond covalently to form long chains giving polymers their unique properties. Polymerisation is the joining up of many monomers to form a big molecule.

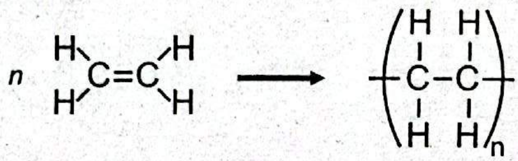
Polymers can be classified into two categories based on their synthesis: addition polymers and condensation polymers.

12.1.1 Addition polymers

Addition polymers are formed by adding monomer units without losing the small molecules. Monomers usually contain double or triple bonds that open and combine to form a polymer. The number of carbon atoms in these chains can vary from 4000 to 40,000.

For example; Ethene is the smallest hydrocarbon containing a carbon-carbon double bond. Ethene molecules can join together to produce very long chains. Part of the double bond is broken, and the electrons in it are used to join neighbouring molecules. This process is called addition polymerisation.

At high temperatures and high pressures, the monomer ethene joins up to give a polymer called polyethylene or polyethene.



Ethene Polyethene

Repeating units: For a polymer, a repeating unit is the same as a monomer, except that the double bond is replaced by a single bond after polymerization.

Repeating unit: $-CH_2-CH_2-$ Polyethylene (PE) consists of ethylene monomer ($CH_2=CH_2$).

Monomer: $CH_2 = CH_2$

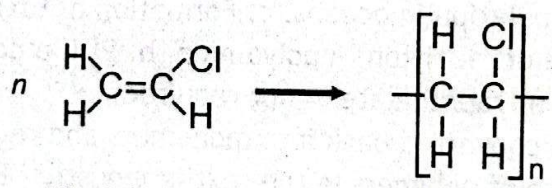
For example, Polypropylene (PP) consists of propylene monomer ($CH_2=CH-CH_3$).

Monomer: $CH_2=CH-CH_3$

Repeating unit: $-CH_2-CH(CH_3)-$ or $-CH_2-\underset{CH_3}{\underset{|}{CH}}-$

Example: Polyvinylchloride consists of vinyl chloride monomer($CH_2=CHCl$).

Chloroethene is an ethene molecule in which one of the hydrogen atoms is replaced by a chlorine atom. It is called vinyl chloride. Ploymerising vinyl chloride gives polychloroethene. Its commercial name is polyvinylchloride(PVC).



Vinylchloride polychloroethene

12.1.2 Condensation polymers

Condensation polymers are formed in a condensation reaction where each time a bond is formed between two monomers, a small molecule (often water) is released.

Some polymers form in a different way than addition polymers. If one monomer contains a –OH group and the other –H, then they can be joined by eliminating a molecule of water. This reaction is called a condensation reaction. This type of polymerisation process is called condensation polymerisation.

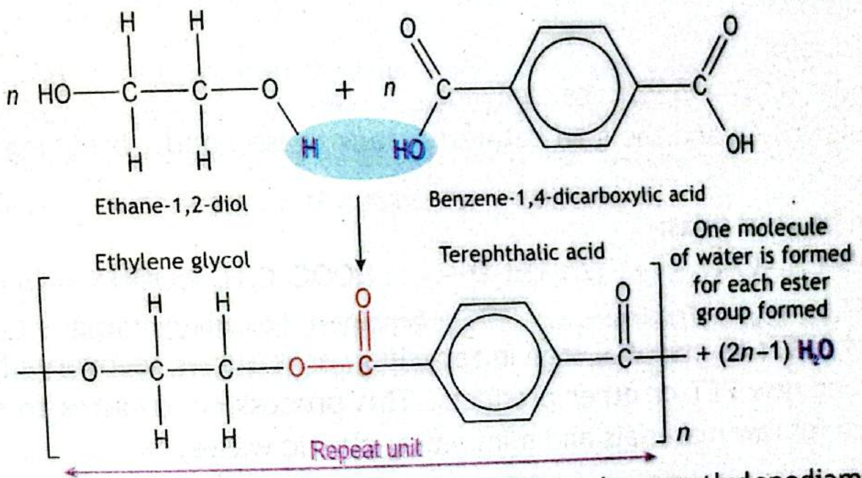
Condensation polymers are usually polyamides or polyesters formed by the reaction of functional groups (e.g. carboxyl and amino in polyamides or carboxyl and hydroxyl group in polyesters) with the removal of a small molecule such as water.

Repeating units: In condensation polymers, the repeating unit usually consists of two different types of monomers, each of which forms the polymer backbone with functional groups that react to form the polymer and release small molecules. Example: Polyesters such as polyethylene terephthalate (PET) are formed from terephthalic acid ($HOOC–C_6H_4–COOH$) and ethylene glycol ($HO–CH_2–CH_2–OH$).

Monomers: terephthalic acid and ethylene glycol (a diol)

Repeating unit: $–OC–C_6H_4–COO–CH_2–CH_2–O–$

Released molecule: water (H_2O)

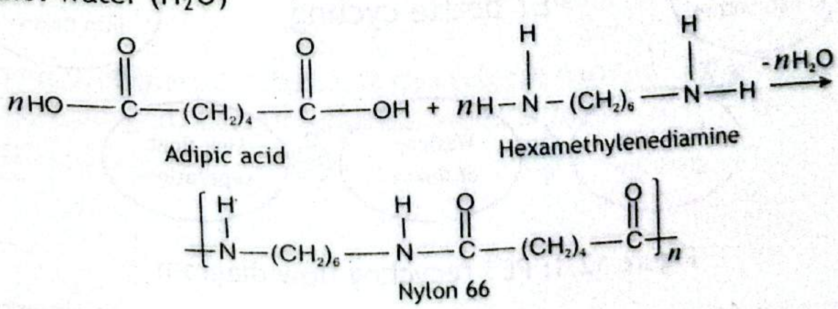


Example: Polyamides such as nylon-6, 6 are formed from hexamethylenediamine ($H_2N–(CH_2)_6–NH_2$) and adipic acid ($HOOC–(CH_2)_4–COOH$).

Monomers: hexamethylenediamine and adipic acid

Repeating unit: $–NH–(CH_2)_6–NH–CO–(CH_2)_4–CO–$

Released molecule: water (H_2O)



Nylon is used to make carpets, clothing, ropes that do not rot, and toothbrushes. Naylon is stronger and durable than natural fibers such as cotton.

Polyester fibres are very strong and flexible and are used to make clothing. For example, terylene, which can give permanent crease, useful for trousers.

Concept Assessment Exercise 12.1

1. What type of bond is involved in the formation of addition polymers?
2. What is released during the formation of addition and condensation polymers?
3. Give an example of a condensation polymer.
4. How do these building blocks come together to form polymers?

PET Recycling and Re-polymerisation

Condensation polymers generally have a higher potential for recycling compared to addition polymers. Polyethylene terephthalate (PET) undergoes acid hydrolysis in the presence of strong acids such as sulphuric acid (H_2SO_4) or hydrochloric acid (HCl) at high temperature (e.g., 200-250°C) and pressure. The reaction breaks down the ester bonds in PET. This reaction produces the monomers from which PET is made i.e., terephthalic acid and ethylene glycol

The Chemical Reaction:

During acid hydrolysis:

1. The ester bonds (-COO-) in PET are cleaved.
2. Water molecules (H_2O) and the acid catalyst attack these bonds, breaking the polymer into smaller molecules.

The reaction can be written as:

$$\underset{\text{PET}}{-(OOC{-}C_6H_4{-}COO{-}CH_2{-}CH_2)_n-} + (2n-1)H_2O \rightarrow \underset{\text{benzene-1,4-dicarboxylic acid}}{n\ HOOC{-}C_6H_4{-}COOH} + \underset{\text{ethane-1-2-diol}}{n\ HO{-}CH_2{-}CH_2{-}OH}$$

Acid hydrolysis of PET is an essential step in recycling, as it allows recovery of pure monomers for reuse in making new PET or other products. This process contributes to sustainability by reducing the need for raw materials and minimizing plastic waste.

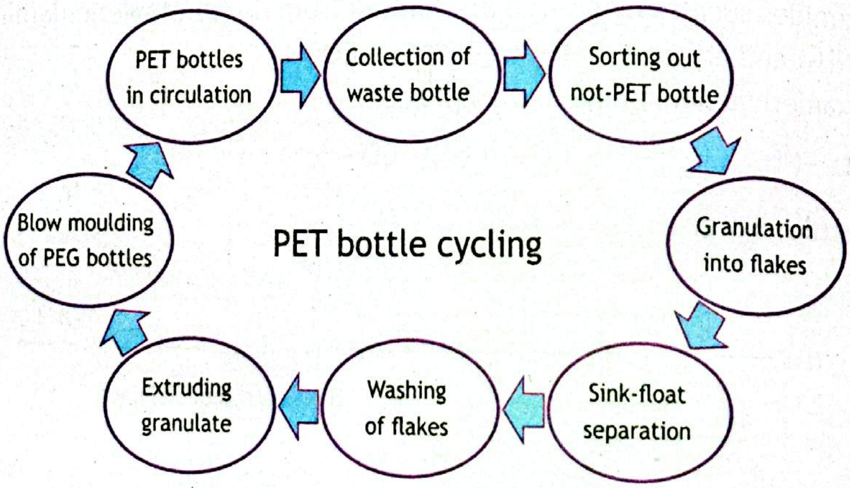


Figure 12.1: PET recycling flow diagram

12.2 Plastics

The word "plastic" is derived from the Greek word "plastikos" which means "malleable" or "moldable" and "plastos" meaning "mouldable." Plastics are synthetic materials made from organic polymers, such as PVC (polyvinyl chloride), polyethylene (polyethylene), nylon, etc. These materials can be melted down and then transformed into solid or slightly flexible shapes. They are also referred to as "long carbon chain polymers". The ability of a material to be moulded or malleable during the manufacturing process means that it can be cast, pressed, or extruded into a variety of forms, including film, fiber, sheet, tube, bottle, and box.

12.2.1 Properties of Plastics

The properties of plastics are directly derived from the characteristics of the polymers they are made from. Some of these are:

1. Molecular Structure

Polymer chains tend to be longer and more durable which can be linear or branched. Branched polymers are softer and more flexible. On the other hand, linear polymers are stronger and more rigid. Cross-linking is also possible, with high cross-linking resulting in tough and heat-resistant plastics, such as vulcanized rubber.

2. Chemical Composition

Chemical composition is determined by the monomer type, which determines the plastic's properties. For example, polyethylene(PE)is flexible and moisture-resistant, while polystyrene (PS) is stiff and brittle. Additives such as plasticizers, stabilizers, and fillers can also enhance the plastic's properties, depending on the processing conditions.

3. Temperature and Pressure

Conditions such as temperature and pressure during polymerisation and moulding affect the plastics' crystalline structure, affecting properties like transparency, tensile strength, and melting point.

12.2.2. Environmental Impact of plastics

Most plastics are highly resistant to degradation due to their strong carbon-carbon backbone. This leads to long persistence to degradation. As plastics degrade slowly, they can break down into microplastics, which are small particles that can contaminate water bodies. These microplastics are harmful to aquatic life and human health.

Incineration

While incineration reduces plastic volume, it can release harmful chemicals and greenhouse gases if not properly managed. Certain plastics, when burned, can emit toxic substances like dioxins and furans.

12.3 Importance of Polymers in the Textile Industry

Polymers are essential for the textile industry because they are versatile and can be used in a variety of applications. The properties of polymers allow them to be used for a variety of purposes, from everyday clothing to specialised industrial applications. Some of the most commonly used polymers in textiles, with their specific characteristics are:

1. **Polyester (PET):** Durability, shrinking and stretching resistance, rapid drying, excellent colour retention, etc. PET is used in clothing (for example, shirts and pants), home furnishing (for example, curtains and bed linens) Industrial applications (ropes and tyre cords).
2. Nylon-6,6 (polyamide) has properties such as high strength, high elasticity, resistance to abrasion, and chemical and oil resistance. It is commonly used in clothing. It can also be used as a part of blended fabrics for different garments. It is also used for making tooth brushes, ropes that don't rot, carpets, and other products.
3. PE (polyethylene) is lightweight, durable, and has properties such as good thermal insulation, water resistance, chemical resistance, moisture resistance, mildew resistance, and other properties. Polyethene is used for making trays, fruit juice containers, milk containers, crates, food packaging products, garbage bags, toys, insulation for wires and cables, and housewares.

12.4 Properties of Plastics and Their Implications for Disposal

The properties of plastics, while beneficial for their intended uses, create significant challenges for disposal. Therefore, plastics cause numerous environmental issues. The following properties of plastics pose implications for disposal.

1. Durability and Longevity

Plastics are made durable, which means that they can withstand a wide range of environmental conditions without breaking down quickly. However, because of the same durability plastics can last hundreds or even thousands of years in the environment. This makes them difficult to dispose off. After being disposed off, plastic can end up in landfill sites or nature for an extended period of time, resulting in long-term problems with waste management.

2. Lightweight Nature

Because plastics are lightweight, they can be easily packed and transported, but they can also be transported by wind or water. This makes it easier for them to spread over long distances, which can lead to extensive environmental pollution, particularly in marine environments.

3. Chemical Composition

The chemical composition of plastics can vary from one plastic material to another. Many plastic materials contain additives to enhance their properties, such as stabilisers, plasticizers, flame retardants, etc. These additives can leach materials into the environment, which can pose a risk to ecosystems and to human health.

4. Recyclability

Some plastics can be recycled. However, their contamination, sorting issues, and economic constraints often limit the amount that can be recycled. Many plastics cannot be recycled effectively, resulting in a large portion of them going to landfill or being burned.

12.4 1 Environmental Challenges Caused by Plastics

Many environmental challenges are caused by plastics. Some of these are as follows.

1. Disposal of plastics in Landfill Sites

The disposal of plastics in landfills has the following implications.

a) Plastics take up a lot of space in a landfill because of their size and resistance to compaction. This means that landfills fill up quickly, leading to more landfilling and exacerbating land use issues.

b) Over time, plastic in a landfill can leach dangerous chemicals into soil or groundwater.

c) As plastic slowly decomposes in a landfill, it breaks down into smaller micro-plastic particles. Micro-plastics can then seep into soils and water bodies and become a persistent environmental pollutant.

2. Accumulation in Oceans

Plastics are a major component of marine litter, and an estimated 8M tons of plastic are dumped into the ocean each year. Plastics accumulate in ocean rings and build up into large floating debris, like the Pacific Garbage Patch. Plastics can also be ingested and entangled by marine animals, which often mistake plastic for food. This can cause gastrointestinal blockage and even death. Microplastics can enter the food chain, and once in the food supply, these pollutants can reach toxic levels in humans.

3. Formation of Toxic Gases from Burning

Incinerating plastics releases a variety of toxic gases and particulates. These substances are known to be carcinogenic and can cause serious health problems for humans and animals.

Burning plastics contributes to air pollution, releasing greenhouse gases like carbon dioxide (CO_2) and methane (CH_4), which aggravate climate change. The emission of other pollutants can also cause respiratory problems, cardiovascular diseases, and other health issues for populations living near incineration facilities.

The residual ash from burning plastics can contain toxic substances that, if not properly managed, can contaminate soil and water sources. This further complicates the disposal process and poses additional environmental risks.

Addressing these challenges requires comprehensive waste management strategies, increased recycling efforts, and the development of more sustainable materials.

KEY POINTS

- Polymers are large molecules built from many smaller repeating units called monome
- Addition polymers are formed by adding monomer units without losing the sma molecules.
- Condensation polymers are formed in a condensation reaction where each time a bon is formed between two monomers, and a small molecule (often water) is released.
- In condensation polymers, the repeating unit usually consists of two different types o monomers.
- Polyesters such as polyethylene terephthalate (PET) are formed from terephthalic acic ($HOOC-C_6H_4-COOH$) and ethylene glycol ($HO-CH_2-CH_2-OH$).
- Polyamides such as nylon-6,6 are formed from hexamethylenediamine ($H_2N-(CH_2)_6-NH_2$) and adipic acid ($HOOC-(CH_2)_4-COOH$).
- The word "plastic" is derived from the Greek word "plastikos" which means "malleable" or "moldable" and "plastos" meaning "mouldable.
- Plastics are synthetic materials made from organic polymers.
- Polymers are essential for the textile industry because they are versatile and can be used in a variety of applications.
- PET is used in clothing.
- Properties of plastics, while beneficial for their intended uses, create significant challenges for disposal.
- Light weight nature of plastic makes it easier for them to spread over long distances, which can lead to extensive environmental pollution.
- Incinerating plastics releases a variety of toxic gases and particulates.

EXERCISE

1. Multiple Choice Questions (MCQs)

i. Which of the following best defines polymers?
   a) Small molecules bonded together to form large molecules
   b) Large molecules built up from many smaller molecules called monomers
   c) Simple molecules consisting of one type of atom
   d) Large molecules made up of metals and non-metals

ii. What type of linkage is found in polyamides?
   a) Ester linkage b) Amide linkage
   c) Glycosidic linkage d) Phosphodiester linkage

iii. Polyethylene is an example of:
   a) A condensation polymer b) An addition polymer
   c) A copolymer d) A natural polymer

iv. The repeating unit of the addition polymer formed from ethene is:
   a) $-CH_2-CH_2-$ b) $-CH-CH-$
   c) $-CH_2-CH-$ d) $-C-C-$

v. Nylon-6,6 is an example of a:
   a) Polyester
   b) Polyamide
   c) Polysaccharide
   d) Polyurethane
vi. Which of the following processes produces water as a by-product?
   a) Addition polymerisation
   b) Condensation polymerisation
   c) Hydrogenation
   d) Hydrolysis
vii. Which statement is not true about PET?
   a) It cannot be recycled
   b) It is a polyamide
   c) It can be converted back into monomers and re-polymerised
   d) It is used only in textiles
viii. What is a major environmental challenge caused by plastics?
   a) They are biodegradable
   b) They are easily recycled
   c) They accumulate in oceans
   d) They are non-toxic when burned
ix. Polyesters are formed from:
   a) Dicarboxylic acids and diamines
   b) Dicarboxylic acids and diols
   c) Diols and diamines
   d) Monocarboxylic acids and diols
x. Which of the following is NOT a property of plastics?
   a) They are lightweight
   b) They are durable
   c) They are easily decomposed by microorganisms
   d) They are versatile in application

2. Short Answer Questions

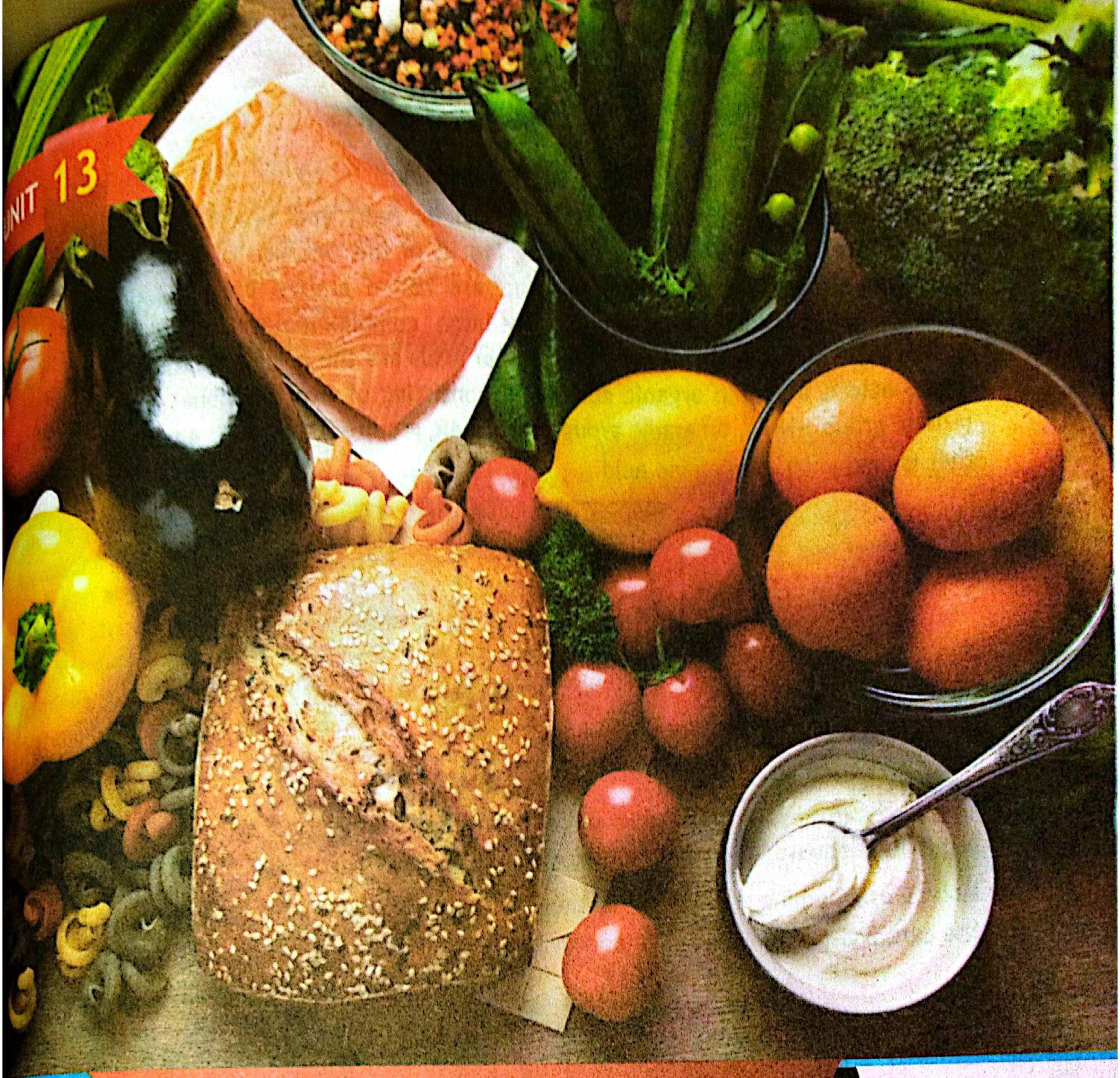
i. Define a polymer.
ii. What is a monomer?
iii. Identify the repeating unit in polyethylene.
iv. Explain what is meant by addition polymerisation.
v. Describe the process of condensation polymerisation
vi. Name the linkage found in polyesters.
vii. What are the monomers required to form Nylon?
viii. Explain one environmental challenge associated with the disposal of plastics in landfills.
ix. Describe the structure of PET.
x. Why is PET considered recyclable?
xi. How are addition polymers formed from monomers?
xii. What is released during the formation of condensation polymers?
xiii. What is the repeating unit in the polymer formed from ethylene glycol and terephthalic acid?
xiv. Why is PET widely used in textiles?
xv. What is a key difference between the polyamides and polyesters?
xvi. What is one benefit of recycling PET?
xvii. What is released during the formation of condensation polymers?
xviii. Give an example of a condensation polymer.
xix. How do the properties of plastics depend on their polymer structure?
xx. What are two environmental challenges associated with plastic disposal?

3. Long Answer Question

i. Describe in detail the process of addition polymerization, giving an example of an addition polymer and its repeating unit.
ii. Explain how condensation polymerisation works, using the formation of polyester as an example. Include the reactants and the type of linkage formed.
iii. Discuss the differences between addition and condensation polymerization, giving examples of polymers formed by each process.
iv. Evaluate the environmental impacts of plastic disposal, covering landfills, ocean accumulation, and the formation of toxic gases from burning.
v. Outline the importance of polymers in the textile industry, giving examples of specific polymers used and their properties that make them suitable for textile applications.
vi. What process allows PET to be reused? Why is this process beneficial?
vii. Assess the role of polymers such as nylon and PET in the textile industry. How do their specific properties make them suitable for different applications?
viii. Evaluate the differences between addition and condensation polymerization in terms of the types of monomers used, the nature of the polymer chains formed, and the by-products produced.
ix. Analyse the environmental impact of addition and condensation polymers. Compare their biodegradability and discuss how this affects their disposal and accumulation in the environment.

THINK TANK

1. Considering the environmental challenges posed by plastics, propose a sustainable strategy for managing plastic waste, including recycling and alternative materials.
2. Analyse the impact of microplastics in marine environments and discuss potential solutions to mitigate their effects.
3. Evaluate the need for developing biodegradable polymers to replace traditional plastics.
4. Imagine you are an environmental scientist tasked with reducing oceanic plastic pollution. Analyse the key sources of plastic waste that end up in the oceans.
5. Polyamide polymers like nylon are used extensively in various applications. Analyse the properties that make nylon a preferred material for such uses.
6. Consider a monomer (such as ethylene or terephthalic acid and ethylene glycol), and deduce the structure of the corresponding polymers that can be made from the.



BIOCHEMISTRY

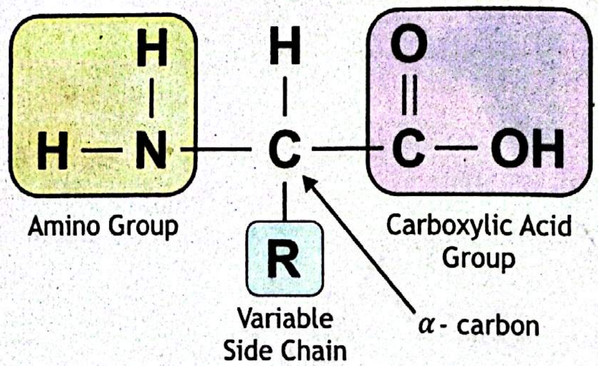
Student Learning Outcomes (SLOs)

- Describe the proteins as natural polyamides and that they are formed from amino acids monomers with the general structure.
- Draw the general structures of proteins
- Explain the sources, use and structure of proteins, lipids and carbohydrates
- Describe the importance of nucleic acids
- Explain vitamins, their sources and their importance to health
- Identify applications of biochemistry in testing (blood cells, pregnancy test, cancer screening, parental generic testing)genetic engineering, gene therapy and cloning

13.1 Proteins

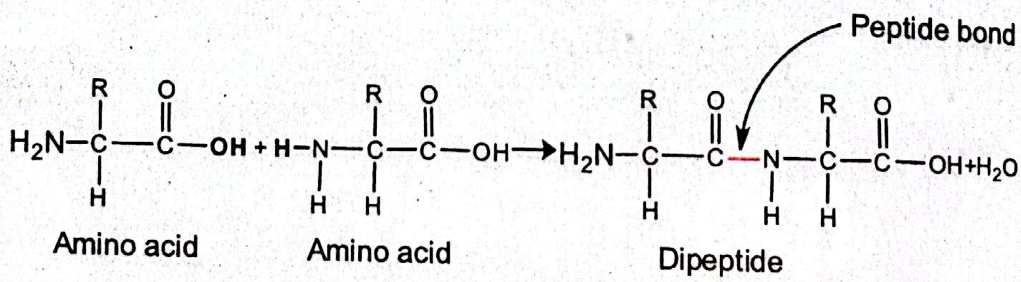
The Basic Unit of Protein - Amino Acids

Proteins are found in our muscles, bones, skin, hair, and almost every part of the bod
Proteins are also known as the building blocks of life because they are the most abunda
molecules present in the body. Proteins are called natural polyamides because they a
naturally occurring polymers. Proteins are large, complex molecules made up of long chain
monomers which are all amino acids. Amino acids are the basic structural unit of protein. A
amino acid is a simple organic compound consisting of two functional groups, a basic grou
(Amine group $-NH_2$), an acidic group (carboxylic group$-COOH$) with a variable alkyl group (I
that is unique to each amino acid.



The body makes proteins through a process called protein synthesis. Protein synthesi requires adequate amounts of amino acids.

Molecules of amino acids join together through the amino ($-NH_2$) group of one molecule an the carboxyl ($-COOH$) group of another molecule by eliminating a water molecule.



The linkage —C(=O)—NH— which joins two amino acid units is called a **peptide bond.** The resulting molecule is called a dipeptide. There is still an amino group on the left and a carboxyl group on the right. Each of these groups can react further to join more amino acid units. In this way, thousands of amino acid units join to form a giant molecule of protein. This sequence of amino acid linkages is called the primary structure of the protein.

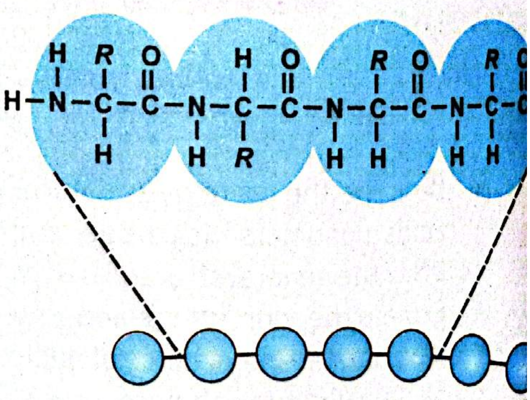


Figure 13.1: Primary structure of

) YOU KNOW?

zymes are proteins that fasten chemical reactions in the body. They act like small chines that help break down food, make molecules, and carry out other important ctions in cells, all without being used up or changed themselves. Hemoglobin is found in d blood cells in our blood and carries oxygen from your lungs to your cells. In addition, a otein called collagen is a strong and tough material that makes up our skin and gernails and even helps to hold our internal organs in place.

.1.1 Classification of Protein

proteins are classified on the basis of the shape, constitution, and nature of the ecule. Each amino acid is connected to the next amino acid by covalent bonds.

Primary structure: Primary protein structure is a sequence of amino acids in a chain.

Secondary structure: Secondary protein structure is formed by folding and twisting of the amino acid chain.

Tertiary structure: Tertiary protein structure is formed when the twists and folds of the secondary structure fold again to form a larger three-dimensional structure.

Quaternary structure: Quaternary protein structure is a protein consisting of more than one folded amino acid chain.

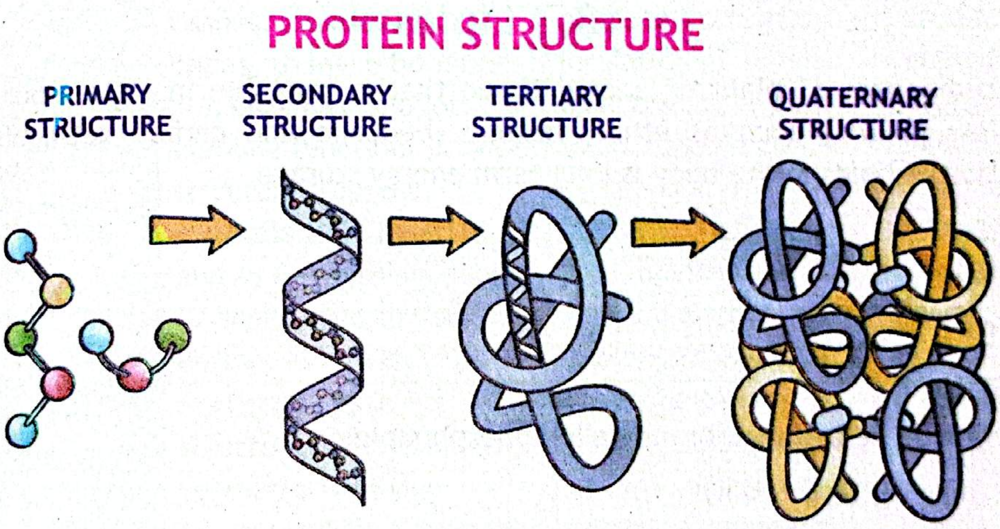
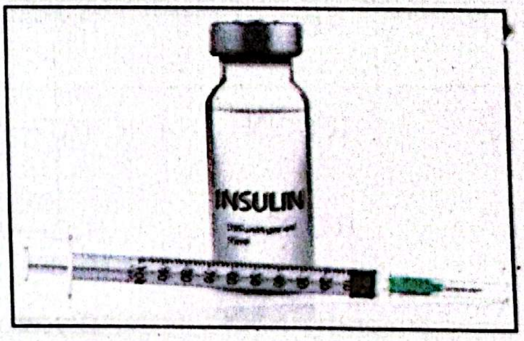


Figure 13.2: Structures of Protein

DO YOU KNOW?

sulin is a protein hormone that is made by specific lls inside the pancreas called beta cells. Insulin signals lls to absorb sugar from the bloodstream. Cells can't sorb sugar without insulin. Insulin protein is first oduced as an immature, inactive chain of amino acids reproinsulin).

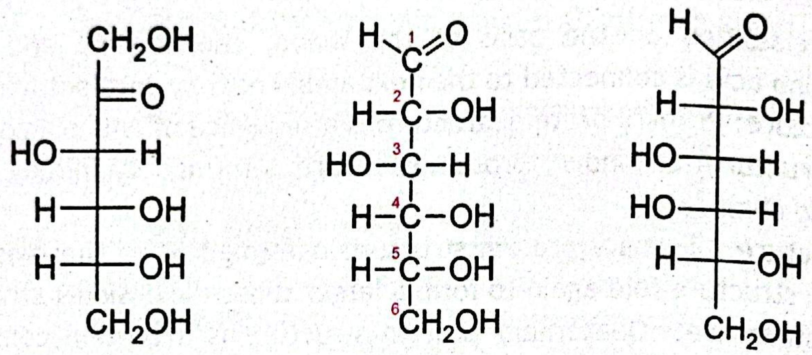


13.2 Carbohydrates

They have a general formula $C_x(H2O)_y$. This formula suggests that they are hydrates of carbon. Plants prepare carbohydrtes through photosynthsis, in the presence of chlorophyll and sunlight.

$$6H_2O_{(l)}+6CO_{2(g)} \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} C_6H_{12}O_{6(aq)}+6O_{2(g)}$$

Plants convert glucose into starch and cellulose. Carbohydrates are monomers and polymers of aldehydes and ketones that have numerous hydroxyl groups attached.



Fructose   Glocose   Galactose

13.3 Lipids

A lipid is a component of plant or animal tissue that is insoluble in water, but soluble in solvents of low polarity such as ether, hexane, benzene and carbon tetrachloride. The primary function of lipids in the body is long-term energy storage.

Lipids include:

a) Fats and oils

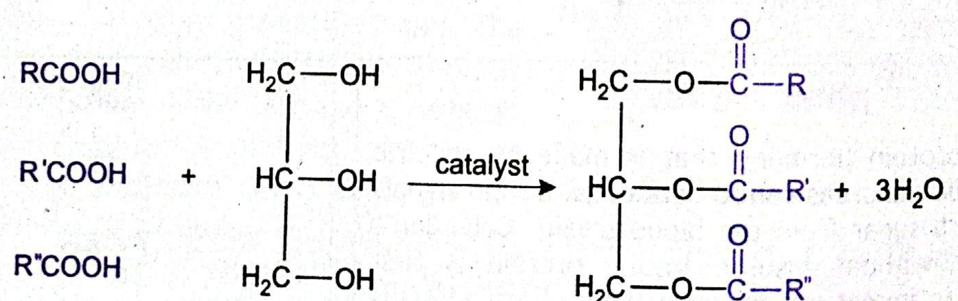
b) Cholesterol

c) Sex hormones

d) Components of the cell membrane called phospholipids

e) Some vitamins (A, D, E and K)

Fats and oils are referred to as simple lipids. They are esters of fatty acids with a trihydroxy alcohol, glycerol. For this reason, they are called glyceryl esters or glycerides. Fatty acids are long-chain carboxylic acids. They are the building blocks of lipids.



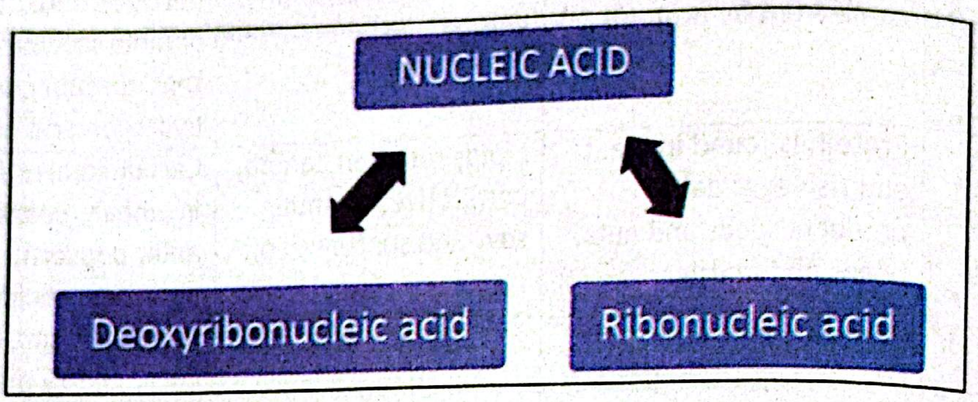
Three fatty acids   Glycerol   Triglyceride

Table 13.1: THE ORGANIC MOLECULES: PROTEINS, LIPIDS AND CARBOHYDRATES

	PROTEIN	LIPIDS	CARBOHYDRATES
DESCRIPTION	Amino acid + amino acid = Protein All vital processes, including immunity and general metabolism, are carried out by proteins	Fatty acids + glycerol = lipids/fats Lipids act as energy storage and are similar to a larger source of energy	Glucose + glucose = Carbohydrates/starch Energy comes from carbohydrates. Carbohydrates are organic molecules that contain carbon, hydrogen and oxygen
SOURCE	Protein is found in meat and fish eggs dairy products seeds and nuts, beans and lentils.	Lipids found in canola, corn, olive, peanut, soy, and sunflower oil	Carbohydrates found in wheat, beans, milk, popcorn, potatoes, cookies, spaghetti, soft drinks, corn, cherry pie, sugar cane
USES	Proteins build and repair tissues, muscles and bones, to make hormones and enzymes, support immune function, provide structural support, maintain fluid balance and as a secondary source of energy and to make hormones and enzymes.	Lipids are used to regulate hormones, insulation, components of cell membranes, cell signaling and absorption of fat-soluble vitamins, and provide energy during prolonged exercise.	Carbohydrates are used for storing energy, supporting digestive health, sparing protein for tissue repair, and playing roles in cell structure and communication.
FUNCTIONS	Protein helps in the structure, function, and regulation of living organisms like digestion, and movement of muscles, and helps to build hair and nails. Protein also serves for cellular communication and acts as a messenger.	Lipids help with moving and storing energy, absorbing vitamins and making hormones.	The primary function of carbohydrates is to provide energy to the body. Carbohydrates help in digestion, absorbed into the stream as blood sugar (glucose)

13.4 Nucleic Acid

Nucleic acids are long-chain organic molecules present in all living cells. Nucleic acids are the main information-carrying molecules of the cell. They determine the inherited characteristics of every living thing. Nucleic acids play an important role in the storage and transfer of genetic data from one generation to another. These are the molecules that contain all the information necessary for an organism to develop traits, carry out life functions, and reproduce.



13.4.1 SIGNIFICANCE OF NUCLEIC ACID

Nucleic acids and DNA in particular, are key macromolecules for the continuity of life. DNA possesses the hereditary information that transfers from parents to children, providing instructions for how (and when) to make proteins needed to build and maintain functioning cells, tissues, and organisms. Nucleic acids carry genetic information which is read in cells to make the RNA and protein.

13.5 Vitamins- Sources and their Importance to Health

Vitamins are organic molecules that are important to an organism in small quantities for proper metabolic function. Vitamins allow your body to grow and develop. Vitamins play important roles in body functions such as metabolism, immunity, and digestion. Important nutrients cannot be synthesized in the organism in sufficient quantities for survival and therefore must be obtained through a balanced diet. There are 13 essential vitamins, including vitamins A, C, D, E, K, and B vitamins such as riboflavin and folate. The best way to meet your vitamin needs is to eat a balanced diet containing a variety of foods.

Figure 13.3: Sources of Vitamins

There are two major types of Vitamins.

1. Fat-soluble vitamins

Vitamins A, D, E, and K are fat-soluble. The body stores fat-soluble vitamins in fatty tissue and the liver, and reserves of these vitamins can stay in the body for days and sometimes months. Dietary fats help the body absorb fat-soluble vitamins through the intestinal tract.

2. Water-soluble vitamins

Vitamins B and C are water-soluble vitamins. They do not stay in the body for long and cannot be stored. They leave the body via the urine. Because of this, people need a more regular supply of water-soluble vitamins than fat-soluble ones.

Different vitamins play different roles in the body, and a person requires a different amount of each vitamin to stay healthy. Vitamin play diverse and essential roles in the body, including supporting metabolism, immune function, growth and development, bone health, antioxidant defense, maintaining healthy skin, hair, and nails. A balanced diet that includes a variety of nutrient-rich food is important for meeting vitamin needs and maintaining overall health. Fortified foods and supplements may be appropriate in some cases. Anyone taking supplements should be careful not to exceed the maximum dose or too much of any vitamin can lead to health problems. Also, some medications can interact with vitamin supplements. Overall, it is important to speak with a healthcare provider before trying any supplement.

13.5.1 Sources and functions of vitamins

1. Vitamin A

- **Sources:** Carrots, sweet potatoes, spinach, kale, apricots, eggs, liver, and dairy products.
- **Function:** Supports vision, immune function, and skin health.

2. Vitamin B Complex

- **Vitamin B1 (Thiamine):** Whole grains,legumes, nuts, and seeds.
- **Vitamin B2 (Riboflavin):** Milk, eggs, almonds, spinach, and fortified cereals.
- **Vitamin B3 (Niacin):** Chicken, turkey, fish, peanuts, and whole grains.
- **Vitamin B5 (Pantothenic Acid):** Avocados, yogurt, eggs, meat, and sweet potatoes.
- **Vitamin B6 (Pyridoxine):** Chickpeas, fish, poultry, bananas, and potatoes.
- **Vitamin B7 (Biotin):** Eggs, nuts, seeds, and sweet potatoes.
- **Vitamin B9 (Folate):** Leafy greens, legumes, seeds, and fortified cereals.
- **Vitamin B12 (Cobalamin):** Meat, fish, dairy products, and fortified cereals.
- **Function:** The B vitamins play roles in energy production, red blood cell formation, and nervous system function.

3. **Vitamin C**
   - **Sources:** Oranges, strawberries, kiwi, bell peppers, broccoli, Brussels sprouts, and tomatoes.
   - **Function:** Supports immune function, acts as an antioxidant, and aids in collagen synthesis.

4. **Vitamin D**
   - **Sources:** Sunlight (synthesis in the skin), fatty fish (salmon, mackerel), fortified milk and orange juice, and egg yolks.
   - **Function:** Essential for bone health and calcium absorption, and supports immune function.

5. **Vitamin E**
   - **Sources:** Nuts and seeds (almonds, sunflower seeds), spinach, broccoli, and vegetable oils (sunflower, safflower).
   - **Function:** Acts as an antioxidant, protecting cells from damage.

6. **Vitamin K**
   - **Sources:** Leafy green vegetables (kale, spinach), broccoli, Brussels sprouts, and fish, meat, and eggs (in smaller amounts).
   - **Function:** Essential for blood clotting and bone health.

13.6 Applications of Biochemistry

Biochemistry is the branch of science dedicated to the study of the chemical processes within a cell.
The findings of biochemistry are applied primarily in medicine, nutrition, and agriculture. In medicine, biochemists investigate the causes and cures of diseases. Several blood tests are carried out to detect the presence of disease, monitor its progression, and evaluate the effectiveness of treatments.

Blood Tests

A blood test is carried out with a blood specimen that measures the concentration of certain chemicals in a blood sample. Blood tests are essential for understanding the body's internal function and balance. They analyse various breakdowns in the blood, including ions, enzymes, sugars, lipids, and proteins, providing crucial insights into overall health. Blood chemistry tests provide significant information about how well our kidneys, liver and other organs are working.

Pregnancy test

A pregnancy test can analyze the state of pregnancy by checking a sample of your urine or blood for a specific hormone. The hormone is called human chorionic gonadotropin (hCG). High levels of hCG are a sign of pregnancy.

Cancer Screening

Cancer screening is a test that looks for early signs of cancer in people without symptoms. It can help spot cancer at an early stage when treatment is more likely to be successful. Cervical screening can even prevent cancer from developing. Cancer screening is for people with no symptoms at all.

Parental Screening Tests

Parental screening test helps to identify genetic disorders, assess the risk of inherited conditions, prevent transmission of infectious diseases, and prepare parents for the care of their children. Parental screening empowers parents to take proactive steps to safeguard the health and well-being of their family. Reproductive genetic carrier screening describes a screening test carried out before pregnancy or in early pregnancy. It is used to identify a couple's chance of having a child with a serious genetic disorder.

13.7 GENETICS

Genetics is the branch of biology that studies genes, heredity, and variation in living organisms. It encompasses on understanding of how traits are passed from parents to offspring through the transmission of genetic information fixed in DNA. It plays an essential role in various fields such as medicine, agriculture, and evolutionary biology, contributing to advancements in understanding and manipulating genetic information for practical applications.

Gene is unit of DNA that is usually located on a chromosome and that controls the development of one or more traits and is the basic unit by which genetic information is passed from parent to offspring and ultimately determines the growth and function of the organism. An organism inherits some genes from each parent and thus the parents pass on certain traits to their offspring.

13.7.1 Genetic Engineering

Genetic engineering is a process that uses laboratory-based technologies to modify the DNA structure of an organism. Genetic engineering aims to alter the genes to enhance the capabilities of the organism. The principle of genetic engineering is to manipulate and modify the genetic material of an organism by adding, removing or repairing part of the genetic material (DNA) and to incorporate desirable traits. Genetic engineering aims to produce vaccines against disease, life-saving drugs, pharmaceutical development, and the treatment of disease.

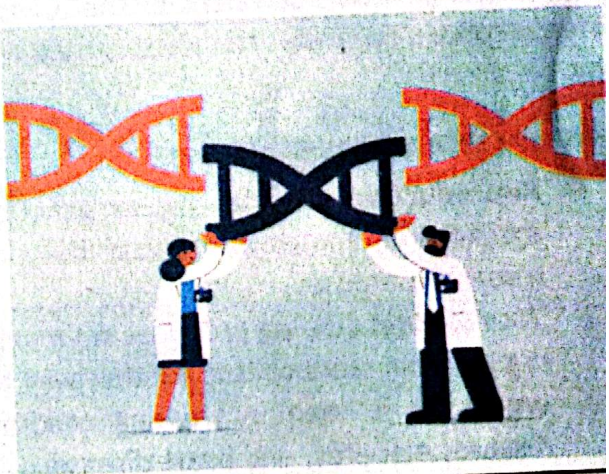


Figure 13.4: Genetic Engineering

13.7.2 Gene Therapy

Gene therapy is a medical technique that involves modifying or manipulating a person's genes to treat or prevent disease. It typically involves the introduction, alteration, or removal of genes within a patient's cells to correct genetic disorders, fight diseases, or improve the body's ability to fight or resist a specific condition. It does not change the DNA in all your body, it targets a single faulty cell. This method involves inserting a healthy copy of a defective gene into a patient's cells. This is often used for conditions caused by a single gene defect. In some cases, gene therapy introduces a new or modified gene into the body to help treat a disease. For example, researchers may introduce a gene that helps the body fight cancer more effectively.

Gene therapy could keep children from carrying such genes (for unfavourable genetic diseases and disorders) that the children got from their patients.

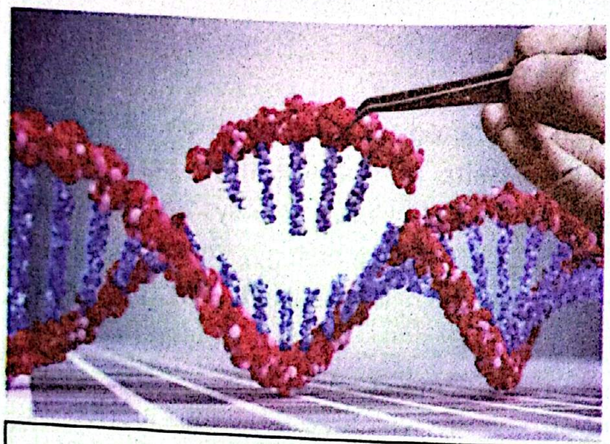


Figure 13.5: Gene Therapy

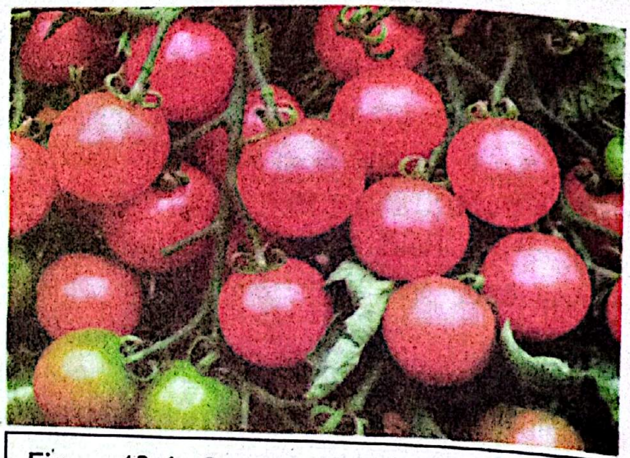


Figure 13.6: Genetically modified Tomato

13.7.3 Cloning

Cloning is the act of rearranging a cell by replacing its nucleus with that of another cell so it becomes the genetic equivalent of the original. In general, cloning means the creation of a perfect replica. Typically, the word is used to describe the creation of a genetically identical copy.

There are three types of cloning.

1. **Reproductive cloning** creates genetically identical organisms. It is widely used in agriculture, conservation, and the production of genetically identical animals for research purposes.
2. **Therapeutic cloning** produces embryonic stem cells for medical research. Cloning new organs from stem cells is another way that stem cells can aid people waiting for donor organs. It is used in treating conditions such as spinal cord injuries, Parkinson's disease, diabetes, and heart disease.
3. **Gene cloning** involves copying specific genes or DNA segments for various purposes, including research, medicine, agriculture, and industry. It is used in biotechnology, genetic engineering, pharmaceuticals, agriculture, vaccines, and genetically modified organisms (GMOs).

DO YOU KNOW?

STEM CELLS:
Stem cells are unique cells in the body that have an amazing ability to transform into different types of cells. They serve as a repair system for the body and can divide and renew themselves over long periods.

They act as repair, division and differentiation systems to complement other cells and maintain the function of various tissues. Stem cells are found in the brain, blood, bone marrow, muscle, skin, heart, and liver tissues.

Concept Assessment Exercise 13.1

1. Discuss the interconnectedness between amino acids, proteins, lipids, and carbohydrates within living organisms.
2. Evaluate the effectiveness and usefulness of vitamins in maintaining overall health and preventing nutrient deficiencies.

KEY POINTS

- **Gene:** A gene is the basic physical and functional unit of heredity. Genes are made up of DNA.
- **Biotechnology:** the use of artificial methods to modify the genetic material of living organisms or cells to produce novel compounds or to perform new functions
- **Cloning:** the production of an exact copy, specifically, an exact genetic copy of a gene, cell, or organism.
- **Genetic engineering:** alteration of the genetic makeup of an organism using the molecular methods of biotechnology.
- **Monomers:** Monomers are simple molecules that bond together to form more complex structures called polymers.
- **Amino Acids:** Amino acids act as the building blocks or monomers for proteins.
- **Proteins:** When multiple amino acids link together through peptide bonds, they form a protein molecule.

EXERCISE

1. Multiple Choice Questions (MCQs)

i. Which of the following is NOT a function of proteins in the body?
   a) Acting as enzymes
   b) Storing genetic information
   c) Providing structural support
   d) Transporting molecules

ii. Which of the following best describes proteins?
   a) Polysaccharides
   b) Polymers of amino acids
   c) Chains of fatty acids
   d) Simple sugars

iii. Which bond is responsible for linking amino acids together in a protein?
   a) Hydrogen bond
   b) Ionic bond
   b) Peptide bond
   d) Covalent bond

iv. Which of the following is a component of nucleic acids?
   a) Amino acid
   b) Fatty acid
   c) Phosphate group
   d) Glucose

v. Which of the following is a characteristic of vitamins?
   a) They provide energy directly.
   b) They are essential for normal body function.
   c) They are inorganic molecules.
   d) They are a primary source of protein.

vi. Which vitamin is important for vision and immune function and is fat-soluble?
   a) Vitamin C
   b) Vitamin B12
   c) Vitamin A
   d) Vitamin K

vii. Which acid carries genetic information?
   a) Amino acid
   b) Nucleic acid
   c) Sulphuric acid
   d) Ascorbic acid

viii. Which vitamin helps the body absorb calcium and is fat-soluble?
   a) Vitamin B12
   b) Vitamin C
   c) Vitamin D
   d) Vitamin E

ix. Which of the following is a primary function of lipids in the body?
   a) Providing immediate energy
   b) Storing genetic information
   c) Long-term energy storage
   d) Catalyzing biochemical reactions

x. How might a diet lacking in lipids affect the absorption of certain vitamins?
   a) It would have no effect since vitamins are not related to lipids.
   b) It would increase absorption because lipids compete with vitamins for absorption.
   c) It would decrease the absorption of fat-soluble vitamins, such as A, D, E, and K.
   d) It would decrease the absorption of water-soluble vitamins, such as C and B.

xi. Which vitamin is essential for blood clotting?
   a) Vitamin A
   b) Vitamin C
   c) Vitamin D
   d) Vitamin E

xii. Which biochemistry application is used to determine parentage?
   a) Pregnancy test
   b) Genetic engineering
   c) Cancer screening
   d) Parental genetic testing

2. Short questions

i. How does the body make protein?
ii. What do vitamins do for our body?
iii. How do parent protect their children from genetic disorders?
iv. Differentiate between genetic engineering and gene therapy.
v. How gene cloning is different from therapeutic cloning?
vi. Explain why proteins are considered natural polyamides.
vii. How do pregnancy tests use biochemical principles to detect pregnancy?
viii. Evaluate the role of nucleic acids in heredity and cell function.

3. Long questions

i. What is the significance of nucleic acids as information-carrying molecules?
ii. Compare and contrast the functions and properties of lipids and carbohydrates.
iii. Why is Protein Structure Important?
iv. Explain the significance of amino acids in living organisms
v. Explain the process of cloning in biochemistry.
vi. What is the difference between genetic engineering and gene therapy?
vii. Why are vitamins essential to human health? Provide two examples with their functions.
viii. Compare and contrast the uses and functions of proteins, carbohydrates, and lipids.

THINK TANK

1. What is the importance of carbohydrates in maintaining energy levels?
2. What is the difference between genetic engineering and gene therapy?

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قومی ترانہ

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تو نِشانِ عزمِ عالی شان ارضِ پاکستان
مرکزِ یقین شاد باد!

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