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CHEMISTRY

FORM 4

CHAPTER 1

CHEMICAL REACTIONS II

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CHEMICAL REACTIONS II - RATES OF REACTIONS

OBJECTIVES

By the end of this chapter, the student should be able to:

1. describe factors that affect rates of reactions
2. describe methods for measuring rates of reactions
3. explain reversible and irreversible reactions

CONTENTS

- Definition of rate of reaction
- factors affecting rate of reaction
 - temperature, surface area, catalysts, and concentration
- measuring rates of reactions
 - how to measure the rate of reaction by monitoring changes of mass of reactants or volume of gas produced per unit time
 - interpreting graphs on rates of reactions (volume or mass against time graphs)
- reversible and irreversible reactions
 - explain reversible and irreversible reactions
 - investigating reversible reactions by hydration and dehydration of copper sulphate
 - investigating irreversible reaction by decomposing CaCO_3
- chemical equilibrium

RATES OF REACTIONS RATE OF REACTION

- The rate of chemical reaction measures how quickly a reactant is used up, or a product is formed.
- It is defined as the change in the amount of a reactant or product per unit time.

The Collision Theory

For a chemical reaction to occur;

- The reactant particles must collide with each other.
- The particles must have enough energy for the collision to be successful.

A successful collision is the one that produces a reaction. The rate of reaction depends on how many successful collisions there are in a given time. The more successful collisions there are, the faster the reaction. The minimum amount of energy needed for a collision to be successful is called **activation energy**.

Factors Affecting the Rate of Reaction

Some of the factors that affect the rate of a reaction are:

a. ***Concentration of the reactants***

- The rate of a reaction increases when the concentration of a reactant is increased.
- When the concentration of the solution increases, the amount of the particles per unit volume also increases.
- Frequency of collisions between reacting particles increases.

b. ***Temperature***

- The rate of reaction increases with an increase in temperature.

- At higher temperatures, the reactant particles have more kinetic energy, they move faster, and collide more often with greater energy causing the rate of reaction to increase.

c. ***Surface area of solid reactants***

- When the size of particles of a solid decrease, surface area of the solid increases, allowing them to collide with other reacting particles more readily hence the rate of reaction increases.
- This is why powdered solids react faster than lumps.

d. ***Use of a catalyst***

- A catalyst is a substance that speeds up a chemical reaction, but remains chemically unchanged itself.
- Catalysts work by lowering the activation energy for the reaction.
- Lowering the activation energy increases the frequency of successful collisions because a greater proportion of collisions now exceed this lower energy.

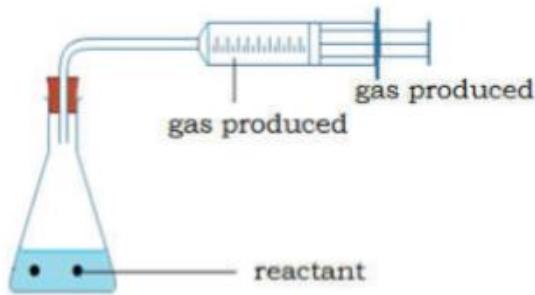
Methods of Measuring Rates of Reactions

There are different methods of measuring the rate of reaction. The method chosen usually depends on the reactants and products involved and how easy it is to measure the changes in them.

- a. Measuring the volume of gas produced.
- b. Measuring the change in mass of reactants or products.
- c. Measuring the time taken for a given mass of reactant to disappear completely.
- d. Measuring the time taken for a certain amount of product to form.

Measuring The Volume Of A Gas Produced.

- This method is used when a gas leaves the container. The volume is measured using a gas syringe.



- The volume of the gas given off is measured at regular time intervals, for example every half a minute.
- Using the syringe, the volume of the gas given off, is noted by checking how the plunger has been pushed.
- For example, if the plunger is pushed to the 20 cm³ mark, it means 20 cm³ of gas has been collected.
- Instantaneous rate of reaction is calculated by the following formula:

$$\text{Rate of reaction} = \frac{\text{volume of gas at } t_2 - \text{volume of gas at } t_1}{t_2 - t_1}$$

- Average rate of reaction is calculated by the following formula:

$$\text{Average rate of reaction} = \frac{\text{total volume of gas produced}}{\text{reaction time}}$$

Worked example

In an experiment, some magnesium and excess of dilute hydrochloric acid were reacted together. The volume of hydrogen produced was recorded every half a minute.

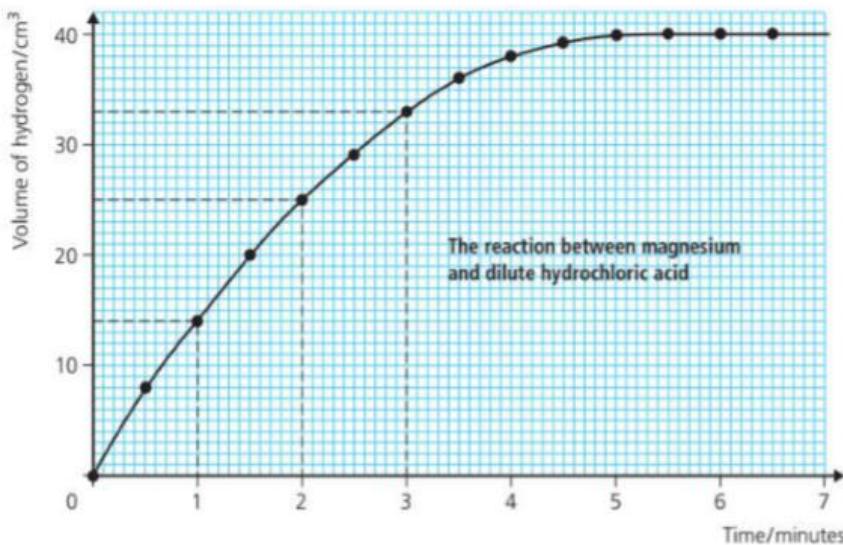
Time (minutes)	Volume of hydrogen (cm ³)
0	0

0.5	8
1.0	14
1.5	20
2.0	25
2.5	29
3.0	33
3.5	36
4.0	38
4.5	39
5.0	40
5.5	40
6.0	40

- a. Plot a graph of volume of hydrogen against time.
- b. What is the rate of reaction (in cm³ of hydrogen per minute) during, the 1st minute, the 2nd minute and the 3rd minute?
- c. How much hydrogen was produced in total?
- d. How long does the reaction last? e. Calculate the average rate of reaction

Solutions

- a. The graph of volume of hydrogen against time is shown below



- b. Rate of reaction in the 1st minute = 14 cm³ of hydrogen per minute

Rate of reaction in the 2nd minute = $\frac{25-14}{1}$
= 11cm³ of hydrogen per minute

Rate of reaction in the 3rd minute = $\frac{33-25}{1}$
= 8cm³ of hydrogen per minute

c. In total, 40 cm³ of hydrogen was produced.

d. After 5 minutes no more hydrogen is produced. The reaction lasts 5 minutes

e. Average rate of reaction = $\frac{\text{total volume of hydrogen}}{\text{total time for the reaction}}$

= $\frac{40\text{cm}^3}{5\text{minutes}}$

= 8cm³ of hydrogen per minute

Reversible and Irreversible Reactions

a. *Reversible reaction*

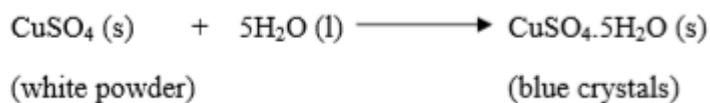
- A reversible reaction is a chemical reaction in which the products can be converted back to reactants under suitable conditions.

Example

When blue copper hydrated copper (II) sulphate is heated, it loses its water of crystallization. A white anhydrous copper sulphate is formed. The equation for the dehydration of blue copper sulphate is:



When water is added to the white anhydrous copper (II) sulphate powder, the colour turns back to blue. This is because the water of crystallization is



regained. The equation for hydration of white anhydrous copper sulphate is:

The overall reaction is given as

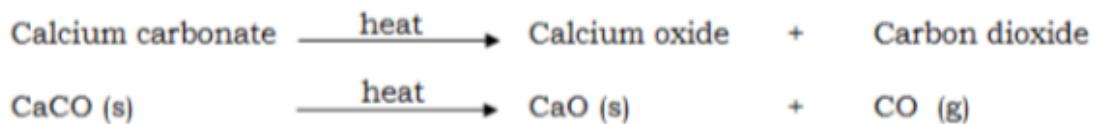


b. ***Irreversible reaction***

- An irreversible reaction is a reaction in which products cannot be converted back into reactants.

Example

When calcium carbonate is decomposed, calcium oxide and carbon dioxide are produced. The reaction cannot be reversed. The carbon dioxide escapes into the air.



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CHAPTER 2

ACIDS AND BASES - THE BRØNSTED-LOWRY THEORY OF ACIDS AND BASES

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ACIDS AND BASES

OBJECTIVES

By the end of this chapter, the student should be able to:

1. define acids and bases
2. identify conjugate acid-base pairs from given equations
3. explain the difference between strength and concentration of an acid or a base
4. explain ways of regulating pH in different environments
5. classify oxides as acidic, basic or amphoteric
6. describe different ways of preparing salts
7. design an experiment to prepare and purify a salt
8. state applications of precipitation

CONTENTS

- define acids and bases
 - discussing the ionisation of acids and bases in water
 - definition of acids and bases according to Bronsted-Lowry theory conjugate acid- base pairs
- identify conjugate acid-base pairs from given equations
 - discussing conjugate acid-base pairs from given equations
 - isolating acid-base pairs from given reactions
- strength and concentration of an acid or a base
 - Investigating the relative strengths of acids and bases using conductivity and pH
 - The strength of acids and bases in terms of extent of ionisation
 - The difference between concentration and strength of acids and bases
- ways of controlling pH in different environments
 - use of lime in treating soil and water acidity
 - the use of magnesium hydroxide (milk of magnesia) in treating stomach upsets
 - the importance of maintaining suitable pH in the human digestive system, soils and water
- classification of metal oxides and non-metal oxides as acidic and basic
 - acidic, basic and amphoteric characteristics of metallic and non-metallic oxides
 - experiments on the reaction of oxides with acids and bases
- preparation of soluble and insoluble salts
 - salts formation in a neutralisation reaction
 - other ways of preparing salts such as
 - precipitation
 - reaction of acids with metals, insoluble bases and carbonates
 - solubility rules
- separation and purification of salts
 - different ways of obtaining and purifying soluble and insoluble salts
 - experiment to prepare and purify a salt



- application of precipitation reactions
 - the applications of precipitation reactions such as treating effluents and water for domestic use

THE BRØNSTED-LOWRY THEORY OF ACIDS AND BASES

The Brønsted-Lowry theory of acids and bases was proposed by a Danish chemist, Johnnes Brønsted and an English chemist, Thomas Lowry. Their definition centres on the proton, H⁺. The proton is what remains after the normal hydrogen atom loses an electron. According to the Brønsted-Lowry theory:

- An acid is a proton donor.



Acid **Proton**

- A base is a proton acceptor.



Base **Proton**

The overall acid-base reaction is:



Acid **Base**

FORMATION OF THE HYDRONIUM ION, H₃O⁺

- The hydronium ion is formed when an acid dissolves in water, and the water gains the hydrogen ions which are donated by the acid.
- For example, when hydrochloric acid dissolves in water, it dissociates into hydrogen ions, H⁺ and chloride ions, Cl⁻ as follows.

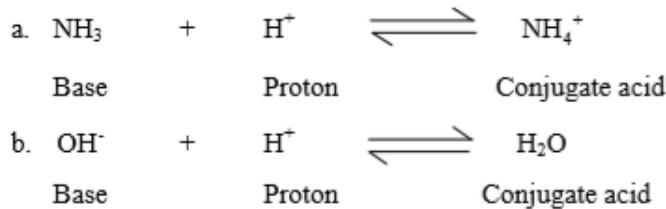


- The protons are then gained by the water to form the hydronium ion, H₃O⁺ as follows:

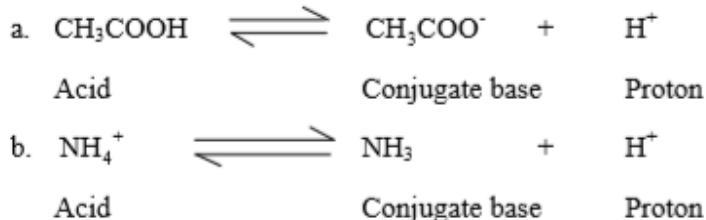


CONJUGATE ACIDS AND CONJUGATE BASES

- The terms conjugate acid and conjugate base are used to describe products of acid-base reactions.
- A conjugate acid** is the ion that is formed when a base gains a proton. Examples are:



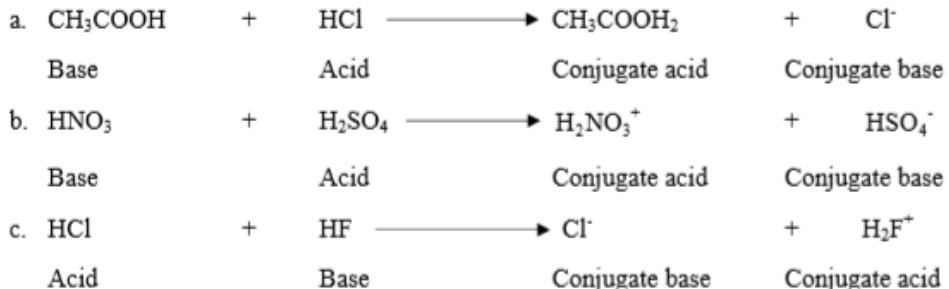
- The ion formed is called the conjugate acid because, if we imagine the reverse of the reaction, it can give up a proton.
- A conjugate base** is the ion that is formed when an acid loses a proton. Examples are:



- The ion formed is called the conjugate base because if we imagine, the reverse of the reaction, it can accept a proton.

Examples

- Identifying conjugate acid and conjugate base in acid-base reactions



Conjugate Acid-Base Pairs

- A conjugate acid-base pair consists of molecules or ions which are connected by the loss of one proton, H⁺ by an acid and by the gain of one proton, H⁺ by a base.
- Every acid-base reactions contain two conjugate acid-base pairs, because the H⁺ is transferred in both the forward and reverse reactions.

Examples

Write down the conjugate acid-base pairs in the following equations.



Solution

The conjugate acid-base pairs are + 4N H (aq)/NH₃ (g) and H₂O (l)/ OH (aq)



Solution

The conjugate acid-base pairs are: H₂SO₄/ H₂SO₄ and H₂NO₃ / HNO₃



Solution

The conjugate acid-base pairs are: CH₃COOH (l)/ CH₃COO⁻ (aq) and H₃O⁺ (aq)/H₂O (l)

Strength of Acids and Bases

The strength of a particular acid or base is based on the degree to which it dissociates into ions in aqueous solutions.

Strong and Weak Acids

A strong acid is the one which ionizes completely in water to give all its hydrogen ions. Examples of strong acids are hydrochloric acid (HCl), sulphuric acid (H_2SO_4) and nitric acid (HNO_3), etc.

The ionization equations for the acids are shown below:



- A weak acid is the one which ionizes partially in water to produce few hydrogen ions. Examples of weak acids are ethanoic acid (CH_3COOH), carbonic acid (H_2CO_3) etc.
- The ionisation equations for the acids are shown below:



The double arrow \rightleftharpoons means that the reaction is reversible.

Strong and Weak Bases

- A strong base is the one which ionizes completely in water to produce more hydroxide ions.
- Examples of strong bases are sodium hydroxide and potassium hydroxide.
- The ionization equations for the bases are:



A weak base is the one which ionizes partially in water to produce few hydroxide ions. A typical example of a weak base is ammonia.



DETERMINING THE STRENGTH OF ACIDS AND BASES USING CONDUCTIVITY APPARATUS

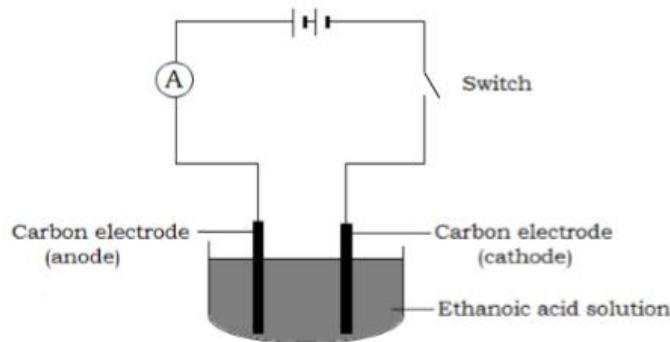
- Acids and bases are able to conduct electricity because they ionize when dissolved in water. However, the electrical conductivity depends on the acid or base being used as electrolyte.
- Strong bases and acids have higher electrical conductivity as compared to weak acids and bases. This is because strong acids and bases ionize completely releasing all the ions which conduct electricity when dissolve in water.
- On the other hand, weak acids and bases are weak electrolytes because they do not ionize completely when dissolve din water and therefore release few ions to conduct electricity.

COMPARING THE ELECTRICAL CONDUCTIVITY OF STRONG AND WEAK ACIDS AND BASES.

Materials: a beaker, 2 carbon rods, 2 cells, connecting wires, distilled water, ammeter, solutions of ethanoic acid, hydrochloric acid, sodium hydroxide and ammonia (of equal concentration)

Procedure:

- a. Put 50 ml of ethanoic acid solution into the beaker.
- b. Arrange the apparatus as shown below.



- c. Close the switch and record the ammeter reading in the table of results.
- d. Rinse the beaker and the carbon electrodes with the distilled water.
- e. Repeat steps *a* to *d* using 50 ml of the solutions of hydrochloric acid, sodium hydroxide and ammonia respectively.

Solution	Ammeter reading
Ethanoic acid	
Hydrochloric acid	
Sodium hydroxide	
Ammonia	

Conclusion

The acid or base whose current reading is higher is a strong acid or base, and the acid or base whose current reading is lower is a weak acid or base.

CONTROL VARIABLES DURING CONDUCTIVITY MEASUREMENTS

- Temperature of the solution
- Electrode surface area
- Electrode spacing

- Concentration of the solution

THE DIFFERENCE BETWEEN STRENGTH AND CONCENTRATION OF AN ACID OR A BASE

- The strength of an acid or tells us how easily it ionizes to produce hydrogen ions while concentration of an acid indicates the proportion of water and acid present in aqueous solution.
- The strength of a base indicates how easily it ionizes to produce hydroxide ions while concentration tells us the proportion of water and base present in aqueous solution.

OXIDES

Oxides are compounds containing oxygen and another element.

TYPES OF OXIDES

Oxides can be classified as basic, acidic or amphoteric.

1. BASIC OXIDES

- ✓ These are formed when oxygen reacts with metals. Examples are magnesium oxide (MgO), iron (II) oxide (Fe_2O_3) and copper oxide (CuO) etc.
- ✓ These compounds are usually ionic in nature.
- ✓ Most of them dissolve in water to form alkalis. Others are insoluble in water.
- ✓ They can neutralize an acid.

2. ACIDIC OXIDES

- ✓ These are formed when oxygen reacts with non-metals. Examples are carbon dioxide (CO_2), sulphur dioxide (SO_2) and phosphorous pentaoxide (P_2O_5).
- ✓ They form carbonic acid, sulphurous acid and phosphoric acid.

- ✓ When dissolve in water, they form a solution that turns blue litmus paper red.

3. AMPHOTERIC OXIDES

- ✓ These oxides have both acidic and basic properties.
- ✓ They react with both bases and acids to form salt and water.
Examples include aluminium oxide (Al_2O_3), zinc oxide (ZnO) and lead (II) oxide (PbO)

WAYS OF REGULATING pH IN DIFFERENT ENVIRONMENTS

The human digestive system, soils and water are some environments whose pH must be maintained for them to function efficiently.

a. THE HUMAN DIGESTIVE SYSTEM

- The hydrochloric acid present in the stomach helps in protein digestion.
- If excess hydrochloric acid is produced, it causes the stomach to ache.
- To deal with this problem, an antacid containing magnesium hydroxide solution (milk of magnesia) is taken in order to neutralize the acid.

b. SOIL AND WATER ACIDITY

- Acid levels in the soil increase when fertilizers are used for a long time.
- When acidic gases dissolve in rain water, they make water more acidic.
- High acidity in water and soils can be controlled by adding lime (calcium hydroxide).

WAYS OF PREPARING SALTS

A salt is product formed when the hydrogen ion of an acid is replaced by a metal or ammonium radical. Salts that do not dissolve in water are said to be soluble salts while those that do not dissolve in water are said to be insoluble salts. The method chosen for the preparation of a particular salt depends on the solubility of the salt in water. The methods of preparing salts include the following:

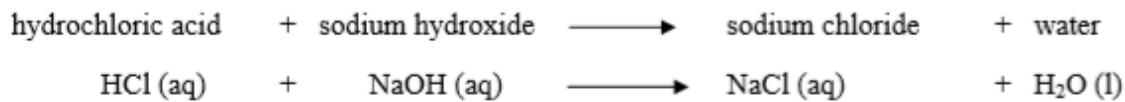
- Reaction of an acid with soluble bases.
- Reaction of acids with metals.
- Reaction of acids with insoluble bases.
- Reaction of acids with carbonates.
- Precipitations.

a. Reaction of acid with a soluble base (alkalis).

This method is used to prepare the salts of very reactive metals such as potassium or sodium. Titration is used in this reaction because both reactants are in solution. The acid is slowly and carefully added to a measured volume of alkali using a burette until the indicator, usually phenolphthalein, changes colour.

Once the end point is reached, the same volume of acid is added to the measured volume of alkali, but this time without the indicator. The solution which is produced can then be evaporated slowly to obtain pure dry crystals of the salt.

For example,

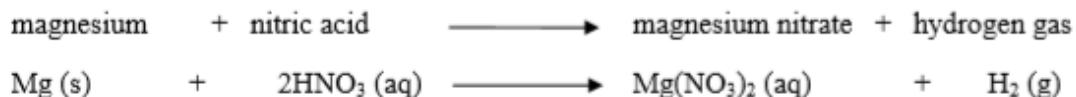


b. Reaction of an acid with a metal

This method can only be used with less reactive metals such as magnesium, aluminium, zinc, iron and tin. Excess metal is added to dilute

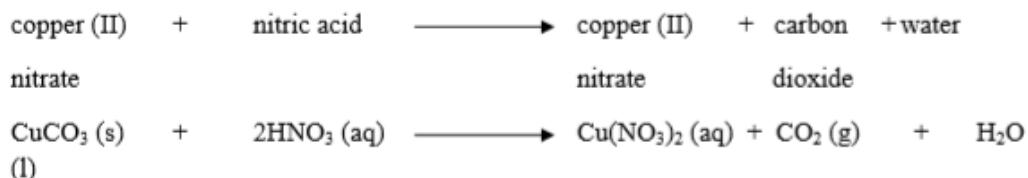
acid. The metal dissolves in then acid forming a salt solution. The salt solution formed is evaporated slowly to form a saturated solution of the salt.

For example,



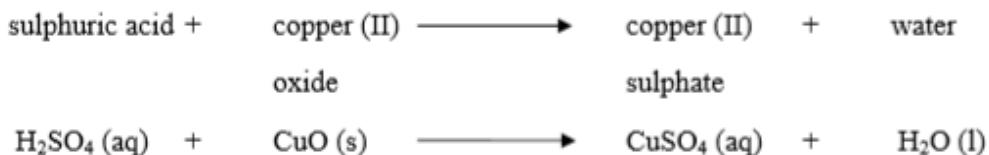
c. Reaction of acid with carbonate

This method is used with any metal carbonate and any acid, providing the salt is soluble. The procedure is similar to that of an acid and a metal. For example, copper (II) carbonate would be added in excess to dilute nitric acid to produce copper (II) nitrate solution.



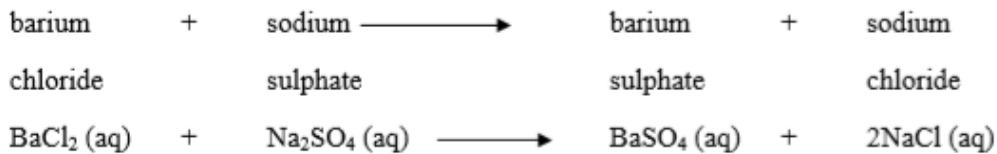
d. Reaction of an acid with an insoluble base

This method can be used to prepare a salt of an unreactive metal, such as lead or copper. In this case, it is possible to use direct reaction of the metal with an acid so the acid is neutralized using particular metal oxide. The reactants are warmed. A typical example is the neutralisation of sulphuric acid by copper (II) oxide to produce copper (II) sulphate.



e. Precipitation

This method is used to prepare an insoluble salt. Solutions of the two chosen soluble solutions are mixed. The insoluble salt formed can be filtered off, washed with distilled water and dried. For example, to produce barium sulphate, barium chloride and sodium sulphate can be used.



SOLUBILITY RULES

Solubility rules guide the choice of a method to be used when preparing salts.

- All potassium (K), sodium (Na) and ammonium (NH_4) are soluble.
- All nitrates and hydrogen carbonates (HCO_3) are soluble.
- All sulphates are soluble except lead sulphate (PbSO_4) and barium sulphate (BaSO_4). Calcium sulphate (CaSO_4) is sparingly soluble.
- All chlorides are soluble except silver chloride (AgCl). Lead chloride (PbCl_2) is only soluble in hot water.
- All carbonates are insoluble except potassium, sodium and ammonium carbonates.

APPPLICATIONS OF PRECIPITATIONS REACTIONS

a. Treatment of water for domestic use

Sodium carbonate can be used to treat water for domestic use. The toxic cations are precipitated as insoluble lead carbonate or mercury carbonates which are then filtered off.

Sodium carbonate is also used to make hard water soft by precipitating the ions that cause water hardness.

b. Treatment of industrial effluents

Effluents refer to liquid wastes discharged from a sewage system, a factory, a nuclear power station or an industrial plant.

When treating industrial effluents, precipitation is carried out to remove toxic ions in the water solution. Ions to be removed are reacted with other ions to produce insoluble solids that can be removed by sedimentation or filtration.

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CHAPTER 3

REDUCTION AND OXIDATION REACTIONS

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REDUCTION AND OXIDATION REACTIONS

OBJECTIVES

By the end of this chapter, the student should be able to:

1. define the terms of *oxidation* and *reduction*
2. assign an oxidation number to an atom in an element, ion or compound
3. identify reducing and oxidizing agents
4. write half and overall redox equations
5. deduce the order of reactivity of metals
6. predict the spontaneity of a reaction
7. describe corrosion
8. state conditions necessary for corrosion and methods of prevention

CONTENTS

- definition of oxidation and reduction oxidation states/numbers
 - removal/addition of oxygen
 - removal/addition of hydrogen
 - loss/gain of electrons
 - increase or decrease of oxidation number/state
- assign an oxidation number to an atom in an element, ion or compound
 - *oxidation number*
 - rules for assigning oxidation numbers
 - working out the oxidation number of an atom present in an element, ion or compound
 - significance of oxidation numbers in
 - naming of inorganic compounds
 - writing formulae of inorganic compounds
- reducing and oxidizing agents
 - defining reducing and oxidizing agents
 - identifying oxidizing and reducing agents from a given equation
 - identifying reduced and oxidised species based on changes in oxidation numbers
- half and overall equations
 - discussing half equations for reduction and oxidation reactions
 - writing and balancing overall redox equations
- Order of reactivity of metals
 - conducting an experiment on the reaction of metals with water and hydrochloric acid
 - arranging metals in order of their reactivity
- displacement reactions (spontaneity of reaction)
 - explaining displacement reaction using reactions of metals with metal ions in solution
 - discussing the reactivity of metals in terms of the ease with which they lose electrons
- activity series
 - using the activity series to predict whether a reaction will take place or not for given reactants

- voltage series
 - explaining the potential difference between different metals using voltage series
 - Calculating the potential difference between different metals using voltage series
- corrosion and its prevention
 - explaining the process of corrosion as a reduction-oxidation reaction of metals
 - discussing corrosion of iron (rusting) in terms of half reaction equations
 - conducting an experiment on conditions necessary for rusting to take place
 - discussing methods of preventing corrosion

OXIDATION AND REDUCTION

1. OXIDATION

a. It is the addition of oxygen to a substance.

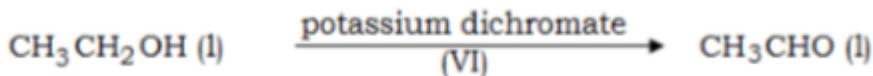
- Consider the reaction between magnesium (Mg) metal and oxygen.



- The magnesium has gained oxygen. We say that it has been oxidized.

b. It is removal of hydrogen from a substance.

- For example, ethanol can be changed to ethanal by an oxidising agent potassium dichromate (VI), in the presence of an acid



- The ethanol molecule has lost two hydrogen atoms to become ethanal. It has been oxidized.

c. It is the loss of electrons by a substance.

- Consider a reaction between magnesium and oxygen to form magnesium oxide, $\text{MgO}(\text{g}) \longrightarrow 2\text{MgO}(\text{s})$

- In this reaction, each magnesium atom loses two electrons. Therefore magnesium has been oxidized.

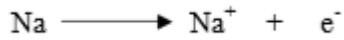
- The oxidation reaction equation will be written as:



- During oxidation, electrons are lost, so they are written on the side of products of the equation.
- d. It is the increase in charge or oxidation number.
- Consider the reaction between sodium and chlorine to form sodium chloride.



- Each sodium atom gives one electron to the chlorine atom and increases its charge from (0) to (+1) according to the equation below.



It is also correct to write:



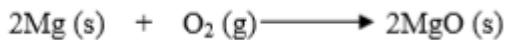
- Since sodium has increased its charge from (0) to (+1), it has been oxidized.

2. REDUCTION

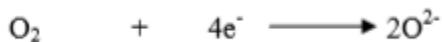
- a. It is the removal of oxygen from a substance.
- For example, when copper oxide is heated with carbon, the following reaction takes place.



- Copper oxide is losing oxygen. It is being reduced.
 - b. It is the addition of hydrogen to a substance.
 - For example, during the chemical equation for the formation of ammonia gas is shown below.
- $$\text{N}_2 \text{ (g)} + \text{H}_2 \text{ (g)} \rightleftharpoons \text{NH}_3$$
- Nitrogen is gaining hydrogen. It is being reduced.
 - c. It is the gaining of electrons by a substance. Consider a reaction between magnesium and oxygen to form magnesium oxide.



- In this reaction, each oxygen atom gains two electrons. Therefore, oxygen is being reduced.
- The reduction reaction equation will be written as:



- During reduction, electrons are gained, so they are written on the reactants part of the equation.
- d. It is the decrease in charge or oxidation number.
- Consider the reaction between aluminium and chlorine to form aluminium chloride.



- During the reaction, each chlorine atom receives one electron from the lithium atom and decreases its charge according to the equation below.
- $$\text{Cl}_2 + 2\text{e}^- \longrightarrow 2\text{Cl}^-$$

- The charge on chlorine has decreased from (0) to (-1). Therefore, chlorine has been reduced

OXIDATION NUMBERS

- An oxidation number is a whole number with a positive or negative sign of the charge on an atom, ion or a compound. It is also called the charge on an atom, ion or a compound.
- It indicates the amount of electrons lost or gained by an element during a chemical reaction. For example, Al^{3+} has an oxidation number of (+3) and O^{2-} has an oxidation number of (-2).

ASSIGNING OXIDATION NUMBERS

While it is now clear that oxidation numbers can be positive or negative, it is important to note that the calculation of such numbers follows a set of rules. The rules are:

1. The oxidation number of an uncombined element is equal to zero.
For example the oxidation number of carbon, $\text{C} = 0$, $\text{Cl}_2 = 0$, $\text{Fe} = 0$ and $\text{H}_2 = 0$, etc.
2. The oxidation number of each hydrogen atom, H is +1.
3. The oxidation number of each oxygen atom, O is -2.
4. The algebraic sum of oxidation numbers of the elements in a compound is equal to zero. For example, $\text{H}_2\text{O} = 0$ means that: $2(\text{H}) + 1(\text{O}) = 2(+1) + 1(-2) = 2 + (-2) = 0$.
5. The oxidation number of a monatomic ion is equal to the charge on the ion. For example, the oxidation numbers of ions of group I elements is +1, group II is +2, group III is +3, group VII is -1, etc.

That is why the oxidation number of $\text{Na}^+ = +1$, $\text{Al}^{3+} = +3$, $\text{Cl}^- = -1$, $\text{P}^{3-} = -3$, etc.

- For a polyatomic ion, the sum of the separate charges inside the ion must be equal to the final charge on the ion itself. For example, the oxidation number of 3N O is -1.

Example 1

Work out the oxidation number of sodium (Na) and chlorine (Cl) in sodium chloride (NaCl).

Solution

It means that $\text{Na} + \text{Cl} = 0$. (Rule number 4)

But Na is in group I and Cl is in group VII of the periodic table.

Therefore the oxidation numbers of Na = +1 and Cl = -1

Example 2

Work out the oxidation number of S in SO_4^{2-} .

Solution

SO_4^{2-} is a polyatomic ion with a charge of -2. The oxidation number of each oxygen atom, O = -2. Let the oxidation number of sulphur be y.

So,

$$y + 4(\text{O}) = -2 \text{ (Rule number 6)}$$

$$y + 4(-2) = -2$$

$$y - 8 = -2$$

$$y = +6$$

Therefore the oxidation number of S in SO_4^{2-} is +6.

Example 3

In the equation below, work out the oxidation number of manganese (Mn) in MnO_4^- and state if it is being reduced or oxidized.



Solution

MnO₄⁻ is a polyatomic ion with a charge of -1 and the oxidation number of each oxygen atom is -2.

Let the oxidation number of manganese (Mn) = z

$$\text{So, } z + 4(\text{O}) = -1 \text{ (Rule number 6)}$$

$$z + 4(-2) = -1$$

$$z - 8 = -1$$

$$z = -1 + 8$$

$$= +7$$

Therefore, the oxidation number of Mn is +7. The oxidation number of Mn decreases from (+7) to (+2), hence manganese (Mn) is being reduced.

HALF EQUATIONS IN REDOX REACTIONS

Consider the equation for the reaction between sodium (Na) and chlorine (Cl₂)

In this reaction the following has happened:

- Each sodium atom has donated one electron to chlorine atom.
Therefore sodium has been oxidized according to the equation below.



- Each chlorine atom has received one electron from sodium atom. Therefore, chlorine has been reduced according to the equation below.



Reduction of chlorine is taking place side by side with the oxidation of sodium. Since reduction and oxidation occur simultaneously, this reaction is called reduction-oxidation reaction or in short redox reaction. Each of the reactions is called a half-reaction because the electrons released by one reaction are accepted by another in order to complete the redox reaction.

SPECTATOR IONS AND NET IONIC EQUATIONS

Spectator ion: This is an ion which does not take part in a chemical reaction.

Ionic equation: This is an equation in which the ions which are involved in a reaction are shown. The equation could be an overall reaction or half reaction. In a net ionic equation spectator ions are excluded.

The equation for the reaction between iron (Fe) and copper sulphate (CuSO_4) solution is shown below.



Writing the equation in terms of the ions present in solution we get:



In this equation, the sulphate ion, SO_4^{2-} (aq) is found on both sides of the equation and nothing has changed on it. This means the SO_4^{2-} ion did not take part in the reaction. It is the spectator ion. The ionic equation for the reaction between iron (Fe) and copper sulphate should therefore be written as follows:



BALANCING REDOX EQUATIONS

There are two rules for writing redox equations

1. In any ionic equation, the charges must balance. This means the sum of charges on the left-hand side (LHS), must be equal to the sum of charges on the right-hand side (RHS) of the equation.

This rule applies to both overall (full) reaction and half-reaction equations.
Examples are

Equation	Charges on LHS	Charges on RHS
$\text{Zn}(\text{s}) + \text{Pb}^{2+}(\text{aq}) \longrightarrow \text{Zn}^{2+}(\text{aq}) + \text{Pb}(\text{s})$	+2	+2
$\text{Br}_2(\text{aq}) + 2\text{e}^- \longrightarrow 2\text{Br}^-(\text{aq})$	-2	-2
$\text{Na}(\text{s}) \longrightarrow \text{Na}^+(\text{aq}) + \text{e}^-$	0	0

2. The number of electrons lost in the oxidation half reaction must be equal to the number of electrons gained in the reduction half reaction.

For example, in the reaction between iron (Fe) and copper sulphate (CuSO_4) solution, the number of electrons lost in the oxidation half reaction is two according to the equation below:

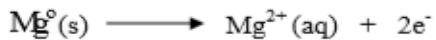


Therefore, the number of electrons gained in the reduction half reaction must also be two.



WRITING OVERALL EQUATIONS FROM TWO HALF REACTION EQUATIONS

To write an overall equation from two half reaction equations, the steps to be followed are:



Write a full equation for the reaction.

Solution

The oxidation half reaction equation is: $\text{Mg}^{\circ}(\text{s}) \longrightarrow \text{Mg}^{2+} + 2\text{e}^-$

Charges	0	+2	+	-2
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The reduction half equation is: $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \longrightarrow \text{Cu}^{\circ}(\text{s})$

Charges	2+	+	2-	0
---------	----	---	----	---

Each of the half equations is balanced. Each side has zero charge (Rule number 1). In the reaction, magnesium (Mg) loses two electrons in an oxidation reaction, which are gained by the copper ions (Cu^{2+}) in a reduction reaction (Rule number 2).

Adding the two half equations we get:

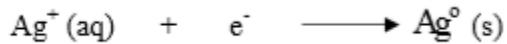


Cancelling out the electrons, the full equation is



Example 2

The half equations for the reaction between zinc (Zn) and silver nitrate (AgNO₃) solution are:



Write an overall equation for the reaction.

Solution

Each side of the half equations has zero charge. Therefore each half equation is balanced. However, zinc (Zn) loses two electrons in an oxidation reaction but silver gains one electron in a reduction reaction.

To equalize the number of electrons lost and gained, the reduction half equation must be doubled. Thus



Adding the two half equations we get:



Cancelling out the electrons, the overall equation is:



OXIDISING AGENTS AND REDUCING AGENTS

The terms oxidising agent and reducing agent are used to describe reactants in reduction– oxidation (redox) reactions.

An oxidising agent is a substance that causes oxidation to take place by accepting electrons from another substance. When accepting the electrons, the oxidising agent is itself reduced.

A reducing agent is a substance that causes reduction to take place by donating electrons to another substance. When donating the electrons, the reducing agent is itself oxidized.

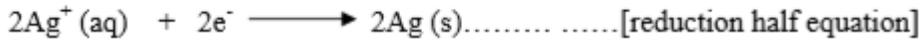
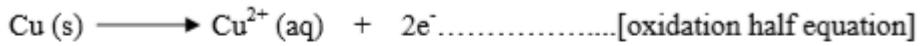
Examples

Write the oxidation and reduction half equations and identify the oxidising agent and the reducing agent in the following equations.



Solution

a. The half equations are:

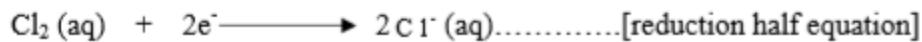
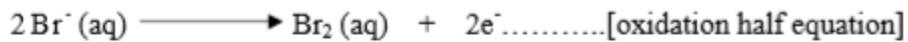


b. Reducing agent: Cu (s), it has increased its charge from 0 to +2
Oxidising agent: Ag⁺ (aq), it has decreased its charge from +1 to 0.



Solution

a. The half equations are:

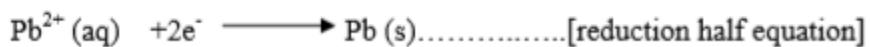
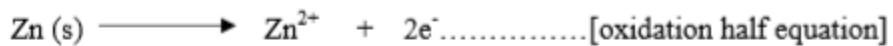


b. The reducing agent is Br⁻ (aq) while the oxidising agent is Cl₂ (g)



Solution

- a. The half equations are:



- b. The reducing agent is Zn (s) while the oxidising agent is Pb²⁺ (aq)

ORDER OF REACTIVITY OF METALS

The order of reactivity of metals can be based on three criteria: reactions of metals with water, reaction of metals with acid, and metals displacement reactions.

a. REACTIONS OF METALS WITH WATER

Some metals such as potassium, sodium, calcium, magnesium, zinc, copper, gold, silver and iron react with water to produce a basic solutions or oxides and hydrogen gas. When their reactions are compared, the order of reactivity of metals is generated as shown below:

Metal	Reaction	Order of reactivity
potassium (K)	very violent with cold water catches fire	most reactive
sodium (Na)	violent with cold water	
calcium (Ca)	less violent with cold water	
magnesium (Mg)	very slow with cold water but vigorous with steam	
zinc (Zn)	quite slow with steam	
iron (Fe)	slow with steam	
copper (Cu)	no reaction	
silver (Ag)	no reaction	
gold (Au)	no reaction	least reactive

↑
Increasing reactivity

b. REACTION WITH HYDROCHLORIC ACID

Most metals react with dilute acids to form a salt solution and hydrogen gas. The order of reactivity of metals with hydrochloric acid is shown below:

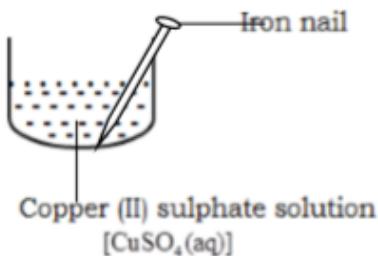
Metal	Reaction with hydrochloric acid	Order of reactivity
Potassium (K)	explosively fast	most reactive
Sodium (Na)	explosively fast	
magnesium (Mg)	vigorous	
zinc (Zn)	quite slow	
iron (Fe)	slow	Increasing reactivity
lead (Pb)	slow, and only if the acid is concentrated	
copper (Cu)	no reaction even with concentrated acid	
silver (Ag)	no reaction	
gold (Au)	no reaction	least reactive

c. DISPLACEMENT REACTIONS OF METALS

A metal displacement reaction is the reaction in which one metal substitutes another metal from a solution. A metal displacing the other is in solid form while the metal being displaced is in aqueous state in solution.

Example

Iron (Fe) metal is placed in an aqueous solution of copper (II) sulphate [$\text{CuSO}_4 \text{ (aq)}$] and the experiment is left for about 5 minutes. Observations are made and recorded.



Observations

After 5 minutes, the following should have been observed

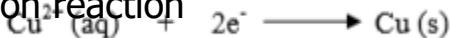
- Iron (nail) began to dissolve.
- A black-brown coating of copper metal formed on the nail.
- The colour of the solution began to turn from blue to pale green.

Explanation

When the iron (Fe) was placed in the solution, it started to dissolve and form iron ions (Fe^{2+}). This is oxidation reaction:



The copper ions (Cu^{2+}) present in the solution captured the free electrons. This is reduction reaction



But since oxidation and reduction occur simultaneously, iron (Fe) goes into the solution as Fe^{2+} ions to take the place of copper ions [Cu^{2+} (aq)]. The copper ions (Cu^{2+}) come out of the solution as copper metal [Cu^0 (s)] and coat on the iron nail.

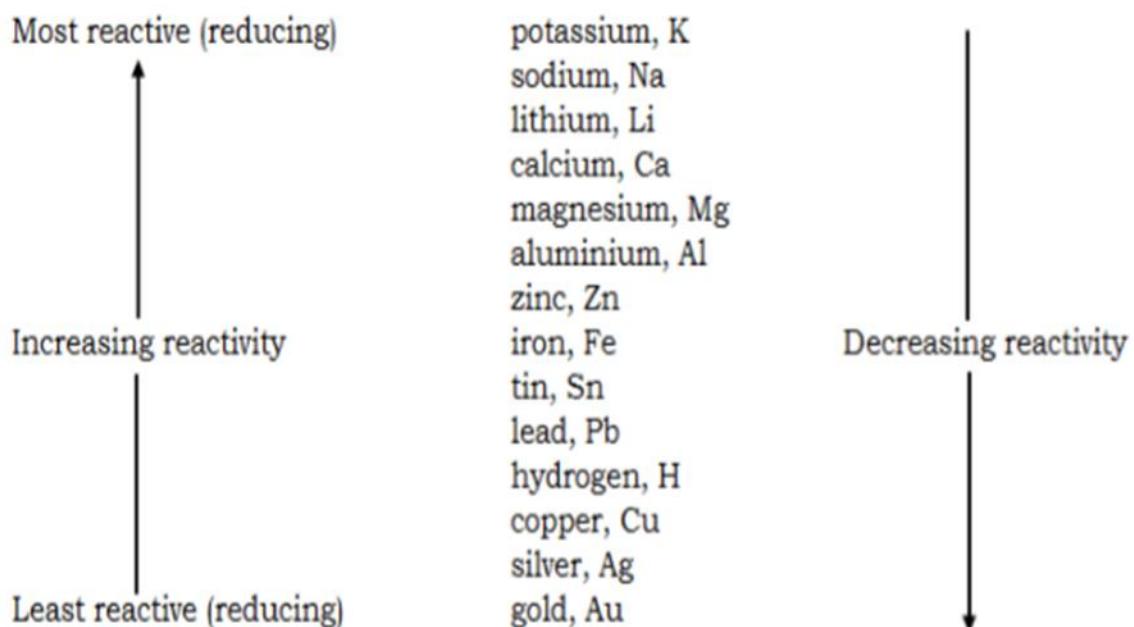
Therefore, in this reaction iron is displaces copper. Since iron can displace copper, we say that iron (Fe) is more reactive than copper (Cu).

The colour of copper (II) sulphate is blue because of the presence of the copper ions. In this reaction, the copper ions are constantly being removed from solution to form copper metal. As time goes by, the concentration of copper ions decreases causing the change in the colour of solution from blue to pale green.

Displacement series

The displacement series is the arrangement of metals in order of their relative chemical reactivity. The displacement series is also called activity series, reactivity series, or redox **series**.

The activity series is as follows:

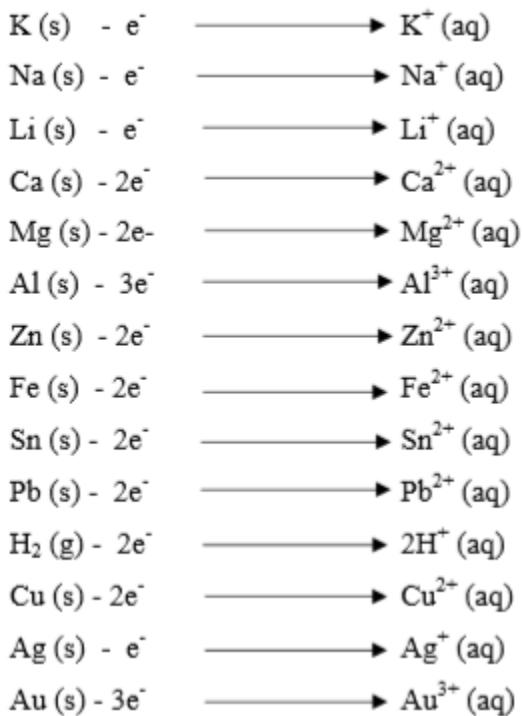


THINGS TO NOTE ABOUT THE ACTIVITY SERIES

1. The most reactive metal is at the top while the least reactive metal is at the bottom.
2. The metals at the top of the series can displace all other metals below them from solutions of their compounds by forcing them to accept electrons. For example, Potassium (K) can displace all the other metals below. Gold cannot displace any of the metals in the list.
3. The metals high on the series can easily donate electrons to metals lower down the series. For this reason, the metals at the top are said to be the most reducing or **most electropositive**.

THE ELECTROCHEMICAL SERIES

This is a list of half equations that shows the ability of one metal to donate electrons to other metals in solution. The series is as follows.



The working principle of the electrochemical series is the same as that of the displacement series. Atoms of an element above can displace ions of an element below. Atoms of an element below will not displace ions of an element above.

POSITIONS OF THE METALS IN THE ELECTROCHEMICAL SERIES

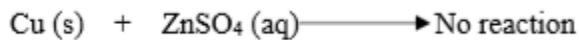
The position of the metals in the series is important in predicting a displacement reaction as well as the rate of reaction.

a. Whether a displacement reaction will take place or not

A reaction will take place if the atom is of an element which is high in the series while the ion is of an element which is lower in the series. For example, a reaction takes place when zinc (Zn) metal is mixed with a solution of copper (II) sulphate.

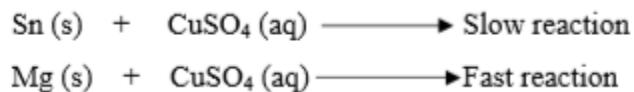


However, if the atom is of an element which is lower in the series while the ion is of an element high in the series, a reaction will not take place. For example, a reaction does not take place if copper (Cu) metal is mixed with a solution of zinc sulphate (ZnSO_4).



b. The rate of reaction

As the gaps between the elements become bigger, the reactions occur easily and fast. As the gaps decrease, the reactions occur slowly. For example



Experiment

Aim: To investigate the displacement reactions of metals.

You are provided with four beakers, distilled water, a measuring cylinder, sand paper, and solutions of copper sulphate, zinc sulphate, iron sulphate and magnesium sulphate. You are also provided with pieces of copper, zinc, iron and magnesium metals.

- a. Pour about 2 cm³ of copper sulphate solution into each of the four beakers.
- b. Clean the copper, zinc, iron and magnesium metals using sand paper.
- c. Put a piece of each metal into each of the four beakers containing copper sulphate solution.
- d. Record the in the table below by indicating "Reaction" or "No reaction".
- e. Rinse the beakers with distilled water.
- f. Repeat steps (a) to (e) using solutions of zinc sulphate, iron sulphate and magnesium sulphate respectively.

Metal salt solution	Metal			
	Copper	Zinc	Iron	Magnesium
Copper sulphate				
Zinc sulphate				
Iron sulphate				
Magnesium sulphate				

g. Use the results to arrange the metals in order of increasing reactivity.

HINT:

- The metal that reacts with all the given solutions is the most reactive.
- The metal that reacts with none of the given solutions is the least reactive.
- The metal that reacts with all the given solutions except the solution of the most reactive metal is the second-most reactive.
- The metal that reacts with all the solutions except the solutions of the first two most reactive is the third-most reactive metal.

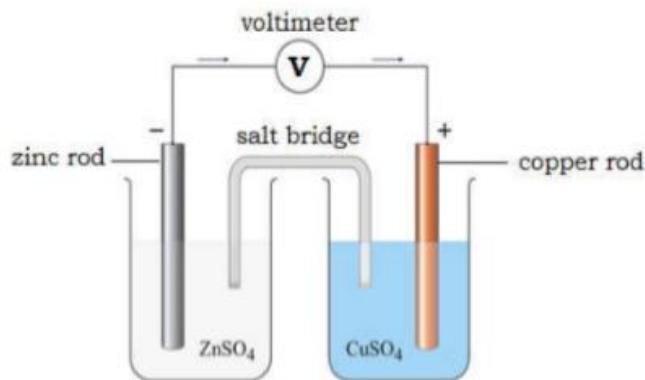
THE ELECTROCHEMICAL CELL

The electrochemical cell is a system in which metallic electrodes are placed into an electrolyte where a chemical reaction uses or generates electricity. Electrochemical cells which generate electric current are called voltaic or galvanic cells.

THE VOLTAIC CELLS

The voltaic cells consist of two separate compartments called half-cells containing electrolyte solutions and electrodes that can be connected in

a circuit. Two dissimilar metals (e.g. copper and zinc) are dipped in an electrolyte. If the metals are connected by an external circuit, one metal is reduced while the other metal is oxidized.

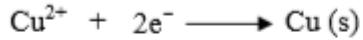


HOW THE VOLTAIC CELLS WORK

- Electrons flow from the more reactive metal (anode) to the less reactive metal (cathode). For example, from the left to the right in the figure above.
- Oxidation occurs at the anode. The name refers to the flow of anions towards it. For example, in the above voltaic cell zinc atoms give up electrons and go into the solution as ions. This is oxidation.



- Reduction occurs at the cathode. The name refers to the flow of cations towards it. For example, in the voltaic cell above copper (II) ions, Cu²⁺ (aq) accept electrons and copper is deposited. This is reduction.



The overall reaction is as follows: $\text{Zn (s)} + \text{Cu}^{2+} \longrightarrow \text{Zn}^{2+}(\text{aq}) + \text{Cu (s)}$

- The salt bridge acts as a transfer medium that allows ions to flow through out without allowing the different solutions to mix and react.
- Since electricity is defined as the flow of electrons, we can say that the redox reaction is giving out electrical energy.

CELL NOTATION OF GALAVANIC CELLS

The standard notation used for all voltaic cells is:

anode | anode.electrolyte | | cathode.electrolyte | cathode

For example



where

| = phase boundary (solid/aqueous)

|| = salt bridge

STANDARD ELECTRODE POTENTIALS

- The cell has an Electromotive Force (EMF) which is defined as maximum potential difference between two electrodes of a voltaic cell. EMF is the driving force of the cell reaction or any redox reaction i.e. the higher the EMF the stronger the reaction. The EMF is measured by a voltmeter, in volts.
- Experiments show that each half reaction has its own special voltage, which is called the **electrode potential**; it is the potential difference between an electrode and the solution in which it is immersed.
- The electrode potentials of metals are different due to differences in reactivity. Metals high in the electrochemical series tend to have high electrode potentials due to a greater ability to donate electrons, which also means a greater voltage.

- Metals lower in the series are made to accept electrons from those higher up, causing them to have a lower voltage. This idea leads to the development of the **voltage series**.

THE VOLTAGE SERIES

The voltage is a list of standard electrode potentials for metals. It is written as follows:

K (s) -	$1e^- \longrightarrow K^+$ (aq)	-2.92 volts
Na (s) -	$1e^- \longrightarrow Na^+$ (aq)	-2.71 volts
Mg (s) -	$2e^- \longrightarrow Mg^{2+}$ (aq)	-2.31 volts
Al (s) -	$3e^- \longrightarrow Al^{3+}$ (aq)	-1.67 volts
Zn (s) -	$2e^- \longrightarrow Zn^{2+}$ (aq)	-0.76 volts
Fe (s) -	$2e^- \longrightarrow Fe^{2+}$ (aq)	-0.44 volts
Sn (s) -	$2e^- \longrightarrow Sn^{2+}$ (aq)	-0.14 volts
Pb (s) -	$2e^- \longrightarrow Pb^{2+}$ (aq)	-0.12 volts
H ₂ (g) -	$2e^- \longrightarrow 2H^+$ (aq)	0.00 volts
Cu (s) -	$2e^- \longrightarrow Cu^{2+}$ (aq)	+0.34 volts
Ag (s) -	$1e^- \longrightarrow Ag^+$ (aq)	+0.80 volts

USING THE VOLTAGE SERIES

- The electromotive force (EMF) of the voltaic cell depends on the difference in the half cell voltages.

$$\begin{aligned}\text{EMF} &= \text{Oxidation electrode potential} + \text{Reduction electrode potential} \\ &= E_{\text{reduction}} + E_{\text{oxidation}}\end{aligned}$$

- Metals far apart in the voltage series would give a larger EMF, while metals close together would give a small EMF.

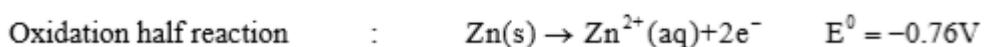
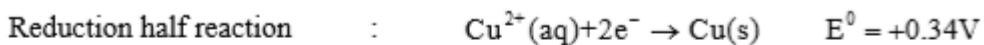
CALCULATING ELECTROMOTIVE FORCE (EMF) OF A CELL

- Write the half equation for each process.
- Look up the standard electrode potentials for each reaction.
- Reverse the sign on the oxidation electrode potential.
- Add the electrode potentials to get the EMF.
- A negative sign on the EMF indicates a spontaneous reaction will occur between the two metals. A negative sign indicates no reaction.

Example

Calculate the electromotive force of the electrochemical cell, Zn(s)|Zn²⁺ (aq)||Cu²⁺ (aq)|Cu(s). Refer to the voltage series.

Solution



$$\begin{aligned}\text{EMF} &= E_{\text{reduction}} + E_{\text{oxidation}} \\ &= +0.34\text{V} - (-0.76)\text{V} \\ &= +1.10\text{ V}\end{aligned}$$

CORROSION AND RUSTING

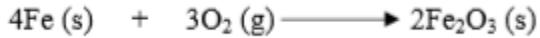
Corrosion is the reaction which occurs when some metals react with atmospheric oxygen and water. Corrosion is an example of a displacement reaction which results in degradation of metals by dissolving and wearing away. During corrosion, the metals get oxidized to form oxides. For example,



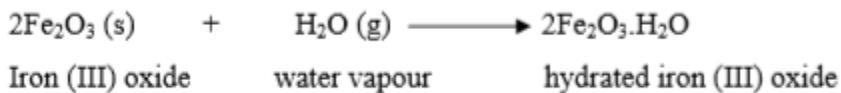
Rusting means the oxidation of iron. Rust is the name of the iron oxide compound formed when iron corrodes (i.e. reacts with oxygen and water).

HOW RUSTING OCCURS

- Iron reacts oxygen to form (brown) iron (III) oxide.



- At the same time, the iron (III) oxide reacts with water to form brown hydrated iron (III) oxide.



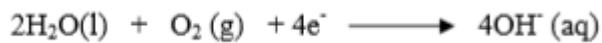
The hydrated iron (III) oxide is known as rust. Rust is a soft, crumbly brown solid.

RUSTING AS A REDOX REACTION

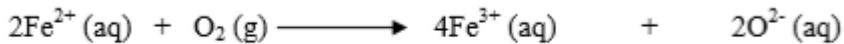
Firstly, iron dissolves in water and ionizes according to the equation:



Water and air capture the electrons and are reduced according to the equation:



The hydroxyl ions react with the iron, Fe^{2+} (aq) ions and more water to form rust. The net ionic equation for the reaction is:



CONDITIONS FOR RUSTING

There are two conditions necessary for rusting to take place.

- ✓ Presence of oxygen.
- ✓ Presence of water

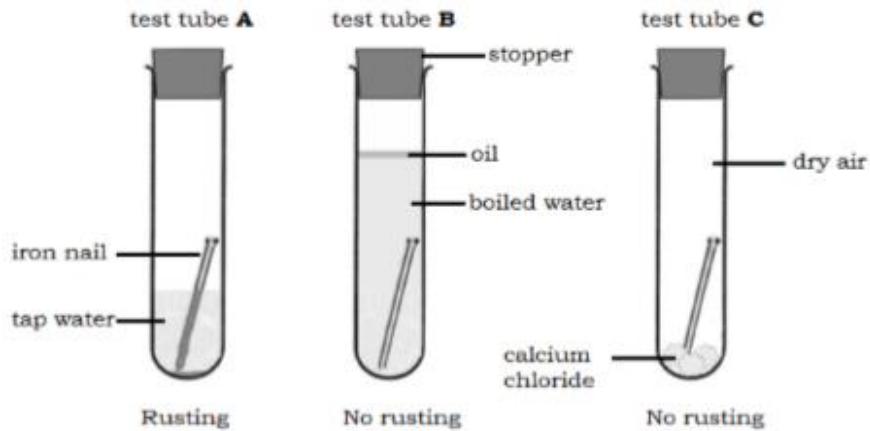
If either oxygen or water is not present, then rusting will not take place.

INVESTIGATING CONDITIONS FOR RUSTING

Materials: test tubes, test tube rack, iron nails, cooking oil, anhydrous calcium chloride, tap water

Procedure:

- a. The apparatus is set up as shown below.



- b. The test tubes are left undisturbed for one week.

Expected results

The nail in test tube **A** will rust while those in test tubes **B** and **C** will not rust. **Explanation**

In test tube **A**, rusting occurs because of the presence of both oxygen and water. The tap water contains air, hence oxygen. All the necessary conditions for rusting are present in test tube **A**. In test tube **B**, rusting will not occur because the boiled water does not contain dissolved oxygen. The oil prevents any atmospheric oxygen from entering. So, only water is present. In test tube **C**, the anhydrous calcium chloride is used to remove water. Hence only air is present. As a result, rusting will not occur.

PREVENTION OF RUSTING

Rusting can be prevented using the following methods.

- **Painting.** It prevents water and oxygen coming into contact with metal.
- **Greasing and oiling.** It prevents water and oxygen from interacting with the metal.
- **Alloying.** An alloy is a mixture of metals. For example, stainless steel is made by mixing iron with chromium, nickel and manganese. The alloy is corrosion resistant.

- **Galvanizing.** This involves covering or coating iron with a molten layer of zinc. The zinc reacts with water and oxygen in preference in preference to iron. Even if the zinc is scratched, the iron does not rust. This is because zinc is higher in the activity series. Zinc coated iron is called galvanized iron. In galvanizing, zinc is being sacrificed to protect iron. Hence this type of protection is called **sacrificial protection.**
- **Coating iron with plastic.**
- **Electroplating.** This is the process of coating a metal with a thin layer of another metal by using electrolysis.

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CHEMISTRY

FORM 4

CHAPTER 4

ELECTROLYSIS

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Compiled By: Stephan S. Kanyenda

ELECTROLYSIS

OBJECTIVES

By the end of this chapter, the student should be able to:

1. describe electrolysis
2. write electrolytic half and overall equations
3. predict of products of the electrolysis of molten and aqueous ionic compounds
4. explain some uses of electrolysis
5. explain the applications of electroplating

CONTENTS

- definition of electrolysis
 - defining electrolysis
 - discussing the process of electrolysis and components of an electrolytic cell (voltmeter)
- write electrolytic half and overall equations
 - writing and balancing half equations at the cathode and the anode
 - adding cathode and anode half equations to form overall equations
- predict of products of the electrolysis of molten and aqueous ionic compounds
 - discussing the ions present in the molten state of an electrolyte and products that are formed at the electrodes
 - discussing the ions present in aqueous solution and the products formed at the electrodes
 - demonstrating preferential discharge using very reactive metals and non-metals
 - conducting an experiment on the electrolysis of molten lead bromide and aqueous sodium iodide
- uses of electrolysis
 - investigating the electrolysis of copper (II) sulphate using inert (graphite) and copper electrodes
 - discussing the uses of electrolysis such as extraction and purification of metals, electroplating, production of chemicals and lead batteries
- purification of copper
 - Describing the process of the purification of copper
- electroplating and its uses
 - discussing applications of electroplating and its benefits to society
 - designing and conducting an experiment to exemplify electroplating

ELECTROLYSIS

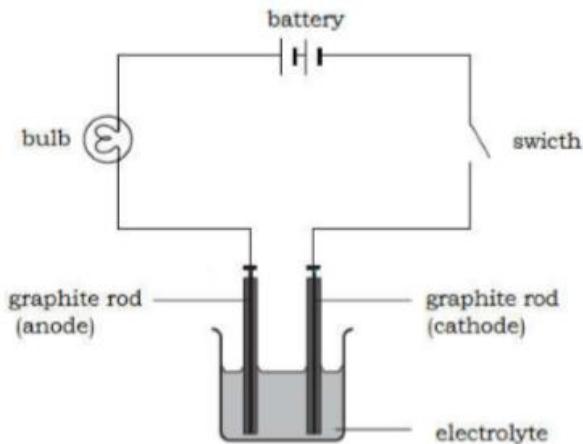
Electrolysis is the decomposition of a compound which is in molten or aqueous state using electrical energy. The process of electrolysis is carried out in an electrochemical cell. Electrolysis works for

- Ionic compounds that are melted or dissolved in water, so that the ions are free to move.
- Covalent compounds that form ions when they are dissolved in water.

COMPONENTS OF AN ELECTROCHEMICAL CELL

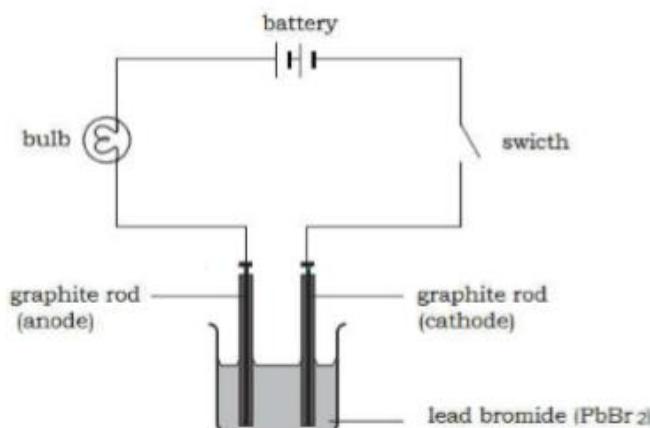
The electrochemical cell consists of a dry cell, an ammeter, bulb, graphite rods and an electrolyte.

- An electrolyte is a compound which when melted or when dissolved in water can conduct electricity and get decomposed by it.
- The graphite rods are called electrodes. The electrode attached to the positive terminal of the battery is called the anode.
- The electrode connected to the negative terminal of the cell is called the cathode.
- Dry cells are used to supply direct current.
- The bulb or ammeter is used to indicate that current is flowing in the circuit.



ELECTROLYSIS OF MOLTEN IONIC COMPOUNDS

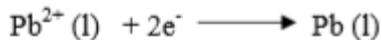
Consider the electrolysis of molten lead bromide in the figure below:



When the switch is closed this what happens:

- Electrons move from the negative terminal of the battery to the cathode.

- In the liquid, ions move to the electrode of opposite charge. Lead ions (Pb^{2+}) are attracted to the cathode while bromide ions (Br^-) are attracted to the anode. The moving ions carry electric current.
- At the cathode, lead ions each receive two electrons and are reduced according to the equation:



Lead collects on the electrode and eventually drops off it.

- At the anode, bromide ions each gives up an electron and are oxidised according to the equation:



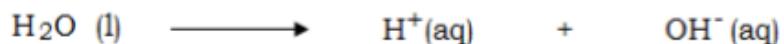
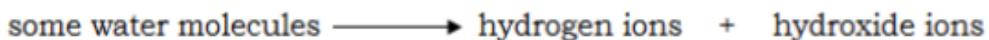
- The bromide gas bubbles off. Combining the anode and cathode reactions we get a redox reaction.



So it must be noted that electrolysis decomposes a molten ionic compound. A metal is obtained at the cathode, and a non-metal at the anode.

ELECTROLYSIS OF AQUEOUS IONIC COMPOUNDS

When a salt such as sodium chloride (NaCl) dissolves in water its ions become free to move. So it can be electrolysed. However, the products are usually different from the products of the electrolysis of molten ionic compounds. This is so because the water itself also produces ions; hydrogen ions (H^+) and hydroxide ions (OH^-). A tiny proportion of its molecules split into ions.



So in the aqueous solution, the H^+ and OH^- ions from water compete with other ions to receive or give up electrons. To predict which ion will win the following rules apply during the electrolysis of aqueous ionic compound.

1. At the cathode, either a metal or hydrogen is formed.

- If a metal is more reactive than hydrogen, its ions stay in solution. The H^+ ions accept electrons, and hydrogen bubbles off.
- If the metal is less reactive than hydrogen, its ions will accept the electrons. The metal forms, leaving the H^+ ions in solution.

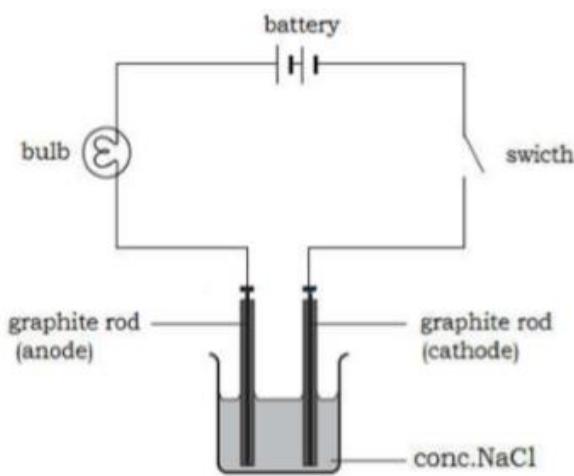
2. At the anode, a non-metal other than hydrogen is formed.

- If a halide ion (Cl^- , Br^- , I^-) is present in sufficient concentration, it will give up electrons more readily than the OH^- ions do. Molecules of chlorine, bromine and iodine.
- If no halide ion is present or if the halide solution is dilute, the OH^- ions will give up electrons and oxygen will be formed.

In either case, the ions are discharged selectively since only at each electrode only one type of ions gets discharged. This is called **preferential discharge**.

DEMOSTRATING PREFERENTIAL DISCHARGE

- a. Electrolysis of brine (concentrated solution of sodium chloride, NaCl (aq)).



The ions present in solution are Na^+ , Cl^- from the salt, and H^+ and OH^- from the water. The figure below shows the reactions at each electrode as the electrolysis proceeds.

- At the cathode, the H^+ accepts electrons since hydrogen is less reactive than sodium. The equation for the reaction is:

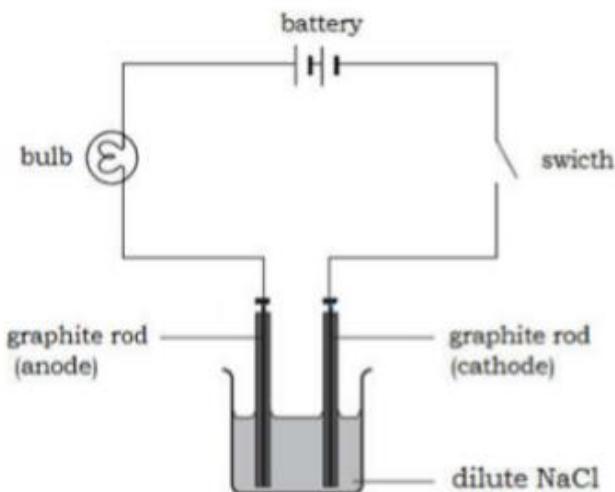
$$2\text{H}^+(\text{aq}) + 2\text{e}^- \longrightarrow \text{H}_2(\text{g})$$
. This is **reduction**. The hydrogen gas bubbles off.
- At the anode, the Cl^- ions give up electrons more readily than the OH^- ions do. The equation for the reaction is:

$$2\text{Cl}^-(\text{aq}) - 2\text{e}^- \longrightarrow \text{Cl}_2(\text{g})$$
. This is **oxidation**. The chlorine gas bubbles off.

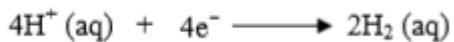
When the hydrogen and chlorine gases bubble off, Na^+ ions and OH^- ions remain behind, so a solution of sodium hydroxide is formed.

b. Electrolysis of dilute sodium chloride

The same ions are present as before. But now the proportion of Na^+ and Cl^- ions is lower since the solution is dilute.



- At the cathode, hydrogen ions gain electrons according to the equation:



This is **reduction**. (The 4 electrons are there to balance the half-equation at the anode)

- At the anode, the OH^- ions give up electrons, since the Cl^- ions are in low concentration. Oxygen gas bubbles off according to the equation:



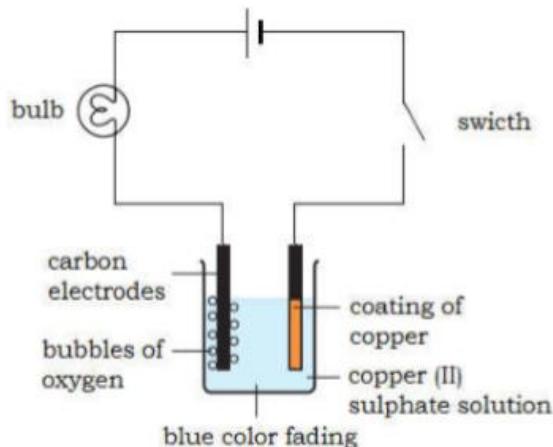
Instead of the dilute sodium chloride being decomposed, it is the water that gets decomposed. In a sense this is electrolysis of water.

EFFECTS OF ELECTRODES ON ELECTROLYSIS

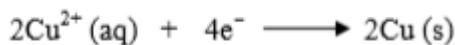
Electrolysis of a solution will give different results depending on electrodes. A comparison is shown in the following **a** and **b**.

a. Electrolysis of copper sulphate aqueous copper (II) sulphate using inert electrodes.

Inert electrodes are the electrodes which allow passage of electric current into and out of electrolyte without themselves getting decomposed. Examples are carbon graphite and platinum.



- At the cathode, copper ions get discharged.



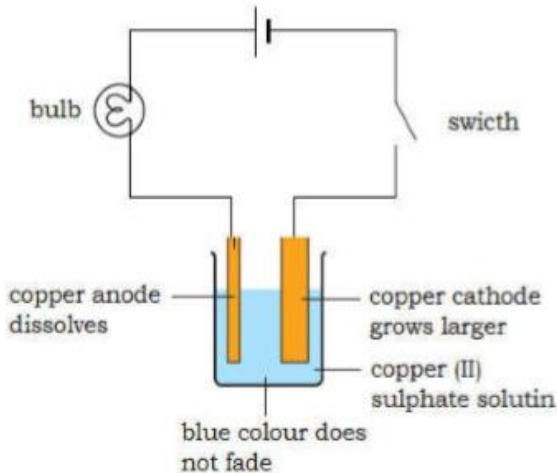
The copper coats the electrode

- At the anode, oxygen bubbles off.

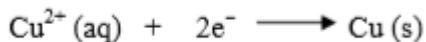


The blue colour of copper sulphate solution fades as the copper ions are discharged.

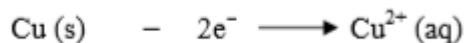
b. Electrolysis of copper aqueous copper (II) sulphate using copper electrodes



- At the cathode, copper is formed and coats the electrode.



- The anode dissolves, giving copper ions.



The copper ions move to the cathode to form copper. The colour of the solution does not fade.

WRITING HALF-EQUATIONS FOR ELECTRODE REACTIONS

To write the correct half-equations for electrode equations, follow the following steps:

- Name the ions present and the products. Write each half-equation correctly.
- Remember, positive ions go to the cathode and negative ions go to the anode.
- Write the correct symbol of the element that forms. For example, Cl₂ (not Cl).

- d. The number of electrons in the equation should be the same as the total charge on the ions in it.

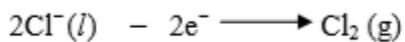
Example

Write the anode and cathode half-equations for the electrolysis of molten magnesium chloride.

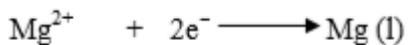
Solution

The ions present in solution are magnesium ions, Mg^{2+} and chloride ions, Cl^- ions.

- At the cathode



- At the anode



USES OF ELECTROLYSIS

1. EXTRACTION OF METALS

Less reactive metals can be extracted from their ores by spontaneous redox reactions. The metal is extracted by dipping the more reactive metal into an aqueous solution of the metal to be extracted. For example, to extract copper (Cu) from its compound, an iron metal can be dipped into the aqueous solution of a compound of copper such as copper (II) sulphate. The reaction between iron and aqueous copper sulphate will be:

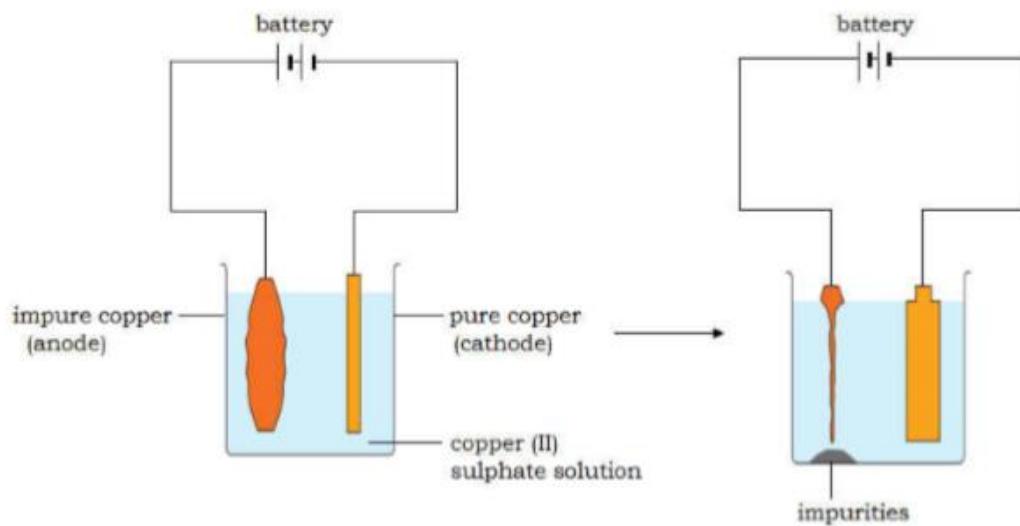


2. PURIFICATION OF METALS

To purify a metal, the mineral ore is dissolved to form an electrolyte and current is passed through it. The metal is extracted as a deposit on the cathode.

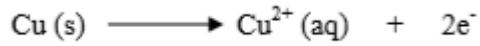
PURIFICATION OF COPPER

The apparatus is connected as shown below.



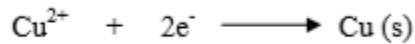
The anode is made of impure copper. The cathode is pure copper. The electrolyte is dilute copper (II) sulphate solution.

The copper in the anode dissolves into the solution. This is oxidation reaction. The half reaction equation at the anode is:



The copper ions are reduced and deposited on the pure copper cathode.

The half reaction equation at the cathode is:



The impurities do not dissolve; they just drop to the bottom of the container.

3. ELECTROPLATING

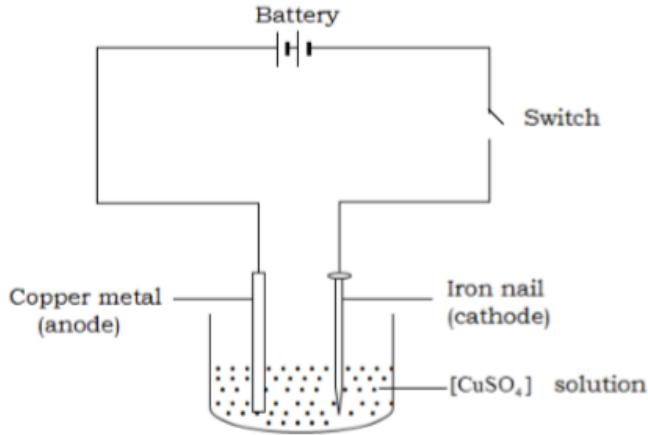
Electroplating is the process of coating a metal with a thin layer of another metal by using electrolysis.

To electroplate a metal, the procedure is as follows.

- First, the metal to be electroplated is thoroughly cleaned.
- An electrolyte whose ions are required to be deposited is selected.
- Direct current (dc) is used instead of alternating current (ac).
- The metal to be electroplated must be made the cathode. Metals for coating must be made the anode so that when they dissolve into the electrolyte, they replace the ions which are being removed from the container.

ELECTROPLATING OF IRON WITH COPPER

The apparatus is set up as shown below:



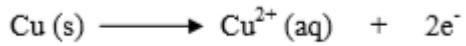
The switch is closed and the experiment is observed for about 10 minutes. Observations are made and recorded.

Observations

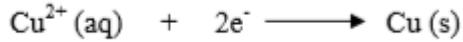
- The iron nail will be coated with copper metal.
- The copper metal in the anode will be eaten up.

Explanation

When the switch is closed, the copper metal in the anode dissolves and is oxidised as follows:



The copper ions (Cu^{2+}) are attracted to the cathode. At the cathode, the copper ions gain electrons and are reduced to copper atoms.



The copper metal coats the iron metal. The iron metal is said to be electroplated.

APPLICATIONS OF ELECTROPLATING AND ITS BENEFITS TO SOCIETY

The process of electroplating is used:

- To make objects look attractive. For example, most necklaces and wristwatches are plated with silver to make them look shiny and beautiful.
- To protect metals from corrosion. For example, steel car bumpers are coated with chromium to protect them from reacting with water.
- To increase the strength or size of the metal. If a metal bar is small, it can be made bigger by adding a layer on it through electroplating.
- To extract and purify metals from ores e.g. copper.

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CHEMISTRY

FORM 4

CHAPTER 5

ISOMERISM

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Compiled By: Stephan S. Kanyenda

ISOMERISM

OBJECTIVES

By the end of this chapter, the student should be able to:

1. define isomers
2. draw the structures of isomers of alkanes, alkenes alkanols, alkanals, alkanones and alkanoic acids
3. describe the effect of branching on physical properties in different organic families

CONTENTS

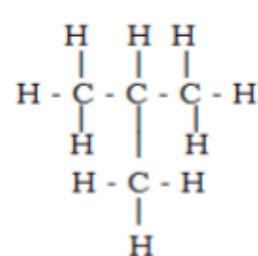
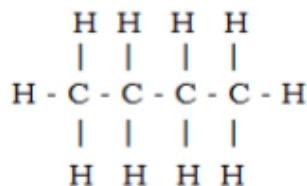
- definition of isomers (compounds with the same molecular formula but different structures)
 - structural and position of functional group isomerism
 - difference between isomers and conformers
- structures and nomenclature of isomers (alkanes, alkenes, alkanols alkanals, alkanones and alkanoic acids)
 - drawing isomers of molecules (of up to five carbon atoms) from the specified families of organic compounds
 - discussing and naming constituent branches of alkanes using IUPAC naming system
 - naming isomers given their structures
- effects of branching on physical properties of organic compounds
 - discussing the polarity of different organic compounds
 - relating the differences in structure of isomers to boiling and melting points and densities

TOPIC 5: ISOMERISM

Isomerism is the existence of compounds with the same molecular formula but different structural formulae.

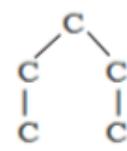
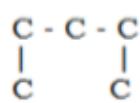
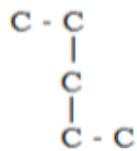
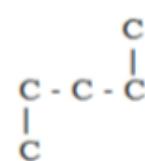
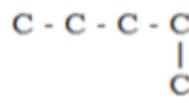
ISOMERS

Isomers are the compounds having the same molecular formula but different structural formulae. Examples are



CONFORMERS

Conformations are compounds that differ from each other by the rotation of a single bond in the molecule.



All the compounds above have the same molecular formulae and same structural formulae, but they have different shapes due to bending, turning, or twisting of the carbon – carbon bonds. Bending, turning or twisting of the C – C bonds in the molecule does not change the structure of the molecule.

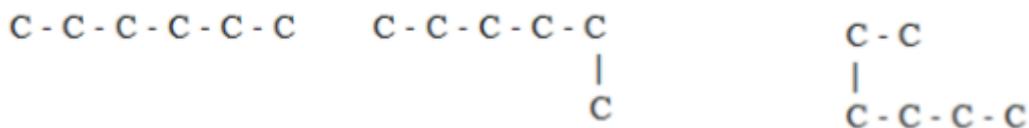
IDENTIFYING ISOMERS OR CONFORMERS

In order to decide whether given structures are isomers or conformation of each other, it is useful to check if there are any branches or junctions in the molecules the molecules have simply been turned, twisted or bent.

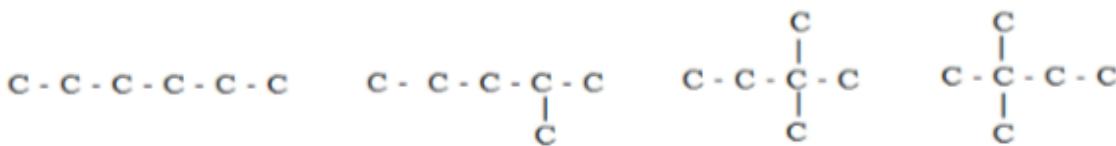
To do this properly, the following steps may assist.

- Working out the carbon skeleton first. The carbon skeleton enables us to see important point about the structure of the molecule.
- Choosing and numbering the longest chain of carbon atoms in the molecule. This chain acts like a reference line inside the molecule. It is called the parent chain. The parent chain allows us to locate accurately the number and position of the junctions in a molecule.
- Naming the compounds. Isomers have the same molecular formulae but different names while conformations have the same molecular formulae and names.

For example, the following carbon structures represent conformations, because there are no junctions in the molecules.



All of the conformations above have the same name: normal hexane (n – hexane).



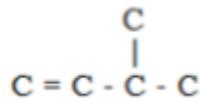
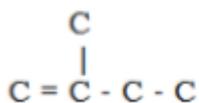
The above compounds will have different names because they have different structural formulae even though they have the same molecular.

TYPES OF STRUCTURAL ISOMERISM

There two types of structural isomerism; chain and position isomerism.

a. Chain isomerism

This is the isomerism due to the differences in the way the carbon atoms are connected to each other in the molecule. For example



b. Position isomerism

This is the isomerism due to the difference in the position of a functional group in the molecule. For example



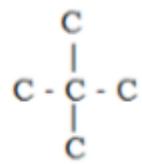
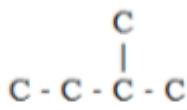
NAMING ISOMERS

Isomers are named systematically. The rules for naming the isomers of compounds vary from one homologous series depending on whether the compounds in the series show chain isomerism or position isomerism or both.

RULES FOR NAMING ISOMERS OF ALKANES

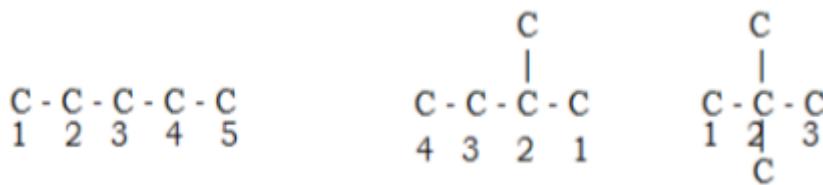
Alkanes do not have a functional group, so they only show chain isomerism. The rules for naming the isomers of alkanes are as follows:

- Write down the carbon skeleton for each molecule. Using C_5H_{12} , the carbon skeletons are:

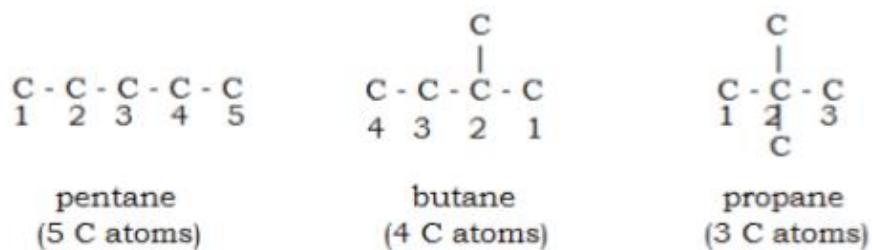


- Number the parent chain in the carbon skeleton. Numbering starts the end of the parent chain nearest the first branch.

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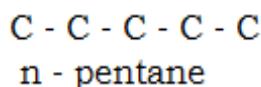
- c. Count up all the carbon in the parent chain and use the number to give a basic name to the compound.



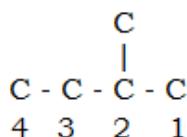
- d. Name the group that is attached to the parent chain. This group is called an alkyl group.

Alkyl group	Name of the alkyl group
CH_3-	Methyl
CH_2CH_3	Ethyl
$\text{CH}_2\text{CH}_2\text{CH}_3$	Propyl
$\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	Butyl

For straight chain single bonded carbon – carbon isomers, there is no branched group. Such isomers start with the prefix 'n-' which stands for normal.

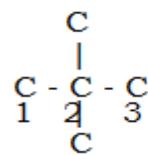


- e. State the positions of the carbon atom on the parent chain where the branch (es) is/are occurring and give a final name to the compound. The number is written before the alkyl name. For example



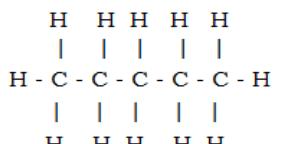
2 - methyl butane

If more than one alkyl group is attached to the parent chain, the numbers indicating the positions of the branches are also written before the alkyl group. The numbers of the alkyl groups having the same number of carbon atoms are indicated by prefixes di-, tri-, or tetra- to mean two, three or four respectively. For example

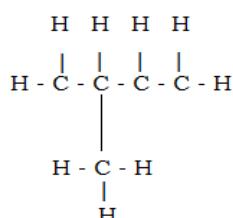


2, 2 - dimethyl propane

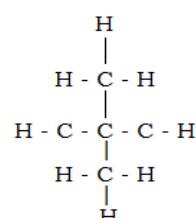
- e. Name the compound fully.



n-pentane



2 - methyl butane



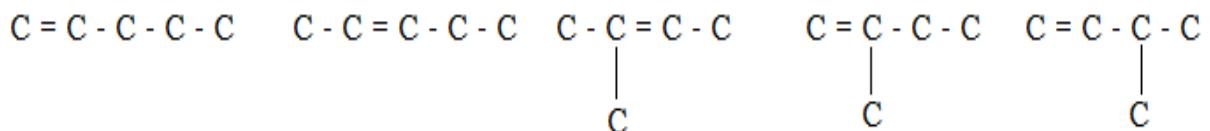
2, 2 - dimethyl propane

RULES FOR NAMING ISOMERS OF ALKENES

Alkenes show both chain and position isomerism due to the presence of the functional group, the carbon – carbon double bond in their structures. The procedure for naming isomers of alkenes is as follows:

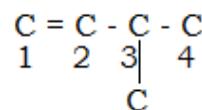
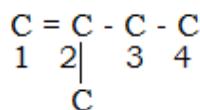
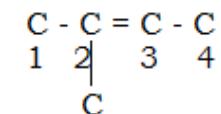
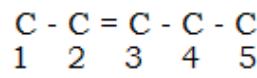
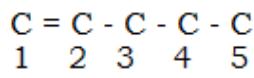
- Write the carbon skeleton using the number of carbon atoms given in the molecular formula. Place the functional group and branches in correct positions.

Let us consider the compound whose molecular formula is C₅H₁₀.

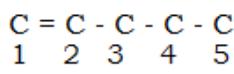


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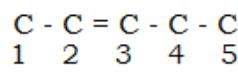
- b. Choose the parent chain and number it. Numbering starts at the end of the parent chain nearest the functional group.



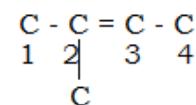
- c. Count up the number of carbon atoms in the parent chain and give a basic name to the compound.



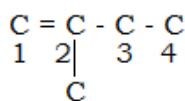
Pentene (5 C atoms)



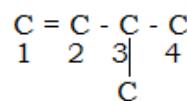
Pentene (5 C atoms)



Butene (4 C atoms)



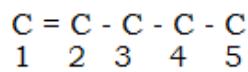
Butene (4 C atoms)



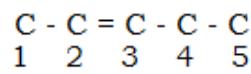
Butene (4 C atoms)

- d. Show the position of the functional group by the lowest number of the carbon atom holding the functional group. Put it before –ene. For example, pent-1-ene or hex-2-ene.

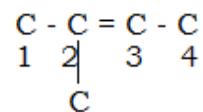
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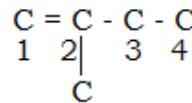
Pent - 1 - ene



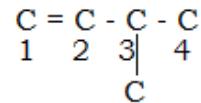
Pent - 2 - ene



But - 2 - ene

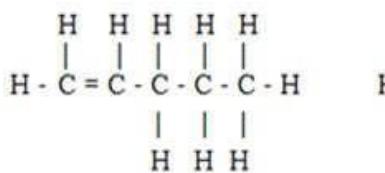


But - 1 - ene

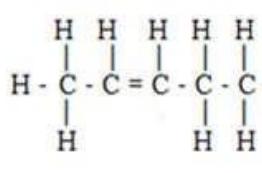


But - 1 - ene

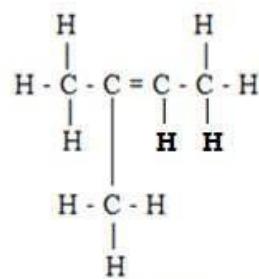
- e. State the position and type of the alkyl group attached. Name the compound fully.



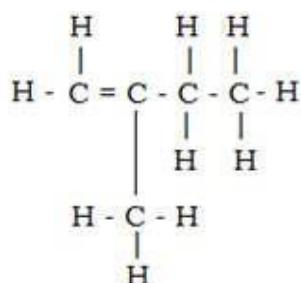
Pent - 1 - ene



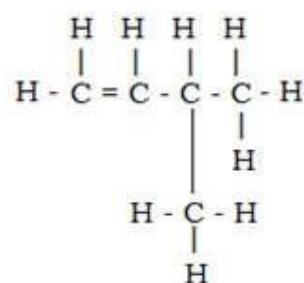
Pent - 2 - ene



2 - methyl but - 2 - ene



2 - methyl but - 1 - ene



3 - methyl but - 1 - ene

RULES FOR NAMING ISOMERS OF ALKANOLS

Alkanols contain the $-OH$ functional group. For this reason, alkanols, just like the alkenes, show both chain and position isomerism.

The rules for naming isomers of alkanols are as follows:

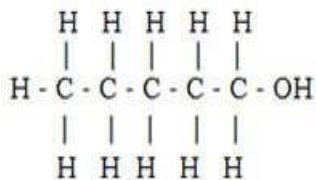
- Draw a straight chain carbon skeleton using the number of carbon atoms and give its name.
- Place the functional group and branches in correct positions.
- Number the parent chain. It is numbered in such a way that the carbon atom to which the

–OH group is attached has the lowest number.

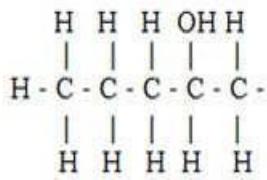
- d. Indicate the position of the functional group using the number of the carbon atom to which the –OH group is attached. Put it before – ol. For example butan-2-ol.

Example

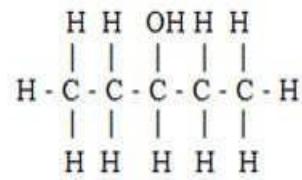
Write down and name all the isomers of the pentanol ($C_5H_{11}OH$).



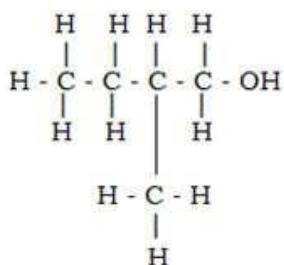
Pentan -1- ol



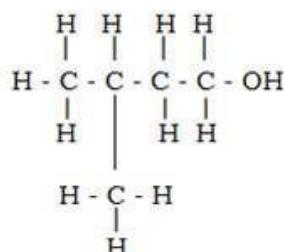
Pentan -2- ol



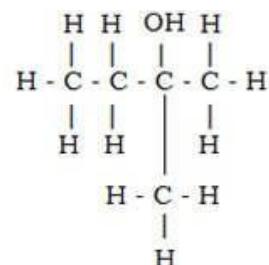
Pentan -3- ol



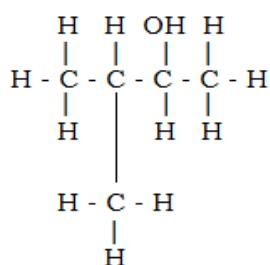
2 - methyl butan -1- ol



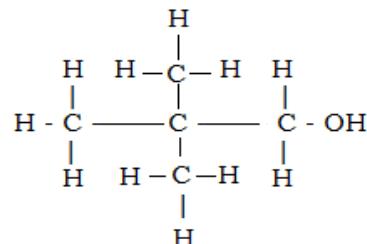
3 - methyl butan -1- ol



2 - methyl butan -2- ol



3 - methyl butan -2- ol



2, 2 - dimethyl propan -1- ol

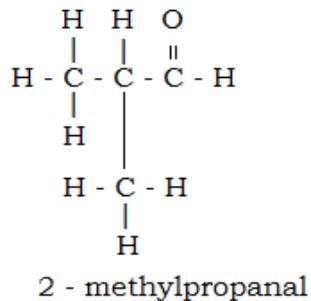
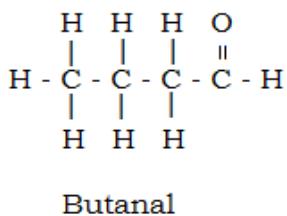
RULES FOR NAMING ISOMERS OF ALKANALS

Alkanals are compounds with a functional group called the carbonyl group, **-CO**. Alkanals only exhibit chain isomerism. They do not show position isomerism because their functional group is always placed at the end of the alkanal molecule.

Example 1:

Write down all the structural isomers of butanal ($\text{C}_3\text{H}_7\text{CHO}$)

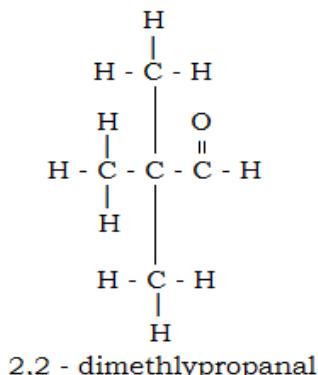
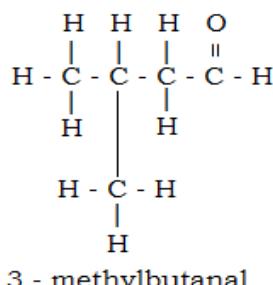
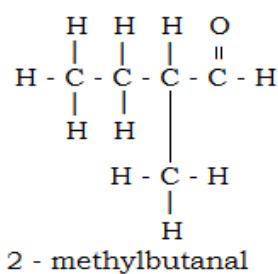
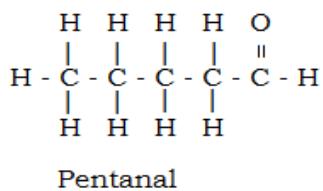
Solution



Example 2:

Write down and name all the structural isomers of pentanal ($\text{C}_4\text{H}_9\text{CHO}$) .

Solution:



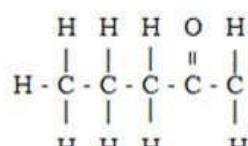
RULES FOR NAMING ISOMERS OF ALKANONES

Alkanones have a functional group similar to that of alkanals, the carboxyl group, **-CO**. Alkanones exhibit both chain and position isomerism. This is because the carboxyl group in alkanones can be shifted to different positions in the molecule.

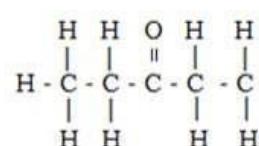
The position of the functional group is indicated by the number of the carbon atom in the carboxyl group. It is put before **-one**. For example, butan-2-one, pentan-3-one, etc.

Example:

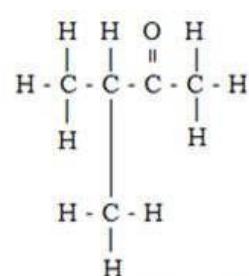
Write down and name all the structural isomers of pentanone ($C_5H_{10}O$).

Solution:

Pentan-2-one



Pentan-3-one



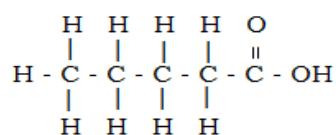
3-methylbutan-2-one

RULES FOR NAMING ISOMERS OF ALKANOIC ACIDS

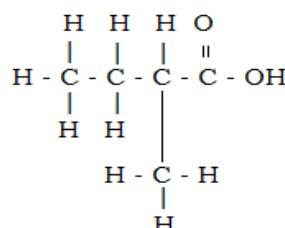
Alkanoic acids are organic compounds whose functional group is the carboxyl group, —COOH . Alkanoic acids only exhibit chain isomerism.

Example 1

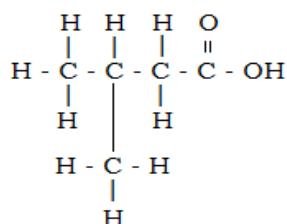
Write down and name all the structural isomers of pentanoic acid (C_4H_9COOH). Solution:



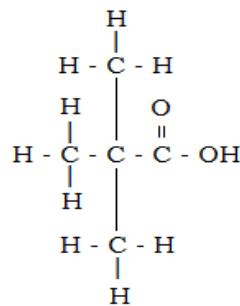
Pentanoic acid



2-methylbutanoic acid



3-methylbutanoic acid



2,2-dimethylpropanoic acid

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CHAPTER 6

POLYMERISATION

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Compiled By: Stephan S. Kanyenda

POLYMERISATION

OBJECTIVES

By the end of this chapter, the student should be able to:

1. define a polymer
2. state types of polymerisation
3. describe properties and uses of synthetic polymers
4. explain the difference between thermosoftening and thermosetting plastics

CONTENTS

- definition of polymers
 - defining the terms *monomers* and *polymers*
 - listing examples of
 - natural polymers such as proteins, DNA and carbohydrates
 - synthetic polymers such as PVC, nylon and terlyene
- types of polymers
- types of polymerisation
 - discussing addition and condensation polymerisation
 - listing examples of addition and condensation polymerisation
- properties and uses of polymers
 - discussing properties of synthetic polymers
 - discussing the uses of synthetic polymers
- thermosoftening and thermosetting plastics
 - discussing the differences between thermosoftening and thermosetting plastics
 - investigating differences between thermosoftening and thermosetting plastics
- ways of moulding plastics

POLYMERISATION

Polymerisation is a chemical reaction in which small molecules join together to form long chain molecules called polymers.

Polymers are long-chain molecules made by joining many small molecules called monomers. **Monomers are** the small molecules which join together to form polymers.

TYPES OF POLYMERS

There are two types of polymers: natural polymers and synthetic polymers.

a. Natural polymers

These are polymers found in all living things. Examples of natural polymers are proteins, carbohydrates, starch, wood, rubber and deoxyribonucleic acid (DNA).

b. Synthetic polymers

Synthetic polymers are manufactured in industries. They are normally called plastics.

Examples of synthetic polymers are: Polythene, Polyvinylchloride (PVC), Terylene, Nylon, Perspex (artificial glass), Polytetraflouoroethene (PTFE) or Teflon and Polyphenylethene (Polystyrene).

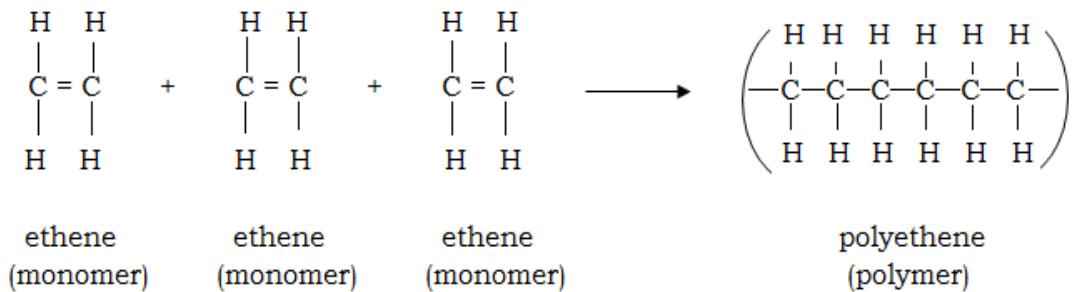
TYPES OF POLYMERISATION

a. Additional polymerisation

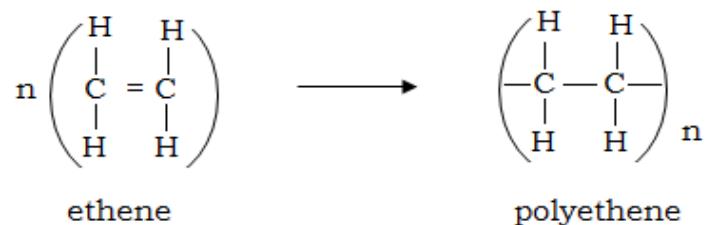
This is a process which involves repeated addition reactions of monomers of the same type. The monomers used in addition polymerisation are unsaturated compounds, for example ethene or derivatives of alkenes e.g. chloroethene.

Examples of additional polymerisation are:

- The polymerisation of ethene

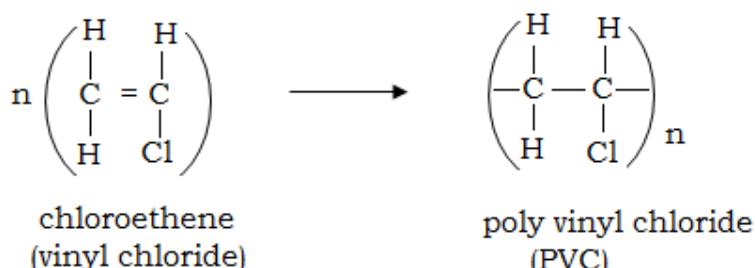
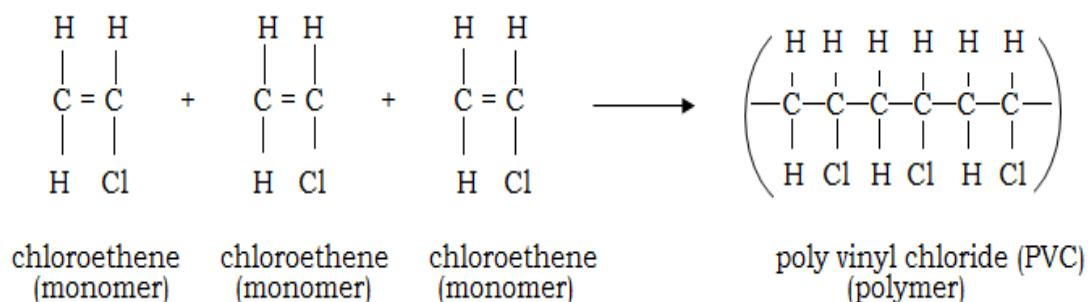


If n molecules of ethene combine, the process may be written as follows:



HOW THE POLYMERISATION OF ETHENE OCCURS

During the polymerisation of ethene, ethene undergoes relatively high temperature and high pressure in the presence of a catalyst. The double bonds between the carbon atoms are broken, enabling many molecules of ethene to join to each other to form polyethene.



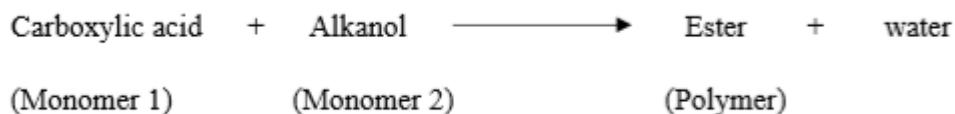
b. Condensation polymerisation

This is a reaction whereby a small molecule is eliminated between two different monomers.

During condensation polymerisation:

- Two different monomers join.
- The monomers join by releasing small molecules e.g. water or hydrogen chloride

The best example of condensation polymerisation is the **esterification reaction**.



Examples of condensation polymers are: Nylon, Terylene (polyester), etc

PROPERTIES OF SYNTHETIC POLYMERS

Different polymers have unique characteristics. However, most of them will have the following characteristics.

- They do not corrode in air or water.
- They are excellent heat insulators.
- They are excellent electrical insulators.
- They do not decompose easily.
- They are relatively light.
- Some are transparent

USES OF SYNTHETIC POLYMERS

Polymer	Monomer	Uses
Polyethene	Ethene	Used in making: <ul style="list-style-type: none"> • pipes and plastic bags • bowls and bottles • packaging material • insulation for electrical wiring
Polyvinylchloride (PVC)	Chloroethene	Used in making: <ul style="list-style-type: none"> • crates and bottles • plastic ropes • artificial leather • water pipes • insulation for electrical
Polystyrene	Styrene	Used in making: <ul style="list-style-type: none"> • insulation material
		<ul style="list-style-type: none"> • packaging (foam) • radio cabinets
Polytetraflouroethene (PTFE) or Teflon	Tetraflouroethene	Used in making: <ul style="list-style-type: none"> • soles of iron • non-stick frying pans

Perspex		<ul style="list-style-type: none">• used as a glass substitute• used in lenses
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ADVANTAGES OF SYNTHETIC POLYMERS

- They are cheap to produce.
- They are resistant to corrosion from acids, alkalis, water and air.
- They are light and therefore portable.
- They are soft and easy to manufacture.
- They can be moulded into complicated shapes more easily.
- They are good heat insulators.
- They are good electrical insulators.

DISADVANTAGES OF SYNTHETIC POLYMERS

- They are non-biodegradable hence difficult to dispose.
- Some give off toxic gases such as carbon mono oxide when they burn.
- They are expensive to recycle.
- Some catch fire easily.

TYPES OF PLASTICS

There are two types of plastics: thermoplastics and thermosetting plastics.

a. Thermoplastics (Thermosoftening plastics)

These are plastics that soften when heated and harden into a new shape when cooled. This is because the intermolecular forces are weak and there are no cross-links or branches between the polymer chains.



Examples of thermoplastics are polythene, PVC, polystyrene, etc.

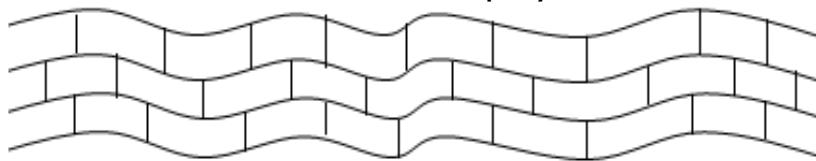
PROPERTIES OF THERMOPLASTICS

- They are flexible. For this reason they do not break easily.
- Their polymer chains are not cross-linked. They can be moulded into different shapes several times.
- They have low melting points. This is because they have weak intermolecular forces between the polymer chains.
- They can easily be recycled.

b. Thermosetting Plastics (Thermosets)

These are plastics which set hard and cannot be melted again once they are made.

This is because the polymers chains are held more strongly due to the presence of cross links between the polymer chains.



Examples of thermosetting plastics are melamine, Formica, Bakelite, among others.

PROPERTIES OF THERMOSETTING PLASTICS

- They are rigid. For this reason, they break rather than stretch under tension.
- Their polymer chains are cross-linked. Therefore, they cannot be moulded into new shapes after they are made.
- They do not melt, but decompose on heating.

- They cannot be recycled.

DIFFERENCE BETWEEN THERMOPLASTICS AND THERMOSETTING PLASTICS

Thermoplastics	Thermosets
They soften and melt when heated	They do not soften on heating
They can be re-moulded into new shape	They cannot be re-moulded into new shape
They have no cross-links between polymer	They have cross-links between polymer
They can be recycled	They cannot be recycled

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CHAPTER 7

WATER

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Compiled By: Stephan S. Kanyenda

WATER

OBJECTIVES

By the end of this chapter, the student should be able to:

1. identify natural sources of water
2. explain the water cycle
3. describe the physical properties of water
4. explain the importance of water
5. describe water hardness and its effects
6. describe methods used to remove water hardness
7. describe sources, effects and prevention of water pollution

CONTENTS

- Natural sources
 - natural sources of water
 - different natural sources of water (underground, surface and atmospheric)
- Water cycle
 - discussing the water cycle
 - drawing the water cycle
- Physical properties of water
 - boiling point
 - density
 - surface tension
- Importance of water
 - reactant
 - coolant
 - solvent
- Hard and soft water
 - meaning of hard and soft water
 - investigating the hardness and softness of water using soap
 - describing the process that results in hard water and naming salts that cause hard water
 - discussing the difference between temporary and permanent hardness of water
 - discussing the effects of water hardness
 - methods used to remove water hardness
 - discussing physical and chemical processes of softening hard water
 - conducting experiments on moving water hardness
- Water pollutants
 - defining water pollution
 - discussing the sources of water pollution; domestic, industrial and agricultural wastes
- Dangers of polluted water
 - Effects of water pollution



- prevention of water pollution
- international and national standards on water quality

TOPIC 7: WATER

NATURAL SOURCES OF WATER

The major natural sources of water can be classified into underground, surface and atmospheric water sources.

1. Underground water sources

These are sources of water found in water tables. They include:

- a. **Wells.** These are holes dug in the ground in order to obtain water.
- b. **Boreholes.** These are deep holes drilled in the ground using machines. They lift water using submersible pumps.
- c. **Springs of water.** These are sources of water that flow out of the ground as small streams or pools.

2. Surface water sources

Examples of surface water sources include dams, lakes, streams, rivers, seas and oceans.

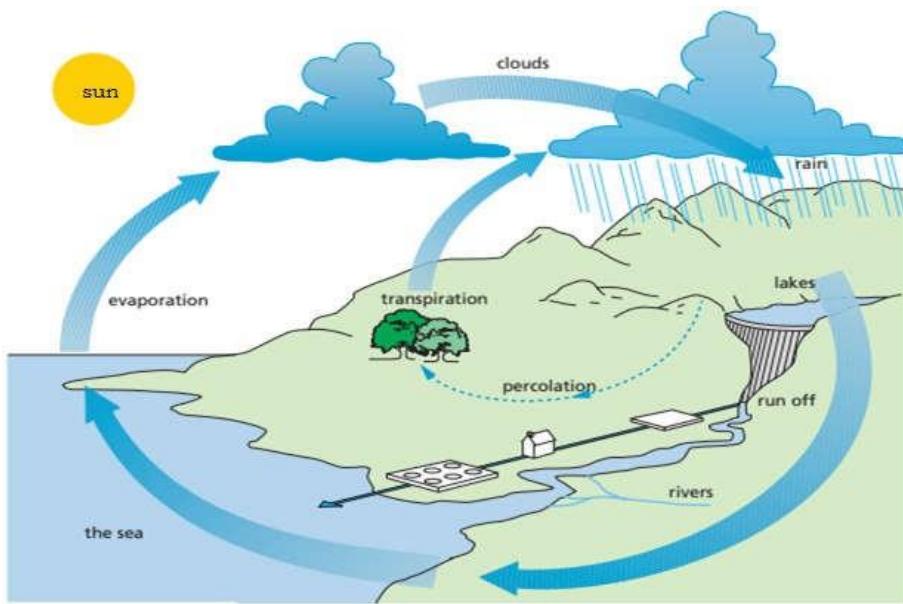
3. Atmospheric water sources

These sources include rainwater collected from rooftops during rainy season.

THE WATER CYCLE

The water cycle is also called the hydrological **cycle**. It describes how water circulates continuously between the earth's surface and the atmosphere.

- Heat from the sun causes evaporation from oceans, seas and lakes. It also causes transpiration. Both evaporation and transpiration cause water vapour to form.
- The water vapour rises, cools and condenses to form tiny droplets of water. These droplets form clouds.
- The clouds are moved by air currents. As they cool, the tiny droplets form larger droplets which fall as rain when they reach a certain size.
- The water that falls as rain runs into streams and rivers and then into lakes, seas and oceans.



PHYSICAL PROPERTIES OF WATER

- Pure water is a colourless, tasteless and odourless liquid.

- It boils at 100°C and freezes at 0°C.
- It has a density of 1g/cm³.

IMPORTANCE OF WATER

Water is used:

- a. as a **coolant**. In car engines it is used to maintain low temperature while in simple distillation it facilitates liquefaction process.
- b. as a **solvent**. It is considered as universal solvent because it dissolves many things.
- c. as a **chemical reactant**. It is used in many chemical reactions which occur in aqueous media.
- d. in hydroelectric power generation. Moving water is used to generate electricity.
- e. for **recreational purposes** such as in swimming pools.
- f. as a **transport medium** for ships, ferries, boats and canoes when transporting people and goods.

HARD AND SOFT WATER

Soft water is the water that contains low mineral content and produces soapy bubbles easily. Examples of soft water are rainwater and distilled water. **Hard water** is the water that has a high mineral content and does not produce soapy bubbles easily. An example of hard water is tap water.

TYPES OF WATER HARDNESS

a. Temporary hardness

Temporary hardness is caused by the presence of dissolved calcium or magnesium hydrogen carbonates. Temporary hardness can easily be removed by boiling.

b. Permanent hardness

Temporary hardness is caused by the presence of calcium or magnesium sulphates. Permanent hardness is difficult to remove and cannot be removed by boiling. It can be removed by distillation or chemical treatment.

ADVANTAGES OF HARD WATER

- Calcium ions present in hard water are required by the body for bones and teeth.
- Coats lead pipes with a thin layer of lead sulphate or lead carbonate and prevents the lead from dissolving in water.
- It is good for the formation of shells in animals.
- Calcium and magnesium present in hard water are necessary for growth of both plants and animals.

DISADVANTAGES OF HARD WATER

- It wastes soap due to scum formation.
- Causes electrical appliances such as kettles and boilers to fail hence making them inefficient.
- Can cause hot water pipes to block.
- Spoils the finish of some fabrics.

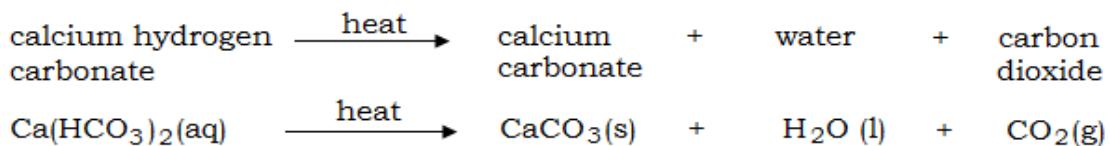
METHODS OF REMOVING WATER HARDNESS

Removal of water hardness is based on whether the hardness is temporary or permanent. The method and can be physical or chemical.

1. REMOVING TEMPORARY HARDNESS

a. Boiling

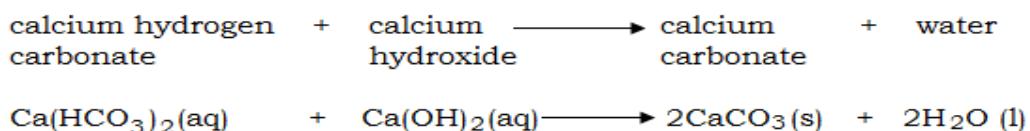
When heated the hydrogen carbonates decompose to form insoluble carbonates. For example



b. Addition of calcium hydroxide or sodium hydroxide

Addition of calcium or sodium hydroxide to water causes precipitation of calcium and magnesium ions in form of carbonates.

For example



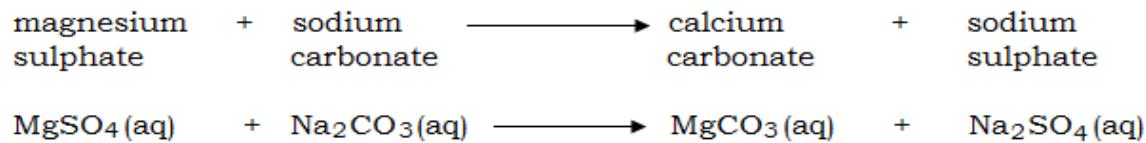
2. REMOVING PERMANENT HARDNESS

a. Distillation

The water is distilled away from the dissolved substances. This method is expensive to be used on a large scale.

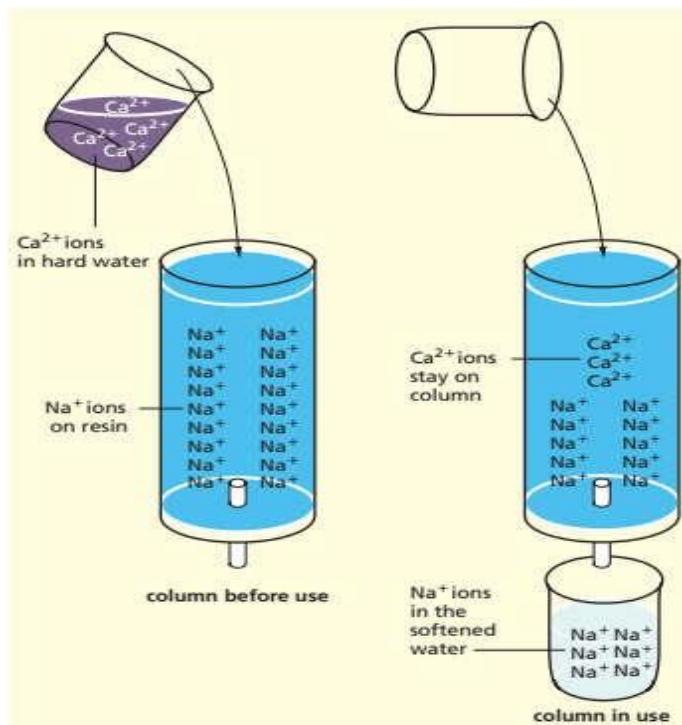
b. Addition of sodium carbonate (soda)

Calcium and magnesium ions are removed as precipitates. For example



c. Ion exchange

The hard water is passed through a container filled with suitable **resin** containing sodium ions. The calcium or magnesium ions causing water hardness are exchanged for the sodium ions in the resin. Sodium ions do not cause water harness.



Sodium ions become part of the softened water and the calcium or magnesium ions become part of the resin.

WATER POLLUTION

It is defined as the addition of harmful substances into water as result of human activities. The harmful substances include toxic metals, plastics, pesticides, and fertilizers.

SOURCES OF WATER POLLUTION

a. Domestic sources.

This involves the release of human faeces and sewage into water bodies such as lakes and rivers.

b. Industrial wastes

These include effluents (liquid wastes) originate from breweries, tanneries, textiles and paper industries. The effluents contain toxic chemicals.

c. Agricultural wastes

These include excessive pesticides, herbicides, weedicides, and fertilizers. These may enter into rivers and lakes through run off after rains.

EFFECTS OF WATER POLLUTION

- It can cause diseases such as cholera, typhoid and hepatitis.
- It leads to destruction of ecosystems.

- It can severely affect aquatic life by decreasing amount of oxygen in water bodies.
- It can cause disruptions in food chains. This happens when toxins and pollutants in the water are consumed by aquatic animals which are then consumed by humans.

WAYS OF CONTROLLING WATER POLLUTION

- Avoiding excessive use of chemicals.
- Treatment of sewage before releasing it into water bodies. It ensures that the pollutants and disease-causing micro-organisms are destroyed.
- Encouraging farmers to use farmyard manure instead of chemical fertilizers.
- Constructing pit latrines away from water sources such as wells to avoid contamination of the water source. The slope of the land should also be considered in putting up a latrine.
- Proper legislation should be put by government to reduce improper dumping of industrial and domestic wastes.
- Petroleum companies should put measures in place to avoid unnecessary accidents resulting from spillage of oils into water bodies.

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CHAPTER 8

GREENHOUSE GASES AND THE OZONE LAYER

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GREENHOUSE GASES AND THE OZONE LAYER

OBJECTIVES

By the end of this chapter, the student should be able to:

1. explain the effects of natural disasters and human activities on the atmosphere
2. explain the effects greenhouse gases
3. describe ways of mitigating the effects of global warming
4. describe the importance of ozone layer
5. explain the depletion of ozone layer and its associated problems

CONTENTS

- Natural disasters
 - Volcanoes
 - Bushfires
 - Effects of extensive burning of organic fuels and deforestation
 - Effects of using CFCs
- Greenhouse gases
 - meaning of greenhouse gases
 - greenhouse gases and their sources
 - Effects greenhouse gases
 - contribution of carbon dioxide and methane to global warming
 - mitigating the effects of global warming
 - Ways of mitigating global warming
 - Role of disaster risk management institutions in mitigating the effects of global warming
- Ozone layer
 - The position of ozone layer in the atmosphere
 - importance of ozone layer
 - depletion of ozone layer and its associated problems
 - depletion of ozone layer by action of chlorofluorocarbons (CFCs)
 - problems associated with depletion of ozone layer
- Standards on air quality
 - Standards on air quality

NATURAL DISASTERS

Natural disasters are extreme, sudden events caused by environmental factors that injure people and damage property. Examples of natural disasters are drought, windstorm, earthquake, wild fires, floods, hurricanes, thunderstorms and volcanic eruptions.

IMPACT OF HUMAN ACTIVITIES ON NATURAL DISASTERS

Human activities can have an impact on natural disasters through floods following these activities;

- **Deforestation.** Hard surfaces such as sewers, parking lots, and concrete surfaces causes water to move faster as compared to natural channels. Cutting down natural vegetation and trees leaves land bare resulting in more erosion when water flows.
- **Urban development.** Urban development has an impact on natural disasters. It destructs the natural system of waterways.
- **Natural wetlands destruction.** The destruction of natural wetlands causes devastating floods during peak floods along river basins. More natural wetlands lower water level during heavy rains.
- **Agriculture.** Large scale practice of agriculture can result in the depletion of top soils causing weakening of vegetation and inability to protect against flooding.

EFFECTS OF NATURAL AND HUMAN ACTIVITIES ON THE ATMOSPHERE

- Destruction of buildings

- Death of animals and human beings
- Change in landscape
- Damage of vegetation
- Global warming due to production of harmful gases

GREENHOUSE GASES

Greenhouse gases are components of air whose accumulation in the atmosphere cause rise in global temperatures. Examples of greenhouse gases are carbon dioxide, sulphur dioxide, nitrogen oxides, and methane.

SOURCES OF GREENHOUSE GASES

Greenhouse gas	Sources
Carbon dioxide (CO ₂)	<ul style="list-style-type: none">▪ Combustion▪ Respiration▪ Fermentation▪ Decomposition
Methane (CH ₄)	<ul style="list-style-type: none">▪ It is the primary component of natural gas.▪ Wetlands▪ Oceans▪ Activities of termites
Nitrogen oxides (NO, NO ₂)	<ul style="list-style-type: none">▪ Natural processes e.g. Lightning and biological processes that occur in plants and animals.▪ Combustion of fossil fuels in car engines and in industries.
Sulphur dioxide (SO ₂)	Sources include fossil fuels combustion at power plants and extraction of metal ores

GLOBAL WARMING

Global warming is the continued rise in the average temperature of the earth due to the accumulative effect of the greenhouse gases in the atmosphere.

HOW DO GREENHOUSES CAUSE GLOBAL WARMING?

- The sun sends out energy as light and ultraviolet (UV) rays.
- These warm the earth, which reflect some of the energy away again, as heat.
- Some of this heat escapes from the atmosphere. However, some of reflected heat energy is absorbed by greenhouse gases in the atmosphere. So, the air and the earth are warmed.

CONTRIBUTION OF CARBON DIOXIDE AND METHANE TO GLOBAL WARMING

Two main greenhouse gases believed to be responsible for global warming are carbon dioxide and methane. The levels of both gases are rising.

- The level of carbon dioxide is rising because we burn more fossil fuels each year. The carbon dioxide from this goes into the atmosphere.
- The level of methane is increasing because there is an increase in animal farming and rice farming around the world, and more landfill sites.

WAYS OF MITIGATING EFFECTS OF GLOBAL WARMING

- Use of renewable sources of energy such as solar energy, wind power, and hydroelectric power.
- Automobiles can be fitted with catalytic converters to clean up exhaust gases before they are released into the atmosphere.
- Afforestation and deforestation in order to reduce the carbon dioxide levels in the atmosphere.

AIR QUALITY STANDARDS

Internationally there are standards of air quality which limit emissions of gases. The air quality standards being used currently are based on the World Health Organisation (WHO.) In line with the WHO guidelines, the Malawi government through the Malawi Bureau of standards (MBS) published guidelines on maximum allowable emissions of both gases and particulate pollutant.

The table below shows ambient air quality standard limits in Malawi.

Pollutant	Maximum concentration in ambient	Averaging period
Suspended particulate matter	25 $\mu\text{g}/\text{m}^3$	1 day
Carbon dioxide	9 ppm	8 hours
	35 ppm	1 hour
Sulphur dioxide	0.20 ppm	1 hour
	0.08 ppm	1 day
	0.02 ppm	1 year

Nitrogen dioxide	0.3 ppm	1 year
Ozone	0.12 ppm	1 hour
Lead	0.50 $\mu\text{g}/\text{m}^3$	1 year
Photochemical oxidants	0.10 ppm	1 hour
	0.08	4 hours

The table below shows air quality standard for motor vehicles in Malawi.

Pollutant	Maximum allowable	Duration	Typical high concentration for
Hydrocarbons	160 $\mu\text{g}/\text{m}^3$	3 hours	6
Carbon monoxide	10 $\mu\text{g}/\text{m}^3$	8 hours	40

Nitrogen dioxide	100µg/m³	1 year	0.1
Oxidants	160µg/m³	1 hour	0.6

ppm means parts per million

µg/m³ means concentration in micrograms per unit volume

THE OZONE LAYER

The ozone refers to a region of the earth's stratosphere that absorbs most the sun's ultraviolet radiation. It is mainly found in the lower parts of the stratosphere from approximately 20km to 30km above the earth.

IMPORTANCE OF THE OZONE LAYER

The ozone layer acts as a natural ultraviolet (UV) rays shield for the earth. It absorbs 93% to 99% of the sun's ultraviolet light. The UV light is very dangerous to life on earth. Exposure to UV rays may cause:

- Skin cancer
- Damage to crops
- Harm to aquatic life

DEPLETION OF THE OZONE LAYER

The ozone layer is destroyed by chlorofluorocarbons (CFCs). Things that release CFCs include coolants, foams and aerosols. When CFCs get to atmosphere, the chlorine atom is released from the CFC molecule. The released chlorine atom splits the ozone to oxygen atoms and oxygen molecules. The free oxygen atom then combines with ozone molecule to form another oxygen molecule.

For example

- $O_3(g) \longrightarrow O_2(g) + [O]$
- $O_3(g) + [O] \longrightarrow 2O_2(g)$

The action of the CFCs results in the depletion of the ozone layer and reduces its UV natural shielding capacity.

PROBLEMS ASSOCIATED WITH THE DEPLETION OF THE OZONE LAYER

Exposure to UV rays has several health related and environmental effects. Some of them are:

- Increased risk for developing several types of skin cancer.
- Cataract problems
- Damage to immune system.
- Aging of the skin. This results in a person looking older than what they actually are.
- Respiratory problems such as difficulty in breathing, chest pain, and throat irritation.
- Leads to the decline of some amphibians by affecting every stage of their life cycle.
- Causes disruptions in the food chain and the oceanic and carbon cycle.
- It alters physiological and developmental processes of the plants.

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CHAPTER 9

WASTE MANAGEMENT

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WASTE MANAGEMENT

OBJECTIVES

By the end of this chapter, the student should be able to:

1. Classify different types of wastes
2. state major sources of wastes
3. describe environmentally friendly ways of treating and disposing wastes
4. state ways of minimising wastes
5. describe the social and economic importance of recycling metals and plastics

CONTENTS

- Types of wastes - classify waste according to
 - physical state
 - degradability
- Major sources of wastes
 - domestic
 - industrial
 - agricultural
 - medical
 - laboratory
- The physical and chemical characterisation of wastes
- treatment and disposal of wastes
 - ways of treating wastes
 - physical
 - chemical
 - biological
 - thermal eg incineration
 - ways of waste disposal
 - landfills
 - damp-site
 - advantages and disadvantages of the different ways of waste treatment and disposal such as landfills, incineration and recycling
- minimization of wastes
 - ways of waste minimization such as reusing, recycling and reduction at source
- social and economic importance of recycling wastes
 - explaining the process of recycling metals and plastics
 - discussing the benefits of recycling metals and plastics

WASTE

Waste refers to unwanted materials produced by human activities.

CLASSIFICATION OF WASTES

Wastes can be classified based on different criteria; physical state and degradability.

1. Classification based on physical state

Based on physical state, wastes can be classified as solid wastes, liquids wastes, gaseous wastes and sludge wastes

2. Classification based on degradability

Based on degradability, wastes can be classified as:

- **Biodegradable wastes.** These are wastes that can decay relatively quickly as a result of the action of bacteria. They include animal and plant waste.
- **Non-biodegradable wastes.** These are wastes that do not decompose naturally. Examples include plastics and glass.

SOURCES OF WASTES

- a. **Domestic sources:** These wastes include food leftovers, plastics, metals, untreated sewage, expired or unused medicines and their containers.
- b. **Industrial sources:** These include used oil, toxic gases, metals and plastics etc.

- c. **Agricultural sources:** These include plant remains excess agricultural chemicals such as pesticides, herbicides, and weedicides.
- d. **Medical sources:** These are wastes from medical centres and hospitals. Examples are plastics, glassware, expired drugs, used syringes, needles, cotton and detergents.
- e. **Laboratory sources:** These include expired chemicals, contaminated chemicals, broken glassware and detergents.

WAYS OF TREATING AND DISPOSING WASTE

a. Open burning

Wastes such as papers, plastics are usually burnt to ashes in open land. This method is discouraged because it causes air pollution due to emission of harmful greenhouse gases.

b. Incineration

This approach involves combustion of waste material. The refuse is burn to ashes in controlled chambers called incinerators. Incineration quickly reduces waste volume, reduces transportation costs and decreases emissions of harmful greenhouse gases.

c. Dump site

This is an open disposal site where wastes are deposited and left uncovered and uncontrolled. It is not good for the environment as it is likely to cause air and water pollution.

d. Sanitary landfills

These are land disposal sites used to bury solid waste. The solid waste is spread in thin layers compacted and covered with a fresh layer of soil such as clay. It is also characterized by the absence of surface water bodies or low water table, preventing the risk of water pollution.

e. Composting

This is the controlled aerobic decomposition of organic waste materials by the action of small bacteria. The waste is dumped into a dug pit so that it decomposes. After it has decomposed, it can be used by farmers as manure.

f. Recycling or re-use

Recycling involves reprocessing of materials that would be considered waste. For, most plastics and paper can be recycled instead of burning them.

Advantages of recycling materials

- It reduces pollution.
- It reduces the cost of producing new products.

Re-using on the other hand involves using a material considered waste for another purpose that was not initially intended for.

For example, instead of dumping used bottles and cans, we can use them for storing water in our homes.

WAYS OF MINIMIZING WASTES

Waste can be minimized by three main ways. These are:

- Recycling
- Reusing
- Reduction at source

RECYCLING OF METALS AND PLASTICS

Recycling of most materials including metals and plastics proceed as follows:

- a. *Collection* – getting the recyclable plastics from different waste disposal sites.
- b. *Sorting* – the plastics are sorted out in terms of type, colour, even how it was made.
- c. *Cleaning* – the goal is to remove impurities and everything that is not recyclable.
- d. *Resizing* – it consists of shredding the material into small particles, making it easier to process, reshape.
- e. *Identification* – the small particles are tested to determine their quality and class.
- f. *Compounding* – it involves smashing and melting the material pellets. The pellets can then be used in the production of other products.

IMPORTANCE OF RECYCLING METALS AND PLASTICS

- It preserves natural resources. It prevents depletion of the metals and materials used to manufacture plastics.
- It reduces emissions of harmful greenhouse gases.

- It promotes economic development by saving money that could be spent on mining and processing of new metals and plastics. The money can be channeled into other development programs that can help raise the living standards of the people and the economy as a whole.
- It saves money since recycled materials are generally cheap. This means the actual cost of buying the material is reduced hence saving money.