



## SECOND TERM E-LEARNING NOTE

**SUBJECT: CHEMISTRY**

**CLASS: SS2**

### SCHEME OF WORK

WEEK	TOPIC
1.	Rates of Chemical Reaction <ul style="list-style-type: none"><li>• Meaning of Rate of Chemical Reaction.</li><li>• Rate Curve.</li><li>• The Collision Theory.</li><li>• Factors Affecting Rate of Chemical Reactions.</li></ul>
2.	Exothermic and Endothermic Reactions <ul style="list-style-type: none"><li>• Heat Content (Enthalpy) of a Substance.</li><li>• Thermodynamics: First and Second Laws.</li><li>• Entropy and Free Energy.</li></ul>
3.	Chemical Equilibrium <ul style="list-style-type: none"><li>• Reversible Reactions</li><li>• Le Chatelier's Principle.</li><li>• Factors Affecting Chemical Equilibrium.</li><li>• Equilibrium Constant.</li></ul>
4.	Oxygen and its Compounds <ul style="list-style-type: none"><li>• General Properties of Oxygen Family.</li><li>• Electronic Structure and Bonding in Oxygen.</li><li>• Preparation, Properties and Uses of Oxygen.</li><li>• Oxides: Classification.</li></ul>
5.	Chlorine and other Halogens <ul style="list-style-type: none"><li>• Electronic Configuration of Halogens</li><li>• Physical and Chemical Properties of Halogens.</li><li>• Laboratory and Industrial Preparation of Chlorine.</li><li>• Compound of Chlorine: Hydrogen Chloride.</li><li>• Test for Chlorides.</li></ul>
6.	Nitrogen <ul style="list-style-type: none"><li>• General Properties of Nitrogen Family.</li><li>• Laboratory Preparation and Industrial Preparation of Nitrogen.</li><li>• Properties and Uses of Nitrogen.</li><li>• Nitrogen Cycle.</li></ul>
7.	Compounds of Nitrogen <ul style="list-style-type: none"><li>• Oxides of Nitrogen</li><li>• Ammonia: Preparation, Properties and Uses.</li><li>• Trioxonitrate (V) acid: Preparation, Properties and Uses.</li></ul>
8.	Sulphur <ul style="list-style-type: none"><li>• General Properties of Sulphur Group.</li><li>• Electronic Structure of Members of Sulphur Group.</li><li>• Allotropes of Sulphur.</li><li>• Uses of Sulphur.</li></ul>
9.	Compounds of Sulphur



- H<sub>2</sub>S, SO<sub>2</sub> and SO<sub>3</sub>: Preparation, Properties and Uses
  - Tetraoxosulphate (VI) acid: Industrial Preparation (Contact Process).
10. Revision

#### REFERENCES

- New School Chemistry for Senior Secondary School by O.Y. Ababio (6<sup>th</sup> edition)
- Calculations on Chemistry by E.U. Akusoba and G.O. Ewelukwa
- WASSCE past Questions and Answers on Chemistry
- UTME past Questions and Answers on Chemistry

#### WEEK ONE

DATE: \_\_\_\_\_

#### TOPIC: RATE OF REACTION

#### CONTENT

- Meaning of Rate of Chemical Reaction.
- Rate Curve.
- The Collision Theory.
- Factors Affecting Rate of Chemical Reactions

#### MEANING OF RATE OF REACTION

The rate of a chemical reaction is the number of moles of reactants converted or products formed per unit time.

Usually, rate of reaction is determined experimentally by measuring change in concentration of one of the components in the reaction with time.

Thus,

$$\text{Rate of reaction} = \frac{\text{change in concentration of reactant or product (mol/dm}^3\text{)}}{\text{Time taken for the change (seconds)}}$$

The unit of the rate of reaction is mol/dm<sup>-3</sup>s<sup>-1</sup> or g dm<sup>-3</sup>s<sup>-1</sup>.

Rate of reaction can also be expressed as:

$$\text{Rate of reaction} = \frac{\text{change in number of mole or mass of reactant or product}}{\text{Time taken for the change}}$$

Then the unit of rate is mols<sup>-1</sup> or gs<sup>-1</sup>

**EXAMPLE:** When 0.5g of calcium trioxocarbonate (IV) was added to excess dilute hydrochloric acid, carbon (IV) oxide was evolved. The complete reaction took 5 minutes. What was the rate of reaction?

SOLUTION:

$$\begin{aligned}\text{Rate of reaction} &= \frac{\text{change in mass of reactant}}{\text{Time taken for the change}} \\ &= \frac{(0.5 - 0)\text{g}}{5 \times 60} = \frac{0.5}{300} \\ &= 1.67 \times 10^{-3} \text{ gs}^{-1}\end{aligned}$$



## WAYS OF MEASURING REACTION RATE

Concentration is one of the properties of a reaction that can change with time.

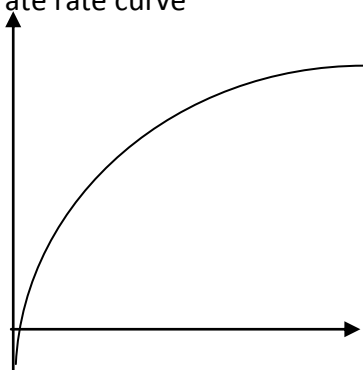
The following properties can also change with time and can thus be used to measure rate of reaction.

1. Decrease in mass of reaction system
2. Volume of gaseous product
3. Amount of precipitate formed
4. Change in colour intensity
5. Change in pH
6. Change in total gas pressure

## RATE CURVE

The rate curve is a graphical illustration of the rate of a reaction.

The following graph illustrate rate curve



## FEATURES OF RATE CURVE

1. It passes through the origin. This is because there is no change in concentration or mass at the start of reaction.
2. It steeps at first, this because the rate is fast at the beginning.
3. It becomes less steep later. This is because the rate slows down.
4. It finally becomes horizontally. This is because the reaction has reached the end points.

The following can be determined from the rate curve

1. Average rate of reaction  
Average rate =  $\frac{\text{total number of mole / mass involved}}{\text{Time taken}}$

2. Rate at a particular instant during the reaction  
Rate at instant = Gradient at a point on the curve

When the rate of reaction has direct variation with concentration, then

$$\text{Rate of reaction} \propto [\text{Concentration of A}]$$

$$R \propto [A]$$

$$R = k[A]$$

Where k is called Rate constant

## EVALUATION

1. What is rate of reaction?
2. State two ways of measuring reaction rate



## **COLLISION THEORY**

The collision theory states that for a chemical reaction to occur the reactant particles must collide and they must collide with a certain minimum amount of energy known as activation energy.

Reacting particles are in continuous motion, thus they possess energy and they also collide with one another. Not all collisions result into chemical reaction. Collisions, which result into chemical reaction, are called **EFFECTIVE COLLISIONS**. Minimum amount of energy required by reacting particles for chemical reaction to occur is called **ACTIVATION ENERGY**. Activation energy is the **ENERGY BARRIER** the reactants must overcome for reaction to occur. It is the minimum energy required for bond breaking for chemical reaction to occur.

Chemical reaction occur only when the energy of the colliding reactant particles is equal to or more than the activation energy. Activation energy must be equal to energy barriers also for chemical reaction to occur.

Every reaction has its own energy of activation. Reactions with low activation energy have high rate of reaction and occur spontaneously. Reaction with high activation energy have low rate of reaction and are not spontaneous.

The graph below illustrates the concepts of the activation energy for endothermic and exothermic reactions.

**EXOTHERMIC REACTION**      **ENDOTHERMIC REACTION**

From graph, it can be seen that

1. Both exothermic and endothermic reactions generally require an initial input of energy to overcome the activation energy barriers.
2. Exothermic reaction once started proceed without any further external energy supply e.g burning of kerosene
3. Endothermic reaction proceeds with continuous supply of external energy e.g cooking of rice.

## **EVALUATION**

1. State collision theory.
2. Graphically differentiate exothermic reaction from endothermic reaction.



## **FACTORS AFFECTING RATE OF REACTION**

From the collision theory, it can be seen that rates of reaction depends on the following features.

1. The energy of the particle.
2. The frequency of collision of the reaction.
3. The activation energy of the reaction.

These features of a chemical reaction are in turn affected by some factors, which can make them to change and consequently affect the rate of reaction. These are factors that affect the rate of reactions. Some important ones are:

1. Nature of reactants.
2. Concentration / pressure (for gases) of reactants.
3. Surface area of reactants
4. Temperature of reaction mixture
5. Presence of light
6. Presence of catalysts

To study the effect of any one of these factors on rate of reaction all other factors must be kept constant.

### **EFFECT OF NATURE OF REACTANTS**

If all other factors are kept constant, different substances will have different rate of reaction with dilute HCl, for example. When dilute HCl reacts with zinc, iron and gold under the same condition, hydrogen gas is evolved fast with zinc, slow with iron and no gas evolved with gold.

The difference in rate of reaction is due to the chemical nature of the elements as they naturally possess different amount of energy content.

### **EFFECT OF CONCENTRATION OF REACTANTS**

The frequency of collision among particles is high when the particles are crowded in a small space, i.e high concentration. This leads to high effective collision and thus high rate of reaction. An increase or decrease in the concentration of the reactants will result in corresponding increase or decrease in effective collisions of the reactants and hence the reaction rate.

### **EFFECT OF SURFACE AREA OF REACTANTS**

This is a very important factor to be considered when a solid is involved in a chemical reaction. Lumped solids offer small surface area of contact for reaction while powdered solids offer large surface area for reaction. Rate of reaction is slow with lumped solid but high with powdered solids.

### **EFFECT OF TEMPERATURE**

Increasing the temperature of a system can lead to an increase in reaction rate in two ways. When heat is raised, energy in form of heat is supplied to the reactant particles, so that

1. The number of particles with energy equal to or greater than the activation energy increases.



- The velocity of all the reactant particles increases due to the greater kinetic energy, leading to a higher frequency of collision.

As a result, the number of effective collisions increases and the reaction proceeds at a faster rate. Decreases in temperature leads to decrease rate of reactions.

### EFFECT OF LIGHT

Some reactions are influenced by light. The rate of reaction is high when the lights intensity is high, low when the intensity is low and does not proceed at all in the absence of light. Such reactions are known as photochemical reaction. Examples of photochemical reactions include.

- Reaction between hydrogen and chlorine and
- Decomposition of hydrogen peroxide
- Reactions between methane and chlorine
- Photosynthesis in plant
- Conversion of silver halides to grey metallic silver.

### EFFECT OF CATALYST

A Catalyst is a substance, which alters the rate of a reaction, but itself does not undergo any change at the end of the reaction.

A positive catalyst increases the rate of reaction by lowering the activation energy of the reaction whereas, the one which increases the activation energy is known as a negative catalyst or an inhibitor.

The diagram below illustrates the energy profile for catalyzed and uncatalyzed exothermic and endothermic reactions

EXOTHERMIC REACTION

ENDOTHERMIC REACTION

### GENERAL EVALUATION/REVISION

- List and explain three factors that can affect the rate of reaction of the following reaction:  $\text{CaCO}_{3(s)} + 2\text{HCl}_{(aq)} \rightarrow \text{CaCl}_{2(aq)} + \text{H}_2\text{O}_{(l)} + \text{CO}_{2(g)}$
- In a chemical reaction, after 10seconds, 6moles from the initial concentration of 16moles of the reactant disappeared. Calculate the rate of the reaction.
- State THREE characteristics of catalyst.
- What is the volume in  $\text{dm}^3$  of 8g of oxygen gas at s.t.p?
- Calculate the percentage of water in sodium trioxocarbonate (VI) heptahydrate

**READING ASSIGNMENT:** New School Chemistry for Senior Secondary School by O.Y.Ababio (6<sup>th</sup> edition) pages 250-261



## WEEKEND ASSIGNMENT

### SECTION A: Write the correct option ONLY

- The minimum amount of energy that colliding molecules must possess for their collisions to be effective is a. thermal energy b. collision energy  
c. activation energy d. kinetic energy
- $Zn_{(s)} + H_2SO_{4(aq)} \rightarrow ZnSO_{4(aq)} + H_{2(g)}$   
The rate of evolution of hydrogen gas in the above reaction will be greatly increased if  
a. the zinc is in the form of pellets b. a smaller volume of H<sub>2</sub>SO<sub>4</sub> is used c. the reaction flask is immersed in an ice bath d. the zinc is in powdered form
- The units of rate of reactions is a.  $\text{mol dm}^{-3} \text{s}^{-1}$  b.  $\text{mol}^{-1} \text{s}^{-1}$  c.  $\text{mol}^{-1}$  d.  $\text{smol}^{-1}$
- If 2g of zinc granules was reacted with excess dilute HCl to evolve hydrogen gas which came to completion after 5min. Calculate the rate of the chemical reaction in  $\text{ghr}^{-1}$   
a.  $48 \text{ghr}^{-1}$  b.  $12 \text{ghr}^{-1}$  c.  $24 \text{ghr}^{-1}$  d.  $240 \text{ghr}^{-1}$
- What do we do to increase the surface area of solid reactants to high rate of reaction?  
a. grinding them into powder b. subjecting the reactants to high pressure c. altering the directing of the reaction d. using reactants of different densities.

### SECTION B

- 1a. Define rate of reaction  
b. State the collision theory
- 2a. Explain in terms of collision theory, how rate of gaseous reaction is affected by an increase in pressure  
b. Give the reason why red-hot iron wool reacts more readily with oxygen than red-hot iron nail

## WEEK TWO

DATE: \_\_\_\_\_

### TOPIC: EXOTHERMIC AND ENDOTHERMIC REACTIONS

#### CONTENT

- Heat Content (Enthalpy) of a substance.
- Types of Heat of Reactions.
- Thermodynamics: First and Second Laws.
- Entropy and Free energy

#### ENERGY

Energy is defined as the ability to do work. It exists in different forms like: heat, light, sound, electrical, potentials (stored), kinetic etc.

#### LAWS OF CONSERVATION OF ENERGY

Energy can be changed from one form to another. The total amount of energy before and after the change remains the same. This observation is stated in the law of conservation of energy which states that energy can neither be created nor destroyed but can be changed from one form to another.

There are types of energy such as chemical energy, heat energy, and light energy.

#### HEAT CONTENT (ENTHALPY) OF A SUBSTANCE



Heat content or Enthalpy of a substance is the characteristic internal energy possess by the substance, which is due to the structure and physical state of a substance. The potential energy is due to the structure while the kinetic energy is due to the physical state. Enthalpy of one substance is different from another. Total enthalpy cannot be measured but only enthalpy change. Generally, an enthalpy change ( $\Delta H$ ) is the heat that would be exchanged with the surrounding, that is, it is the amount of energy involved in a reaction.

Thus,

Enthalpy change = Heat of products – Heat of reactants

That is,  $\Delta H = H_{\text{products}} - H_{\text{reactants}}$

The enthalpy change of a given reaction is always written side by side with the given equation and it may be either a positive or negative value.

Example:  $\text{HCl}_{(\text{aq})} + \text{NaOH}_{(\text{aq})} \rightarrow \text{NaCl}_{(\text{aq})} + \text{H}_2\text{O}_{(\text{l})}$   $\Delta H = -57.3\text{kJ}$

Unit of enthalpy change( $\Delta H$ ) is Joules(J) or kilojoules(kJ)

### **EXOTHERMIC AND ENDOTHERMIC REACTIONS**

#### **EXOTHERMIC REACTION**

A chemical reaction in which heat is given off to the surrounding is known as exothermic reaction. When an exothermic reaction occurs, heat is liberated and transferred from the chemicals to the surroundings and the temperature of the reaction mixture rises. The reaction vessel will feel hot.

Examples of exothermic reactions include:

1. Reaction between calcium oxide and water
2. Reaction between an acid and a base.
3. Combustion of fuel
4. Corrosion of metals
5. Respiration

In exothermic reaction, enthalpy change is negative since the heat content of the products is less than the heat content of the reactants.

#### **ENDOTHERMIC REACTION**

An Endothermic reaction is a type of reaction in which heat is absorbed from the surroundings. When an endothermic reaction occurs, heat energy is absorbed and transferred from the surrounding to the reactants and the temperature of the reaction mixture falls. The reaction vessel will feel cold.

Examples of endothermic reactions are:

1. Thermal decomposition of calcium trioxocarbonate (IV)
2. Thermal dissociation of ammonium chloride
3. Action of light on silver bromide in photographic film
4. Photosynthesis in plants

In endothermic reaction, the heat content of the product is more than the heat content of the reactant; hence the enthalpy change is positive.

### **ENERGY LEVEL DIAGRAMS**

Energy changes can be presented by diagrams, which shows at once whether reactions are exothermic or endothermic.





## EVALUATION

1. What is enthalpy?
2. Giving TWO examples each, define endothermic and exothermic reactions.

## HEAT OF REACTION AND CHEMICAL BONDS

During chemical reactions, chemical bonds are broken, atoms are regrouped and new bonds are formed. Bond breaking requires energy and bond forming evolves energy. The minimum amount of energy required for bond breaking is called activation energy. While bond breaking is endothermic, bond forming is exothermic. Thus, heat of reaction comes from breaking and forming of chemicals bond. Heat reaction is negative [exothermic] when bond-breaking energy is less than bond forming energy. Heat of reaction is positive [endothermic] when bond-breaking energy is more than bond forming energy.

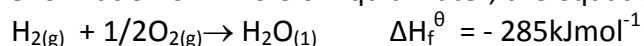
## TYPES OF HEAT CHANGES IN CHEMICAL REACTIONS

### HEAT OF FORMATION

The amount of heat evolved or absorbed when one mole of a substance is formed from its elements is known as heat of formation [or enthalpy of formation].

The standard heat of formation of a substance ( $\Delta H_f^\theta$ ) is the heat evolved or absorbed, when one mole of that substance is formed from its elements under standard conditions.

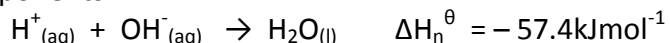
For the formation of 1 mole of liquid water, the equation is



Thus,  $\Delta H_f^\theta$  of water =  $-285\text{kJmol}^{-1}$

### HEAT OF NEUTRALIZATION

Neutralization is an exothermic reaction. The amount of heat evolved during a neutralization reaction in which one mole of water is formed is known as the heat of neutralization (or enthalpy of neutralization). The standard heat of neutralization  $\Delta H_n^\theta$  is the amount of heat evolved when 1 mole of hydrogen ions,  $\text{H}^+$ , from an acid reacts with 1 mole of hydroxide ions,  $\text{OH}^-$ , from an alkali to form 1 mole of water under standard conditions. Heat of neutralization is also known as heat of formation of one mole of water from its ionic components.



### HEAT OF COMBUSTION

Combustion reaction is always exothermic. The amount of heat evolved when one mole of a substance is burned completely in oxygen is known as the heat of combustion or enthalpy of combustion. The standard heat of combustion of a substance,  $\Delta H_c^\theta$ ; is the heat evolved when one mole of the substance is burned completely in oxygen under standard conditions. A bomb calorimeter is usually used for accurate determination of heat of combustion.

Heat of combustion can be determined from the relation below:

$$\text{Heat of combustion} = \frac{\text{Heat energy produced}}{\text{Mass burnt}} \times \frac{\text{molar mass}}{1}$$

When the heat evolved by the burning substance is used to raise the temperature of a known mass of water, then the expression for heat of combustion can be given as:

$$\text{Heat of combustion} = \frac{mC\Delta\theta}{\text{Mass burnt}} \times \frac{\text{molar mass}}{1}$$



Where  $m$  = mass of water

$C$  = Specific heat capacity of water

$\Delta\theta$  = change in temperature, that is,  $\theta_2 - \theta_1$

### HEAT OF SOLUTION

Heat of solution can be exothermic or endothermic. Heat of solution is the heat evolved or absorbed when one mole of a substance is dissolved in so much water that further dilution results in no detectable heat change.

Standard heat of solution,  $\Delta H_s^\theta$ , is the amount of heat evolved or absorbed when 1 mole of substance is dissolved in so much water that further dilution results in no detectable heat change at standard conditions.

### EVALUATION

Define each of the following:

1. Heat of combustion
2. Heat of neutralization

### THERMODYNAMICS

Thermodynamics is the study of relationship between heat and other forms of energy.

System in thermodynamics is any part of the universe chosen for thermodynamics consideration, i.e. the physical and chemical phenomenon or process occurring in a given environment. A system can be isolated, closed or open.

Surrounding is the environment in which a phenomenon or a process occurs.

*The first law of thermodynamics states that energy can neither be created nor destroyed but may be converted from one form to another.*

In thermodynamics, heat is represented by  $q$  and other forms of energy are referred to as work denoted by  $w$ . The conditions or state of a chemical system is changed when:

- i. Heat is evolved or absorbed, and / or
- ii. Work is done on or by the system

In any case, the internal energy,  $U$ , of the system is affected and it is changed.

From first law, heat is changed into internal energy of the system it may be represented by *change in internal energy = Heat absorbed by the system + Work done by the system*

$$\text{i.e. } \Delta U = q + w$$

Work done by the system is negative since this lead to decrease in internal energy, therefore:

$$\Delta U = q - w$$

For a gaseous system,  $w = P \Delta V$

$$\Delta U = q - P \Delta V$$

$$\Delta U = \Delta H - P \Delta V$$

$$\Delta H = \Delta U - P \Delta V$$

### EVALUATION

1. State the first law of thermodynamic
2. Calculate: (a) the heat adsorbed by a system when it does 72J of work and its internal energy decreases by 90J (b)  $U$  for a gas that releases 35J of heat and has 128J of work done on it.



## SECOND LAW OF THERMODYNAMIC

The second law of thermodynamic states that a spontaneous process occurs only if there is an increase in the entropy of a system and its surroundings

Factors which determines the spontaneously of a process are:

- enthalpy, H: The heat content of the substances involved
- entropy, S: The measure of degree of disorderliness or randomness of a substance
- free energy G: The energy which is available for doing work.

## ENTROPY (S)

Entropy is the measure of degree of disorderliness or randomness of a system. The standard entropy change ( $\Delta S^\theta$ ) is a state function because it depends on the initial and final state of the system. That is:

$$\Delta S^\theta = S^\theta_{\text{products}} - S^\theta_{\text{reactants}}$$

The S.lunit of is  $\text{JK}^{-1}\text{mol}^{-1}$

Entropy increases from solid to liquid to gaseous state because as you go from solid to liquid to gaseous state, randomness increases, that is;  $\Delta S^\theta$  tends to positive.

For a reversible process at constant temperature,

$$\Delta S = \Delta H/T$$

When  $\Delta S$  is positive, there is increase in entropy. When  $\Delta S$  is negative there is decrease in the entropy of a system.

## GIBB'S FREE ENERGY

The free energy of a system is the energy which is available for doing work in the system; that is, the driving force that brings about a chemical change.

The standard free energy change ( $\Delta G^\theta$ ) is a state function because it depends on the initial and final state of the system. That is:

$$\Delta G^\theta = G^\theta_{\text{products}} - G^\theta_{\text{reactants}}$$

Free energy takes into account the effect of the enthalpy and entropy factors as represented in the equation below:

$$G = H - TS$$

For a change at constant temperature,

$$\Delta G = \Delta H - T \Delta S$$

NOTE:

- When  $\Delta G$  is negative, the reaction is spontaneous or feasible.
- When  $\Delta G$  is positive, the reaction is not spontaneous, unless the resultant effect of both  $\Delta H$  and  $\Delta S$  leads to a net decrease in  $\Delta G$
- When  $\Delta G$  is zero, the system is in equilibrium

**Example:** The reaction:  $\text{C}_{(s)} + \text{O}_{2(g)} \longrightarrow \text{CO}_{2(g)}$

is carried out at a temperature of  $57^\circ\text{C}$ . If the enthalpy change is  $-500\text{J}$  and the entropy change is  $+15\text{J}$ . Calculate the free energy change

Solution:

$$\begin{aligned}\Delta G &= \Delta H - T \Delta S \\ &= -5000 - (57 + 273) \times (+15)\end{aligned}$$



$$\begin{aligned} &= -5000 - 330 \times 15 \\ &= -5000 - (+4950) \\ &= -5000 - 4950 \\ &= -9950\text{J or } -9.950\text{kJ} \end{aligned}$$

### GENERAL EVALUATION/REVISION

1. Define standard heat of formation and standard heat of neutralization
2. Define exothermic and endothermic reactions giving two example each
3. What is the number of oxygen atoms in 32g of the gas? [ $N_A = 6.02 \times 10^{23}$ ]
4. State the modern periodic law
5. The table below refers a portion of the periodic table:

I	II	III	IV	V	VI	VII	VIII
Lithium			Carbon P				
X						Q	
Y	R						

- a. The most reactive metal
- b. The most reactive non-metal
- c. Name the family of the elements represented by P, Q and R
- d. The element Q forms compounds with lithium and carbon. Write the formula of each compound formed

### READING ASSIGNMENT

New School Chemistry for SSS by O.Y. Ababio(6<sup>th</sup> edition) pages 230- 242

### WEEKEND ASSIGNMENT

#### SECTION A: Write the correct option ONLY

1. A chemical reaction in which heat is absorbed is said to be a. thermostatic b. isothermal c. exothermic d. endothermic
2. For the reaction:  $\text{H}_3\text{O}^+_{(\text{aq})} + \text{OH}^-_{(\text{aq})} \rightarrow 2\text{H}_2\text{O}_{(\text{l})}$  the heat change accompanying the process is heat of a. formation b. hydration c. neutralization d. combustion
3. A reaction in which  $\Delta H$  is negative is a. isothermic b. endothermic c. adiabatic d. exothermic
4. How much heat will be liberated if 10g of hydrogen burns in excess oxygen according to the following equation:  
 $\text{H}_{2(\text{g})} + 1/2\text{O}_{2(\text{g})} \rightarrow \text{H}_2\text{O}_{(\text{l})}; \Delta H_{\text{C}}^\ominus = -286\text{Kj}$  a. -1430kj b. -2860kj c. -572kj d. -286kj
5. Which of the following statement is TRUE about the dissolution of sodium hydroxide pellets in water? a. It is an endothermic process b. Heat of solution of sodium hydroxide is positive c. Heat is gained from the surrounding d. Heat of solution of sodium hydroxide is negative

#### SECTION B

1. State THREE factors that determine the spontaneity of a chemical reaction.
2. 0.92g of ethanol raised the temperature of 100g of water from 298K to 312.3K when burned completely. What is the heat of combustion of ethanol?



## TOPIC: CHEMICAL EQUILIBRIUM

### CONTENT

- Reversible Reactions
- Le Chatelier's Principle
- Factors Affecting Chemical Equilibrium
- Equilibrium Constant

### EQUILIBRIUM

Equilibrium can be defined as the state of a system where there is no observable or detectable change in the properties of the system with respect to time. Examples of system in equilibrium

- a. a balanced see – saw
- b. a saturated solution of NaCl

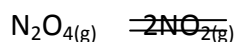
### STATIC AND DYNAMIC EQUILIBRIUM

Static equilibrium is attained when a system in equilibrium is in a state of rest or stationary state.

Example of this is balanced see – saw

Dynamic equilibrium can occur during a physical change or a chemical change that is reversible. Dynamic equilibrium involving a physical change is referred to as *physical equilibrium* while that involving a chemical change is a chemical equilibrium.

A system is said to be in a state of dynamic equilibrium when both the forward and backward reactions take place at the same rate. Example



### EQUILIBRIUM IN REVERSIBLE REACTION

A reversible reaction is one which proceeds in both forward and backward directions under suitable conditions.

For example:  $\text{NH}_4\text{Cl}(\text{s}) \longrightarrow \text{NH}_3(\text{g}) + \text{HCl}(\text{g})$

A reversible reaction is said to be in dynamic equilibrium when both the forward and backward reaction are occurring at the same rate, thereby producing no net change in concentrations of the reactants or products.

### Properties of system in equilibrium

1. A chemical reaction at equilibrium is in dynamic state with the rates of the forward and backward reactions are equal.
2. The equilibrium position can be reached from reactants alone or from product alone
3. For equilibrium to be established, the system must be closed

### EVALUATION

1. When is a reversible reaction said to be in dynamic equilibrium
2. List three properties of a system in a state of equilibrium

### FACTORS AFFECTING THE POSITION OF EQUILIBRIUM

The position of equilibrium depends on the following set of condition



- i. Temperature
- ii. Concentration
- iii. Pressure (for gases)

Variation in any of these factors will upset the balance of the system and results in a shift in the position of the equilibrium. These factors and their effect on chemical systems in equilibrium were studied by Le Chatelier's who formed the Le Chatelier's principle.

**Le Chatelier's principle** states that if a chemical system is in equilibrium and one of the factors involved in the equilibrium is altered, the equilibrium position will shift so as to neutralize the effect of the change.

Importance of Le Chatelier's principle in chemical industry: It helps to

- i. Define optimum conditions for chemical process
- ii. Reduce undesirable reversibility
- iii. Predict the effect of an altered factors on the equilibrium

### EFFECT OF TEMPERATURE

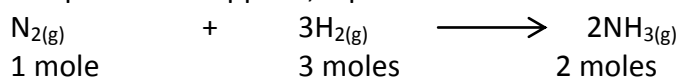
For an endothermic reaction, increase in temperature shifts the position of equilibrium to the right. That is, the forward reaction is favoured while a decrease in temperature favours the backward reaction. The reverse is the case for exothermic reactions.

### EFFECT OF CONCENTRATION

In a system of equilibrium, if the concentration of reactants is increased or product decreased, the forward reaction will be favoured, that is; equilibrium position shifts to the right. Also, if the concentration of the products is increased or reactant decreased, the backward reaction will be favoured, equilibrium position shifts to the left.

### EFFECT OF PRESSURE

Pressure of gas is proportional to the number of moles. Increase in number of moles implies increase in pressure and vice versa. If the forward reaction proceeds by decreases in number of moles (pressure), an imposed increase pressure will favour forward reaction. Reverse is the case if it proceeds by increase in number of moles (pressure). In other words, when high pressure is applied, equilibrium will shift to the side with less number of moles while when low pressure is applied, equilibrium will shift to the side with greater number of moles.



Increase in pressure favours forward reaction while decrease in pressure favours backward reaction

### EFFECT OF CATALYST

A catalyst does not change (affect) the position of equilibrium. Addition of catalyst, however increase the rate of both forward and backward reaction by lowering the activation of energy of the reaction.

Equilibrium position is attained at faster rate when a catalyst is present.

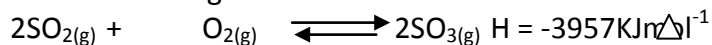
### EVALUATION

1. State Le Chatelier's principle
2. Explain the effect of



- i. Increase in temperature
- ii. decrease in pressure

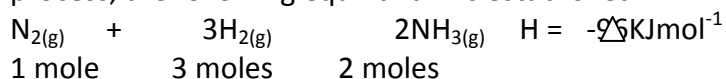
on the following reaction



### HABER PROCESS

Haber process is an industrial process for the manufacture of ammonia.

Ammonia,  $\text{NH}_3$ , is an important chemical for the manufacture of fertilizers. During the process, the following equilibrium is established



### CHOICE OF TEMPERATURE

Since forward reaction is exothermic, Le Chatelier's principle shows that the greatest yield of ammonia,  $\text{NH}_3$ , would be obtained at low temperature. However, if the temperature is too low, time taken to reach equilibrium would be much. A temperature of  $500^\circ\text{C}$  gives reasonable yield of ammonia.

### CHOICE OF PRESSURE

Since forward reaction leads to decrease in number of moles (pressure), Le Chatelier's principle shows that high yield of ammonia would be obtained at high pressure. The pressure of 25atm gives a satisfactory yield.

### CHOICE OF CATALYST

Iron is used as catalyst in Haber process. Iron is found to be effective in speeding up the rate of which equilibrium is reached. It is used in form of small pellets which increased the surface area available for contact.

### EQUILIBRIUM CONSTANT (K) AND LAW OF MASS ACTION

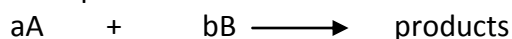
The law of mass action states that at constant temperature, the rate of reaction is proportional to the active masses of each of the reactants;

The active mass of the reactants is the concentration of the substance raised to the power of coefficient (number of mole) of that substance in the equation of reaction under study.

**NOTE:** Active mass = molar concentration x activity coefficient

In most reactions, the active masses of the reactant may be taken as their molar concentrations.

Example:



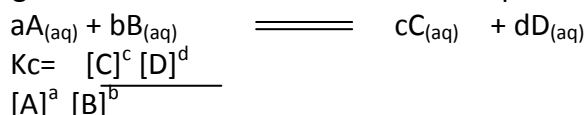
Thus,  $r \propto [\text{A}]^a$  and  $r \propto [\text{B}]^b$

where [ ] represents concentration in  $\text{mol dm}^{-3}$

$$r \propto [\text{A}]^a \times [\text{B}]^b$$
$$r = k [\text{A}]^a [\text{B}]^b$$

where k is called equilibrium constants

Applying the law to the reversible reaction represented by the equation below:

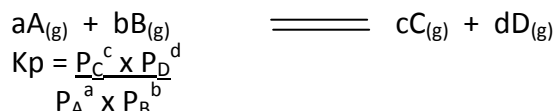




Where  $K_c$  is called equilibrium constant

For reactions involving gases, the equilibrium constant is expressed in terms of the partial pressures of the gases involved in the reaction.

Therefore, for the general gaseous reaction:



Where  $K_p$  is equilibrium constant for the gaseous reaction,  $P_A$ ,  $P_B$ ,  $P_C$  and  $P_D$  are partial pressures of gases A, B, C and D respectively.

**NOTE:** For a given reaction, concentrations of solids are ignored. A  $K_c$  or  $K_p$  value greater than one tells you that product formation is favoured at equilibrium; while a  $K_c$  or  $K_p$  value less than one tells you that reactants formation is favoured at equilibrium. A system in equilibrium has  $K_c$  or  $K_p$  value equal to one.

### GENERAL EVALUATION/REVISION

1. State the conditions for the optimum yield of ammonia in Haber process.
2. State Le Chatelier's principle
3. Define the following terms and state how they vary across a period and down a group: Ionization energy, Electronegativity, Electron affinity
4. Define oxidation, reduction, oxidizing agent and reducing agent in terms of electron transfer
5. An organic compound contains the following by mass: 0.188g of C, 0.062g of H and 0.25g of O. If the vapour density of the compound is 16, determine its molecular formula.

### READING ASSIGNMENT

New School Chemistry for Senior Secondary School by O.Y. Ababio (6<sup>th</sup> edition) Pages 265-275

### WEEKEND ASSIGNMENT

**SECTION A:** Write the correct option ONLY.

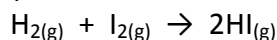
1. When the concentration of both reactants and product are equal  
a.  $K = 1$     b.  $K > 1$     c.  $K \geq 1$     d.  $K = 0$
2. In the reaction  
 $2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$      $H = -x \Delta / \text{mole}$   
increase in temperature favours the  
a. backward reaction    b. forward reaction    c. yield of  $SO_3$
3. How is the equilibrium constant for the forward reaction ( $K_f$ ) related to that of the reverse reaction ( $K_r$ )? a.  $K_r$  is the additive inverse of  $K_f$  b.  $K_r$  is the multiplicative inverse of  $K_f$  c.  $K_r$  is same as  $K_f$  d. The product of  $K_r$  and  $K_f$  is zero
4. The equilibrium constant expression involves a. solid, liquid and gaseous species b. gaseous species only c. species in aqueous solution only d. species in aqueous solution and gases only
5. Increase in pressure favours the forward reaction for an equilibrium reaction that proceeds with a. increase in pressure b. decrease in number of moles c. no change in pressure d. increase in number of moles





## SECTION B

1. State the Le Chatelier's principle
2. Calculate (a) the equilibrium constant ( $K_p$ ) for the reaction below at  $45^\circ\text{C}$   
(b) the equilibrium constant for the backward reaction below:



Given that the partial pressure for  $\text{H}_2$ ,  $\text{I}_2$  and  $\text{HI}$  are  $0.065\text{atm}$ ,  $0.45\text{atm}$  and  $0.245\text{atm}$  respectively. From your answer, deduce which of the reaction is favoured.

## WEEK FOUR

DATE: \_\_\_\_\_

### TOPIC: OXYGEN AND ITS COMPOUNDS

#### CONTENT

- General Properties of Oxygen Family.
- Electronic Structure and Bonding in Oxygen.
- Preparation, Properties and Uses of Oxygen.
- Oxides: Classification

Oxygen is the most abundant element on earth. It constitutes 21% by volume of atmospheric air.

*Occurrence:* It occurs as free elements in nature and in combined states.

#### GENERAL PROPERTIES OF OXYGEN FAMILY

Elements in group VI include: Oxygen (O), Sulphur (S), Selenium (Se), Tellurium (Te), and Polonium (Po). their properties are as follows:

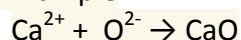
1. They are non-metals and exist as solid at room temperature except for oxygen
2. They are electron acceptors and oxidizing in nature.
3. They do not react with water in any form. But oxygen and sulphur combine directly with hydrogen to yield water and hydrogen sulphide respectively.

#### ELECTRONIC STRUCTURE AND BONDING IN OXYGEN

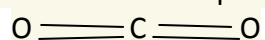
Oxygen has an atomic number of 8; hence its electronic configuration is  $1s^2 2s^2 2p^4$ . This shows that oxygen needs two electrons in order to attain an octet configuration.

Oxygen atom has six valence electrons and can acquire a stable octet configuration by:

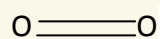
1. Accepting two electrons from electropositive elements like metals to form negative oxide ion,  $\text{O}^{2-}$ . Example



2. Entering into covalent bond formation with non-metals by covalently sharing two out of its six outer electrons. Example formation of carbon (IV) oxide molecule.



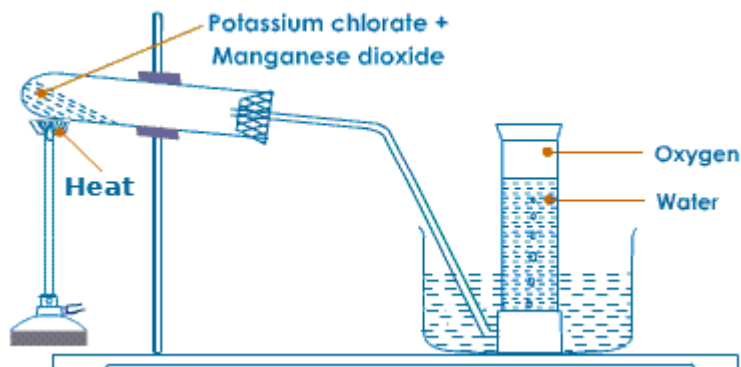
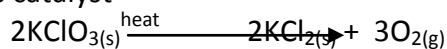
3. Forming covalent bond with itself.



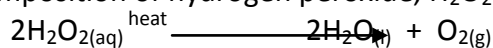
#### LABORATORY PREPARATION OF OXYGEN



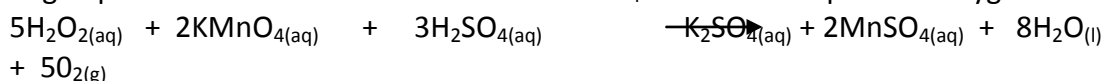
- By the thermal decomposition of potassium trioxochlorate (V) in the presence of  $\text{MnO}_2$  as catalyst



- By decomposition of hydrogen peroxide,  $\text{H}_2\text{O}_2$  in the presence of  $\text{MnO}_2$  as catalyst



Hydrogen peroxide also reacts with acidified  $\text{KMnO}_4$  in the cold to produce oxygen



**NOTE:** If the gas is required dry, it is passed through anhydrous calcium chloride or concentrated tetraoxosulphate (VI) acid and collected over mercury.

## INDUSTRIAL PREPARATION

- Electrolysis of water
- Fractional distillation of liquid air: This preparation involves two main processes:
  - Liquefaction of air  
Air is first passed through caustic Soda,  $\text{NaOH}_{(aq)}$  to remove  $\text{CO}_2$ . It is then subjected through series of compressions, expansions and cooling until liquid air is obtained at  $-200^\circ\text{C}$ .
  - Fractional distillation of liquid air  
The liquid air is led to a fractional distillation column. On distillation, nitrogen with a lower boiling point of  $-196^\circ\text{C}$  is evolved first, leaving behind liquid oxygen. Further heating converts the liquid oxygen to a gas at  $-183^\circ\text{C}$

## EVALUATION

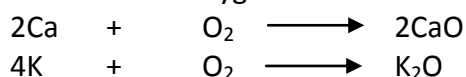
- Explain the laboratory preparation of oxygen
- By what process is oxygen obtained from air

## PHYSICAL PROPERTIES

- It is colourless, odorless and tasteless diatomic gas
- It is neutral to litmus
- It is slightly soluble in water
- Gaseous oxygen is denser than air
- Gaseous oxygen liquefies at  $-183^\circ\text{C}$

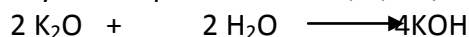
## CHEMICAL PROPERTIES

- Reaction with metals: Oxygen combines directly with most metals to form basic oxides

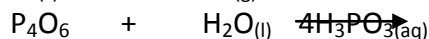
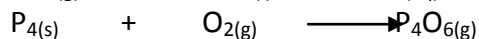
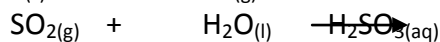
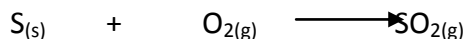




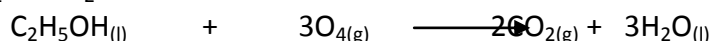
The oxides of very electropositive metals, K, Na, Ca dissolves in water to form alkalis



2. Reaction with non-metals: Non-metals burn in oxygen to acidic oxides. These are known as acid anhydrides as they dissolve in water to form acids.



3. Most hydrocarbon and compounds of carbon, hydrogen and oxygen burn in oxygen to give  $\text{CO}_2$  and  $\text{H}_2\text{O}$



## USES OF OXYGEN

- It is used in oxy-ethylene flame
- It is required for respiration
- It is used in steel industry for the removal of C, S and P impurities from pig iron
- Liquid oxygen and fuel are used as propellant for space rockets
- Oxygen is used in the manufacturer of tetraoxosulphate (VI), trioxonitrate (VI) acid and ethanoic acid.

## TEST FOR OXYGEN

When a glowing splinter is inserted into a gas jar containing an unknown gas and the glowing splinter is rekindled, then the gas is likely oxygen gas or dinitrogen (I) oxide gas. If the gas is colourless and reacts with nitrogen (II) oxide to produce reddish-brown fumes of nitrogen (IV) oxide, then the gas is confirmed to be oxygen gas.

## EVALUATION

- State two physical properties of oxygen
- Using equation only, state two chemical properties of oxygen

## OXIDES

Oxides are binary compounds formed when oxygen combines with other elements

### Types of oxides (classification)

- Basic Oxides:** These are oxides of metals e.g.  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{MgO}$ ,  $\text{CaO}$  etc. They react with acids to form salt and water only. Example  
$$\text{Na}_2\text{O}_{(s)} + 2\text{HCl}_{(aq)} \longrightarrow 2\text{NaCl}_{(s)} + \text{H}_2\text{O}_{(l)}$$
- Acidic Oxides:** These are oxides of non-metals which dissolves in water to form acids e.g.  $\text{CO}_2$ ,  $\text{SO}_2$ ,  $\text{NO}_2$  etc. They react with alkali to form a salt and water only e.g.  $\text{CO}_2(g) + 2\text{NaOH}_{(aq)} \longrightarrow \text{Na}_2\text{CO}_{3(aq)} + \text{H}_2\text{O}_{(l)}$
- Amphoteric Oxides:** These are oxides of metals which can react with both acids and alkalis to form salt and water only. They include the oxides of Al, Zn, Pb and Sn.  
Example  
$$\text{ZnO}_{(s)} + \text{H}_2\text{SO}_4 \longrightarrow \text{ZnSO}_{4(aq)} + \text{H}_2\text{O}_{(l)}$$
$$\text{ZnO}_{(s)} + 2\text{NaOH}_{(aq)} + \text{H}_2\text{O} \longrightarrow \text{Na}_2\text{Zn}(\text{OH})_{4(aq)}$$
- Neutral Oxides:** These are oxides of non-metals which are neither acidic nor basic. They are neutral to litmus. They include  $\text{CO}_2$ ,  $\text{H}_2\text{O}$  and  $\text{N}_2\text{O}$



5. **Peroxides:** These are oxides which contain higher proportion of oxygen than ordinary oxides e.g  $\text{Na}_2\text{O}_2$ ,  $\text{CaO}_2$  and  $\text{BaO}_2$ . They react with dilute acid to produce hydrogen peroxide,  $\text{H}_2\text{O}_2$

#### GENERAL EVALUATION/REVISION

1. Mention four air pollutants and state their effects
2. State two air pollution control measures
3. Mention four types of oxides and give two examples each.
4. Describe the electrolysis  $\text{CuSO}_4(\text{aq})$  using platinum electrodes
5. Using equations only, state the products of the electrolysis of brine

#### READING ASSIGNMENT

New School Chemistry for Senior Secondary School by O.Y.Ababio (6<sup>th</sup> edition) pages 368-373

#### WEEKEND ASSIGNMENT

##### SECTION A: Write the correct option ONLY

1. The most abundant element on earth is a. nitrogen b. helium c. silicon d. oxygen
2. Determination of the proportion of oxygen in air can be done by passing a given volume of air through a. lime water b. alkaline pyrogallol solution c.  $\text{FeSO}_4$  solution d. concentrated  $\text{H}_2\text{SO}_4$
3. Which one of the following is an amphoteric oxide? a.  $\text{SiO}_2$  b.  $\text{Al}_2\text{O}_3$  c.  $\text{CuO}$  d.  $\text{K}_2\text{O}$
4. Most acid anhydrides react with water to form acids. Which of these is a mixed anhydride? a.  $\text{N}_2\text{O}$  b.  $\text{NO}$  c.  $\text{NO}_2$  d.  $\text{SO}_2$
5. A gas which is neutral to litmus and rekindles a glowing splinter is a.  $\text{O}_2$  b.  $\text{O}_3$  c.  $\text{H}_2\text{O}_2$  d.  $\text{H}_2$

##### SECTION B

1. Using diagram ONLY, describe the preparation of dry oxygen gas in the laboratory
2. Why is oxygen collected over mercury?

#### WEEK FIVE

DATE: \_\_\_\_\_

#### TOPIC: CHLORINE AND OTHER HALOGENS

##### CONTENT

- Electronic Configuration of Halogens
- Physical and Chemical Properties of Halogens.
- Laboratory and Industrial Preparation of Chlorine.
- Preparation, Properties and Uses.
- Compound of Chlorine: Hydrogen Chloride.
- Test for Chlorides

#### HALOGENS

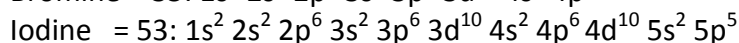
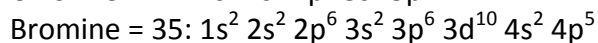
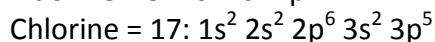
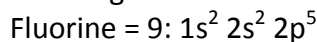
Halogens (salt formers) are found in group VII of the periodic table. They are the most reactive nonmetals. They have seven valence electrons, they exist as diatomic molecules, and they are coloured and ionizes to form univalent negative ions. They form electrovalent compounds with metals. In the group are chlorine, fluorine, bromine, iodine and astatine.



## ELECTRONIC CONFIGURATION OF HALOGENS

The halogens meaning salt makers are found in group VII of the periodic table. The electronic configuration of the halogens is one electron short of the noble gas structure (i.e. contains seven electrons on their outermost shells), and the chemistry of the group is dominated by the tendency to complete the octet arrangement by receiving an electron.

The electronic configurations of the halogens are shown below:



## PHYSICAL PROPERTIES OF THE HALOGENS

1. They are usually univalent, and easily accept one electron from other atoms to form ionic compounds (especially from metals e.g Na & K). They also share electrons with themselves or with non-metals to form covalent compounds.
2. They exist in their natural states as non-polar diatomic molecules.
3. Fluorine and chlorine are gases, bromine is a liquid and iodine is a solid.
4. The halogens are coloured, with typical penetrating odour. The colours deepen down the group. Fluorine is pale-yellow, chlorine is greenish- yellow, bromine is red and iodine is violet.
5. They are volatile substances. Their volatility decreases down the group.
6. All the halogens except fluorine, dissolve to some extent in water, fluorine reacts with water to give oxygen and hydrogen fluoride.

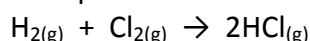
## CHEMICAL PROPERTIES OF THE HALOGENS

The halogens are very reactive elements. Their reactivity decreases down the group.

Fluorine is the most reactive halogen. They are also strongly electronegative. Their

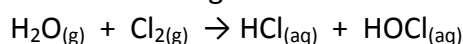
Electronegativity decreases down the group.

1. As oxidizing agents. Halogens are strong oxidizing agent. They do so by accepting electrons and forming halide ions especially in the reaction with metals. The oxidizing power decreases down a group.
2. Reaction with metals: Halogens react with metals to form ionic compounds.  $2\text{Na}_{(s)} + \text{F}_{2(g)} \rightarrow 2\text{NaF}_{(s)}$
3. Reaction with hydrogen: Fluorine explodes with hydrogen even in the dark, chlorine reacts slowly in the dark but explode in bright sunlight, bromine reacts with hydrogen in the presence of platinum catalyst; while iodine reacts partially with hydrogen on heating. Example



Stability of the hydrogen halides decreases down the group. Hydrogen fluoride is a liquid with a boiling point of  $19^{\circ}\text{C}$ . The other hydrogen halides are gases.

4. Reaction with water: Fluorine reacts vigorously with water to give off oxygen gas. Chlorine reacts very slowly with water to give a mixture of hydrochloric acid and oxochlorate (I) acid which later decomposes to give hydrochloric acid and oxygen gas. The oxygen gas given off by the oxochlorate (I) acid is responsible for the bleaching action of moist chlorine gas and chlorine water.





### EVALUATION

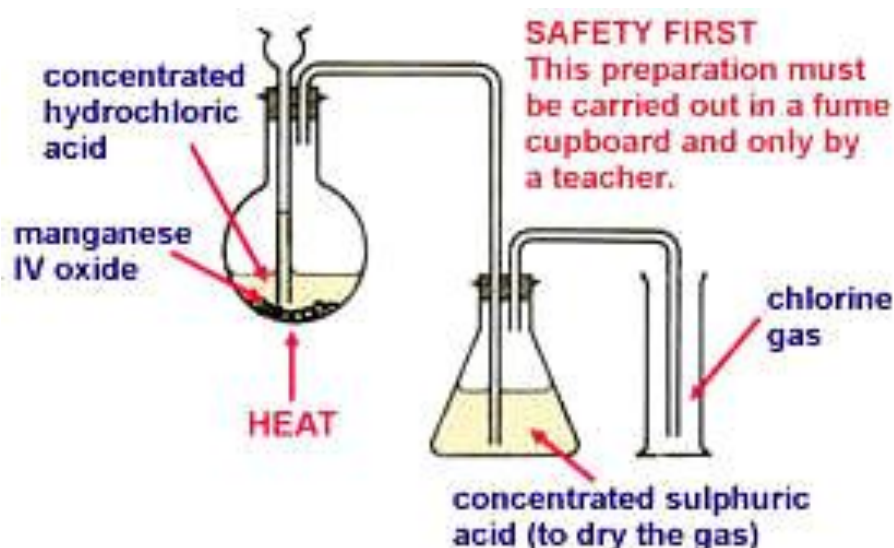
1. Write the electronic configuration of the following atoms/ions: Cl, F<sup>-</sup>, Br.
2. Give three physical properties of the halogens

### CHLORINE

Chlorine is the most important element in the halogen family. It does not occur as free element in nature because it is too reactive. It is usually found in combined state as chlorides.

### LABORATORY PREPARATION OF CHLORINE

1. By the oxidation of concentrated HCl with strong oxidizing agent such as MnO<sub>2</sub> or KMnO<sub>4</sub>



2. By heating concentrated H<sub>2</sub>SO<sub>4</sub> with a mixture of NaCl and MnO<sub>2</sub>  
$$2\text{NaCl}_{(s)} + \text{MnO}_{2(s)} + 2\text{H}_2\text{SO}_{4(aq)} \rightarrow \text{Na}_2\text{SO}_{4(aq)} + \text{MnSO}_{4(aq)} + \text{H}_2\text{O}_{(l)} + \text{Cl}_{2(g)}$$

### INDUSTRIAL PREPARATION

Chlorine is manufactured industrially by the electrolysis of brine and molten NaCl, MgCl<sub>2</sub> or CaCl<sub>2</sub>.

### EVALUATION

1. Explain one laboratory preparation of dry chlorine gas.
2. Name the method of collection of chlorine gas and explain why it can be collected by the method.

### PHYSICAL PROPERTIES

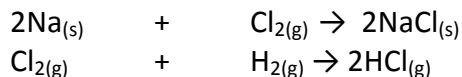
1. Chlorine is a greenish-yellow gas with unpleasant choking smell.
2. It is a poisonous gas.
3. It is about 2.5 times denser than air.



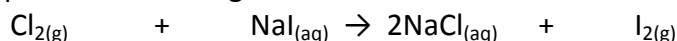
4. It can be liquefied under a pressure of about 6atm.
5. It is moderately soluble in water.

### CHEMICAL PROPERTIES

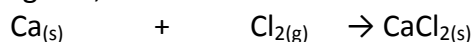
1. It is very reactive and tends to attain stability by forming electrovalent compound with metals and a single covalent bond compounds with non-metals.



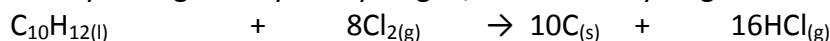
2. It displaces other halogens from solution of their acids and salts



3. It combines directly with other elements except oxygen, nitrogen carbon and the noble gases; to form chlorides



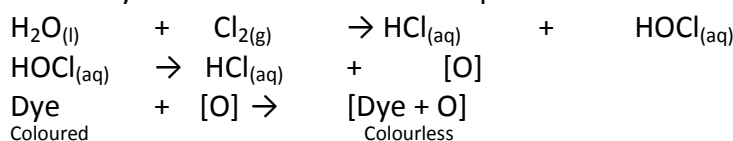
4. It has a very strong affinity for hydrogen; it removes hydrogen from its compounds.



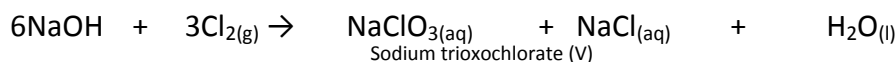
5. It is a powerful oxidizing agent: it oxidizes green  $\text{Fe}^{2+}$  to yellow  $\text{Fe}^{3+}$



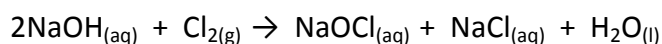
6. It has a bleaching action: in the presence of water, chlorine bleaches most dyes and inks except printer's ink. The bleaching action of chlorine is due to its ability to react with water to form oxochlorate (I) acid which decomposes to release oxygen which oxidizes the dye to form a colourless compound.



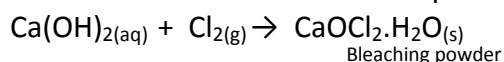
7. It reacts with hot concentrated NaOH solution to give a mixture of trioxochlorate (V) and chloride of the metal.



With cold dilute solution of NaOH, a pale yellowish mixture of oxochlorate (I) and chloride of the metal is formed.



8. It reacts with slaked lime solutions to produce bleaching powder



### TEST FOR CHLORINE

1. It turns dampened blue litmus paper pink and then bleaches it. It is acidic gas.
2. It turns dampened starch-iodide dark blue. Chlorine turns starch-iodide paper blue because it displaces iodine from the iodide. The iodine liberated then turns the starch blue.

### USES OF CHLORINE

1. It is a powerful germicide [due to its oxidizing nature].
2. It is used as a bleaching agent for cotton, wool, pulp etc.
3. It is used in the manufacture of polyvinyl chloride (PVC) and synthetic rubber.
4. It is used in the manufacture of organic compound e.g  $\text{CHCl}_3$ ,  $\text{CCl}_4$ .
5. It is used in producing  $\text{KClO}_3$ , for making matches and fireworks.



6. It is used for making  $\text{NaClO}_3$ , a weed killer.
7. It is used for making domestic antiseptics e.g acidified  $\text{NaClO}$  solution.

## EVALUATION

1. Mention FOUR physical properties of chlorine.
2. Using balanced equations, state FIVE chemical properties of chlorine.

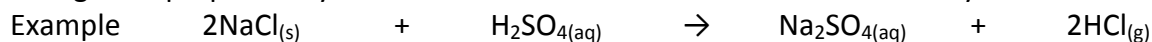
## COMPOUNDS OF CHLORINE

### HYDROGEN CHLORIDE

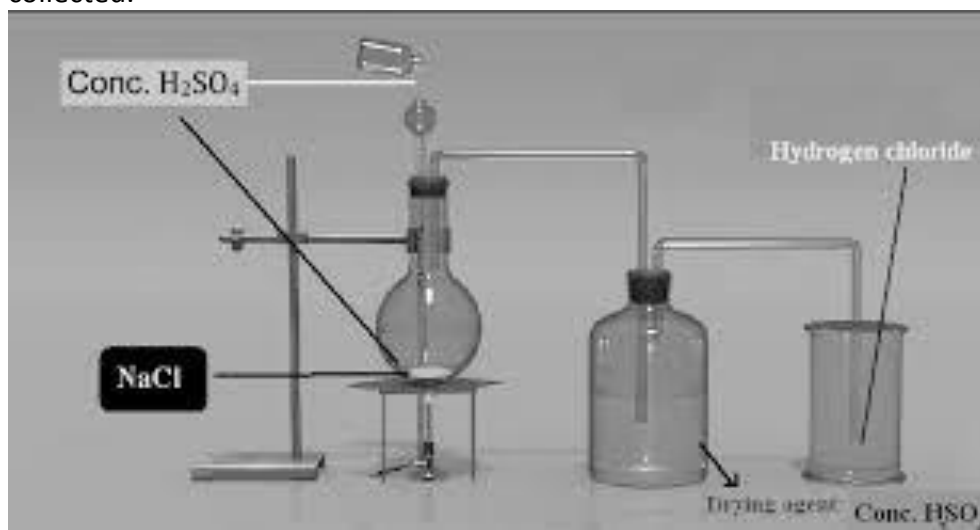
Hydrogen chloride (marine-acid gas) exists as a gas at room temperature. It dissolves in water to form hydrochloric acid. It occurs in traces in the air as industrial by-product and is considered as air pollutant; but it can be easily washed down as acid rain since it is very soluble in water.

### LABORATORY PREPARATION

The gas is prepared by the action of hot concentrated  $\text{H}_2\text{SO}_4$  on any soluble chloride.

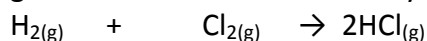


Note:  $\text{NaHSO}_4$  is first formed at a lower temperature and later at higher temperature  $\text{HCl}$  gas is formed. The gas is dried by passing it through concentrated  $\text{H}_2\text{SO}_4$  in another flask and collected.



### INDUSTRIAL PREPARATION

Pure  $\text{HCl}$  gas can be produced in large scale by direct combination of hydrogen and chloride gas obtained from the electrolysis of brine.



### PHYSICAL PROPERTIES

1. Pure  $\text{HCl}$  gas is colourless and has sharp irritating smell
2. It turns damp blue litmus paper red
3. It is about 1.25 times denser than air
4. It is very soluble in water, forming aqueous  $\text{HCl}$  acid
5. It is readily dissolved in non-polar solvent like chloroform and toluene; but the solution does not conduct electricity and has no acidic properties because hydrogen chloride which is a covalent molecule does not ionize when it dissolve in non-polar





solvents. But it dissolves in water and ionizes. The ions formed in aqueous solution are responsible for the acidic property and conductivity of its aqueous solution.

6. It forms misty fumes in moist air because it dissolves in the moisture to form tiny droplets of HCl acid.
7. It does not support combustion.

### CHEMICAL PROPERTIES

1. It combines directly with  $\text{NH}_3$  and produces a white fumes of ammonium chloride  
$$\text{HCl}_{(g)} + \text{NH}_{3(g)} \rightarrow \text{NH}_4\text{Cl}_{(s)}$$
2. It reacts with various heated metals to form their respective chloride and hydrogen  
$$\text{Zn}_{(s)} + 2\text{HCl}_{(g)} \rightarrow \text{ZnCl}_{2(s)} + \text{H}_{2(g)}$$

### TEST FOR HYDROGEN CHLORIDE

1. A gas rod that has been dipped in ammonia solution is brought near the gas jar containing the unknown gas, if there are dense white fumes on the glass rod, then the gas is hydrogen chloride gas.
2. Few drops of silver trioxonitrate (V) is added to the gas jar containing the unknown gas and shaken. If white precipitate of silver chloride is observed, then the gas is hydrogen chloride gas.

### EVALUATION

1. State TWO physical and TWO chemical properties of hydrogen chloride gas
2. An unknown gas is colourless, has an irritating smell, fumes in moist air and turns blue litmus paper red; describe how you will confirm the gas to be hydrogen chloride gas.

### CHLORIDES

Chlorides are normal salts formed when metallic ion replace the hydrogen ion in hydrochloric acid. Chlorides are prepared by neutralization reaction. Chlorides are soluble in water with exception of few.

#### Soluble chlorides

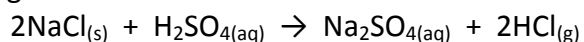
NaCl,  $\text{NH}_4\text{Cl}$ , KCl  
 $\text{CaCl}_2$  etc

#### Insoluble chlorides

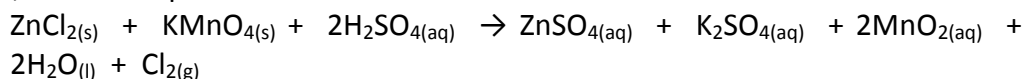
$\text{CuCl}_2$ , AgCl,  $\text{PbCl}_2$

### PROPERTIES

1. Chlorides are not decomposed by heat. They can only be recovered from solution by evaporation to dryness or sometimes by crystallization.
2. They react with hot concentrated tetraoxosulphate (VI) acid to produce hydrogen chloride gas.



On heating a chloride with concentrated tetraoxosulphate (VI) in the presence of a strong oxidizing agent, chlorine is produced.



### TEST FOR CHLORIDES



The test solution is acidified with dilute trioxonitrate (V) acid to prevent precipitation of other salts. Few drops of  $\text{AgNO}_3(\text{aq})$  is then added to the acidified solution in a test tube, a white precipitate of  $\text{AgCl}$  which readily dissolves in excess  $\text{NH}_3(\text{aq})$  solution indicates the presence of a chloride.

### GENERAL EVALUATION/REVISION

1. Explain why hydrogen chloride in toluene does not conduct electricity but its aqueous solution does conduct electricity.
2. Describe a test for a soluble chloride.
3. Give FOUR uses of chlorine gas.
4. Define Ionization energy and Electronegativity.
5. State the second law of thermodynamics.

**READING ASSIGNMENT:** New School Chemistry for Senior Secondary Schools by O.Y. Ababio (6<sup>th</sup> edition) pages 356-361

### WEEKEND ASSIGNMENT

**SECTION A:** Write the correct option ONLY

1. The gas released when chlorine reacts with water in the presence of sunlight is a.  $\text{Cl}_2$  b.  $\text{H}_2$  c.  $\text{O}_2$  d.  $\text{N}_2$
2. A misty white fume produced when  $\text{HCl}$  gas react with ammonia is a.  $\text{NH}_4\text{OH}$  b.  $\text{NH}_4\text{Cl}$  c.  $\text{NaCl}$  d.  $\text{ZnCl}_2$
3. The reaction between common salt and concentrated tetraoxosulphate (VI) acid liberates a.  $\text{SO}_2$  b.  $\text{O}_2$  and  $\text{Cl}_2$  c.  $\text{HCl}$  gas d.  $\text{H}_2$
4. Apart from hydrogen chloride gas, which other common gas is used in the demonstration of fountain experiment? a.  $\text{H}_2\text{S}$  b.  $\text{SO}_2$  c.  $\text{NH}_3$  d.  $\text{CH}_4$
5. What property makes hydrogen chloride suitable for the fountain experiment? a. It is very soluble in water b. It is slightly soluble in water c. It dissolves in water to give an acidic solution d. It forms acid rain

### SECTION B

1. Explain why hydrogen chloride in toluene does not conduct electricity but its aqueous solution does conduct electricity.
2. Describe a test for a soluble chloride.

### WEEK SIX

DATE: \_\_\_\_\_

### TOPIC: NITROGEN

#### CONTENT

- General Properties of Nitrogen Family.
- Laboratory Preparation and Industrial Preparation of Nitrogen.
- Properties and Uses of Nitrogen.
- Nitrogen Cycle.

### GENERAL PROPERTIES OF NITROGEN FAMILY (GROUP VA ELEMENTS)

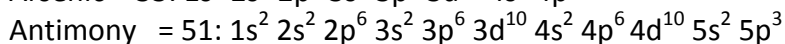
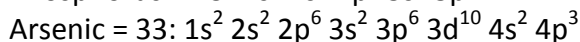
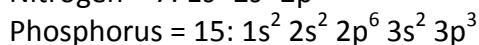
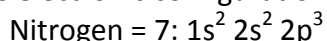
The group V elements include: Nitrogen, Phosphorus, Arsenic, Antimony and Bismuth. There are more differences than similarities between the elements in this group.



1. Nitrogen is a diatomic gas and does not exhibit allotropy. Phosphorus is a typical non-metal and exhibits allotropy. Arsenic and Antimony are metalloids; while bismuth is a metal.
2. Nitrogen is a colourless gas. Phosphorus exists in variety of allotropic forms like white and red phosphorus. Arsenic exists as a dull grey metallic solid. Antimony and bismuth is silvery-white solid.
3. Nitrogen is the most electronegative element in the group. It combines with metals and non-metals to form a variety of compounds.

### ELECTRONIC CONFIGURATION

The electronic configuration of the group V elements is as follows:



### NITROGEN

Nitrogen occurs chiefly as a free element in the air. It makes up 78% by volume of the atmosphere. It also exists in combined form in many compounds e.g ammonia, urea, proteins etc.

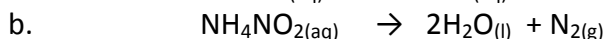
### LABORATORY PREPARATION

#### From Air

It can be obtained from air by passing air through caustic soda to remove  $\text{CO}_2$  and overheated copper turnings to remove  $\text{O}_2$  respectively. The nitrogen obtained is not pure, it contains 1% by volume of rare gases and it is denser than air.

Pure nitrogen is obtained in the laboratory by chemical method. The following chemicals are used to prepare nitrogen.

1. Thermal decomposition of ammonium dioxonitrate (III)





- Thermal decomposition of ammonium heptaoxodichromate (VI)  
$$(\text{NH}_4)_2\text{Cr}_2\text{O}_7(\text{s}) \rightarrow \text{Cr}_2\text{O}_3(\text{s}) + 4\text{H}_2\text{O}(\text{l}) + \text{N}_2(\text{g})$$
- Oxidation of ammonia by hot Copper (II) oxide  
$$2\text{NH}_3(\text{g}) + 3\text{CuO}(\text{s}) \rightarrow 3\text{Cu}(\text{s}) + 3\text{H}_2\text{O}(\text{g}) + \text{N}_2(\text{g})$$
- Reduction of dinitrogen (I) oxide by red-hot copper.  
$$\text{N}_2\text{O}(\text{g}) + \text{Cu}(\text{s}) \rightarrow \text{CuO}(\text{s}) + \text{N}_2(\text{g})$$

## INDUSTRIAL PREPARATION

Industrially, nitrogen is obtained by fractional distillation of liquid air.

## EVALUATION

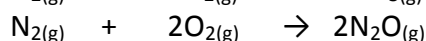
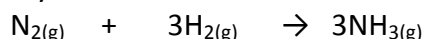
- Write the electronic configuration of nitrogen and phosphorus.
- Using balanced equations, state TWO methods of preparing nitrogen in the laboratory.

## PHYSICAL PROPERTIES

- It is colourless, odourless and tasteless
- Pure nitrogen is lighter than air.
- Slightly soluble in water
- Melting point – 210<sup>o</sup>C and boiling point is -196<sup>o</sup>C

## CHEMICAL PROPERTIES

- It reacts with very electropositive metals to form nitrides  
$$3\text{Mg}(\text{s}) + \text{N}_2(\text{g}) \rightarrow \text{Mg}_3\text{N}_2(\text{s})$$
- It reacts with non – metals like hydrogen and oxygen to form ammonia and oxides respectively.

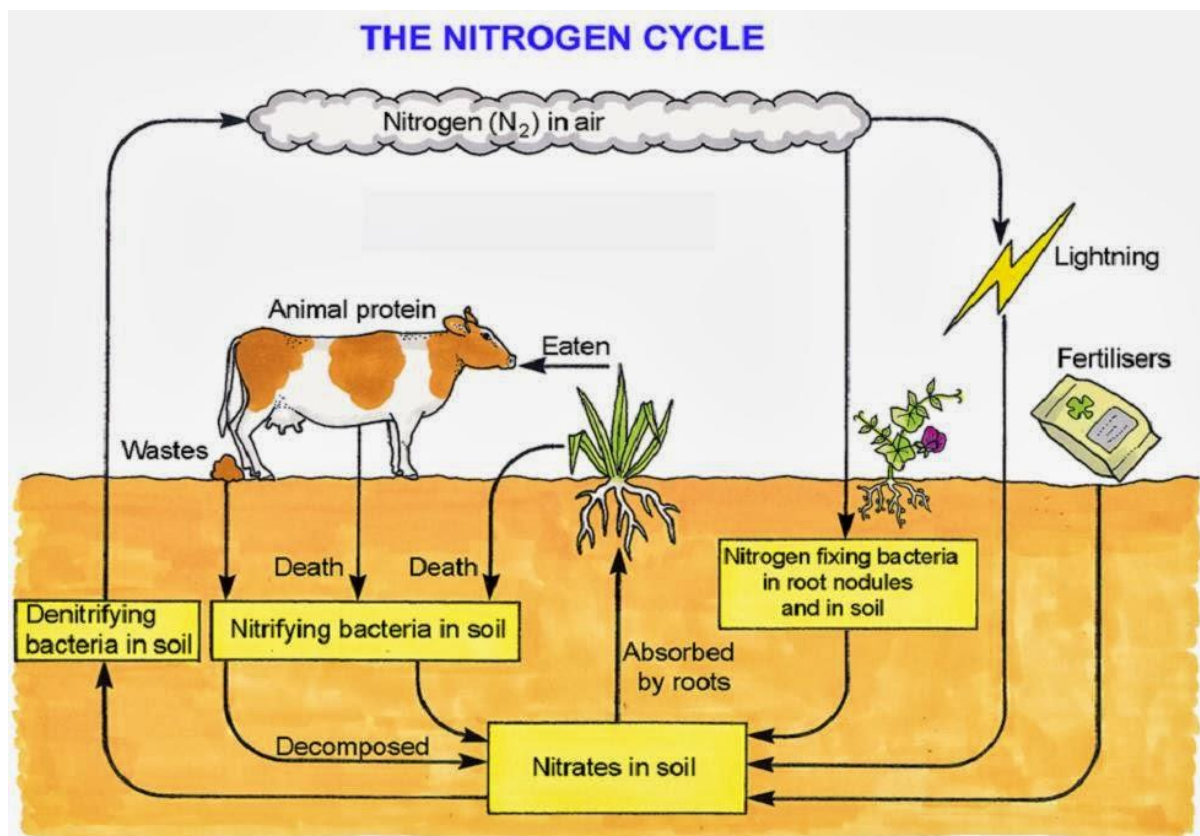


## USES

- It is used industrially to manufacture ammonia.
- Liquid nitrogen is used as a cooling agent.
- It is used as preservative in packaged foods to prevent rancidity.

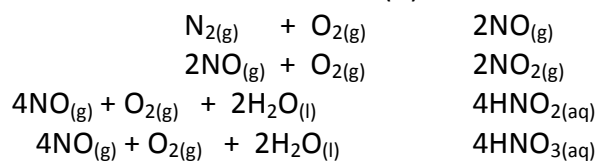
## EVALUATION

- State TWO physical properties and TWO chemical properties of nitrogen.
- Mention THREE uses of nitrogen.



The stages in which atmospheric nitrogen is converted into soil nitrogen and back to free nitrogen occurs in the following ways:

1. Oxidation of atmospheric nitrogen: During lightning and thunderstorm, there is electrical discharge in the atmosphere which cause atmospheric nitrogen and oxygen combine to form oxides of nitrogen which can dissolve in rain water as dioxonitrate (III) and trioxonitrate (V) acids. These acids go into the soil and react with mineral salts in the soil to form trioxonitrate (V) salts which is absorbed by plants.



2. Action of nitrogen-fixing bacteria: Soil micro-organisms like Rhizobium living in root nodules of leguminous plants are able to convert atmospheric nitrogen into organic nitrogenous compounds which are used directly by the host plants. These compounds are released into the soil when these plants die. Other free living micro-organisms in the soil like Azotobacter and Clostridium are also able to convert atmospheric nitrogen directly into trioxonitrate (V) which is absorbed by plants. These processes are known as nitrogen fixation.
3. Decay of organic matter: When plants and animal die, putrefying bacteria and fungi in the soil converts organic nitrogenous compounds to ammonia. Nitrifying bacteria like Nitrosomonas and Nitrobacter convert the ammonia to trioxonitrate (V) which can again be absorbed by plants. These processes are known as nitrification.
4. Denitrification: Trioxonitrate (V) salt in the soil can be converted to gaseous nitrogen by denitrifying bacteria. The process is known as Denitrification. The nitrogen so formed escapes into the atmosphere, where it becomes atmospheric nitrogen. Denitrifying bacteria therefore reduces the quantity of trioxonitrate (V) in the soil.



### GENERAL EVALUATION/REVISION

- Using balanced equation ONLY, show how nitrogen can be prepared in the laboratory.
- Outline the stages involved in the nitrogen cycle.
- Write the electronic configuration of  $N^{3-}$  and  $P^{5-}$ .
- Balance the following redox equation:  $I^- + MnO_4^- \rightarrow IO_3^- + MnO_2$  in basic medium
- State the effect of the following on the equilibrium position of the reaction below:  
 $3Fe(s) + 4H_2O(g) \rightleftharpoons Fe_3O_4(s) + 4H_2(g) \quad \Delta H = +ve$ 
  - Increase in temperature
  - Increase in pressure
  - Using iron filings instead of iron rod.

### READING ASSIGNMENT

New School Chemistry for Senior Secondary Schools by O. Y. Ababio (6<sup>th</sup> edition), pages 404-405, 422-423.

### WEEKEND ASSIGNMENT

#### SECTION A: Write the correct option ONLY

- In which group of the periodic table is nitrogen found? (a) 2 (b) 5 (c) 7 (d) 6
- The boiling point of nitrogen in  $^{\circ}C$  is (a) -183 (b) -196 (c) 200 (d) 240
- The percentage of nitrogen in air is (a) 78 (b) 75 (c) 71 (d) 67
- The following are uses of nitrogen except a. as a cooling agent b. to prevent rancidity c. in the manufacture of fertilizers d. in laundry.
- The atomicity of nitrogen is (a) 1 (b) 2 (c) 3 (d) 4

#### SECTION B

- Briefly describe the preparation of nitrogen from air in the laboratory.
- State three physical properties and two chemical properties of nitrogen.

### WEEK SEVEN

DATE: \_\_\_\_\_

#### TOPIC: COMPOUNDS OF NITROGEN

#### CONTENT

- Oxides of Nitrogen
- Ammonia: Preparation, Properties and Uses.
- Trioxonitrate (V) acid: Preparation, Properties and Uses.

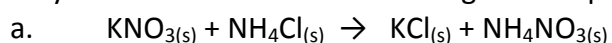
#### OXIDES OF NITROGEN

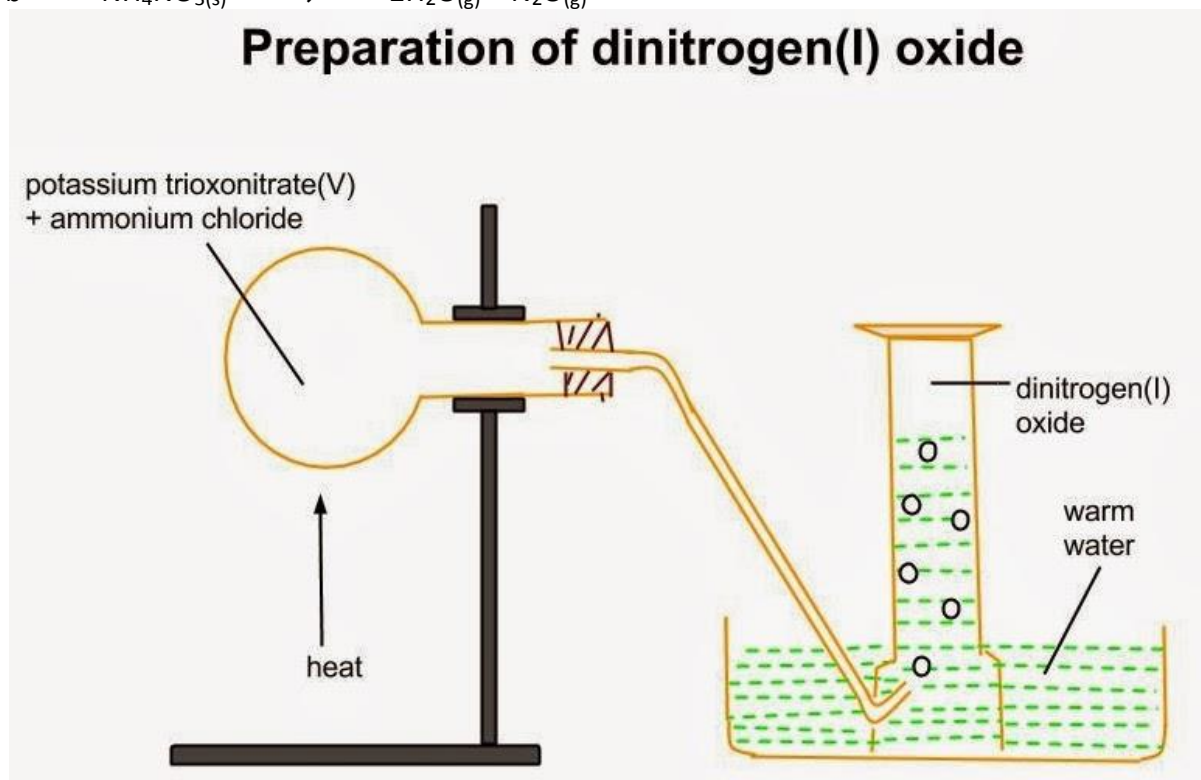
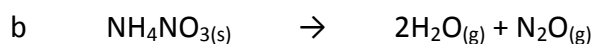
##### NITROGEN (I) OXIDE, $N_2O$

Nitrogen (I) oxide is known as laughing gas as it causes uncontrollable laughter when inhaled.

#### LABORATORY PREPARATION

The gas is prepared in the laboratory by thermal decomposition of ammonium trioxonitrate (V). Ammonium trioxonitrate (V) is not heated directly since the reaction is exothermic and may become uncontrollable leading to an explosion.



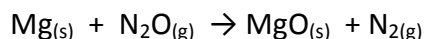


### PHYSICAL PROPERTIES

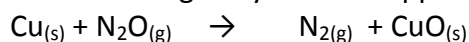
1. It is a colourless gas with a faint pleasant sickly smell and it has a sweetish taste.
2. It is fairly soluble in cold water.
3. It is 1.5 times denser than air.
4. It is neutral to moist litmus paper.

### CHEMICAL PROPERTIES

1. It decomposes on strong heating (about  $600^\circ\text{C}$ ) to form nitrogen and oxygen.  
$$2\text{N}_2\text{O}(\text{g}) \rightarrow \text{O}_2(\text{g}) + 2\text{N}_2(\text{g})$$
2. It supports the combustion of any burning substance which is hot enough to decompose it.



3. It is reduced to nitrogen by heated copper or iron



### TEST FOR $\text{N}_2\text{O}$

A glowing splinter is inserted into the gas jar containing the unknown gas. If the splinter is rekindled, the gas is either oxygen or nitrogen (I) oxide. If the gas has a pleasant smell and does not produce brown fumes with nitrogen (IV) oxide; then the gas is nitrogen (I) oxide.

**USE:** Nitrogen (I) oxide is used as anesthetic for minor surgical operations.

### EVALUATION

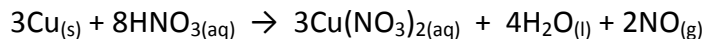
1. Describe the laboratory preparation of nitrogen (I) oxide.
2. Describe a test to distinguish between nitrogen (I) oxide and oxygen gas.



## **NITROGEN (II) OXIDE, NO**

### **LABORATORY PREPARATION**

Nitrogen (II) oxide is prepared by reacting 50% trioxonitrate (IV) acid with copper.



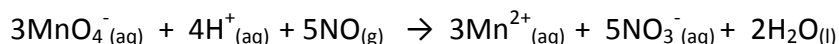
Some of the nitrogen (II) oxide gas reacts with oxygen in the flask to form brown fumes of nitrogen (IV) oxide which is dissolved in water as the gas is pass through water.

### **PHYSICAL PROPERTIES**

1. It is a colourless and poisonous gas.
2. It is almost insoluble in water.
3. It is slightly denser than air.
4. It is neutral to litmus.

### **CHEMICAL PROPERTIES**

1. It reacts readily with oxygen to form brown fumes of nitrogen (IV) oxide
$$2\text{NO}_{(g)} + \text{O}_{2(g)} \rightarrow 2\text{NO}_{2(g)}$$
2. It decomposes on heating at high temperature to form equal volume of nitrogen and oxygen
$$2\text{NO}_{(s)} \rightarrow \text{N}_{2(g)} + \text{O}_{2(g)}$$
3. It is reduced to nitrogen by hot metals
$$2\text{Cu}_{(s)} + 2\text{NO}_{(g)} \rightarrow 2\text{CuO}_{(g)} + \text{N}_{2(g)}$$
4. It acts as reducing agent decolourizing acidified potassium tetraoxomanganate (VI) slowly



### **TEST FOR NO**

1. Using air: the gas jar containing the unknown gas is opened, if the gas turns reddish-brown, then the gas is NO.
2. Using iron (II) tetraoxosulphate (VI): A solution of FeSO<sub>4</sub> which has been acidified with a little dilute H<sub>2</sub>SO<sub>4</sub> acid is poured into the gas jar containing the unknown gas. If the solution turns dark brown, then the gas is NO.

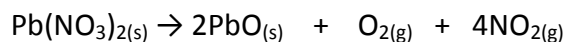
### **EVALUATION**

1. Give an equation to show the laboratory preparation of nitrogen (II) oxide.
2. State TWO physical and TWO chemical properties of nitrogen (II) oxide.

## **NITROGEN (IV) OXIDE, NO<sub>2</sub>**

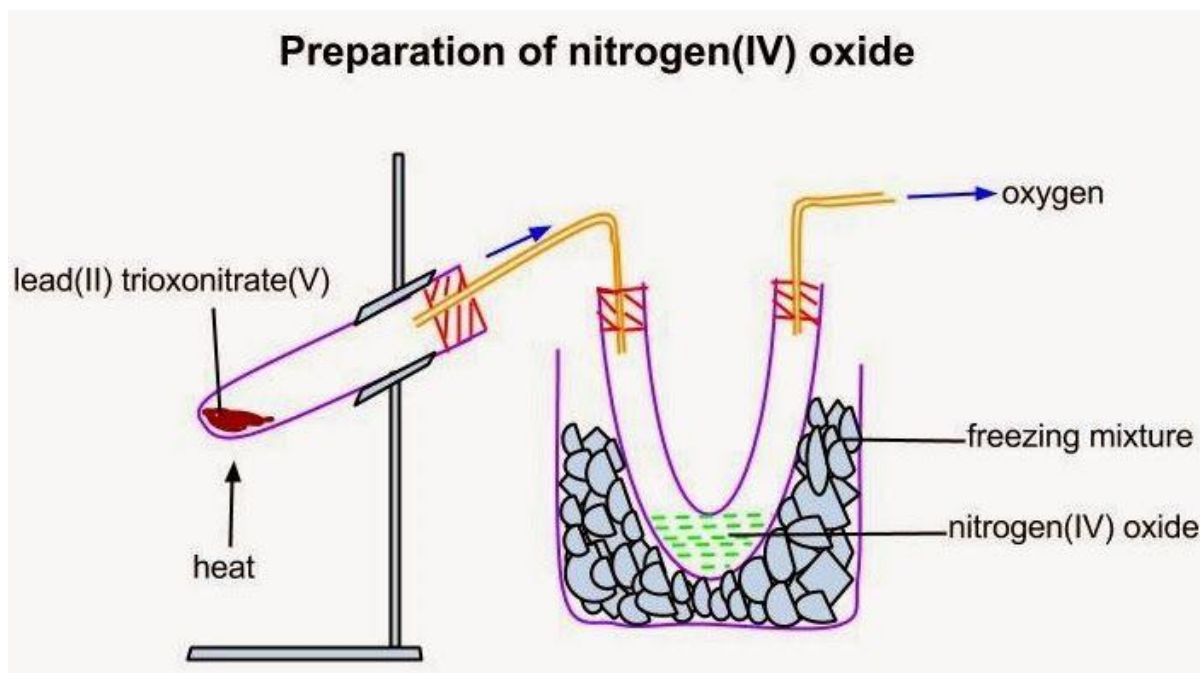
### **LABORATORY PREPARATION**

Nitrogen (IV) oxide is prepared by thermal decomposition of lead (II) trioxonitrate (V) because the nitrate does not contain water of crystallization which can interfere with the preparation.



The gas mixture obtained is passed through a U- tube immersed in a freezing mixture. Nitrogen (IV) oxide liquefies as a green liquid (yellow if pure) in the tube while oxygen escapes out.



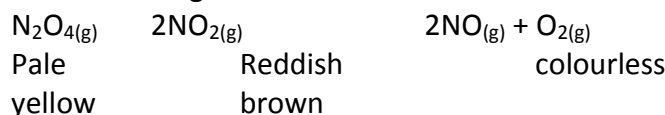


### PHYSICAL PROPERTIES

1. It is a reddish – brown gas.
2. It has an irritating smell and is poisonous.
3. It turns damp blue litmus paper red and dissolves in water to form acidic solution.
4. It liquefies into yellow liquid at 21°C.
5. It is much heavier than air.

### CHEMICAL PROPERTIES

1. Nitrogen (IV) oxide exists mainly as dinitrogen (IV) oxide,  $N_2O_4$  at low temperature. It decomposes on heating as follows.



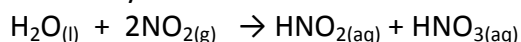
2. It supports combustion as it decomposes on heating to nitrogen and oxygen



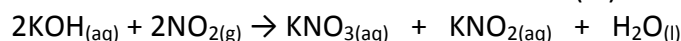
3. It is reduced to nitrogen by reducing agent.



4. It dissolves in water to form a mixture of dioxonitrate (III) and trioxonitrate (V) acids. It is a mixed acid anhydride.



5. It reacts with alkalis to form mixture of dioxonitrate (III) and trioxonitrate (V) salts



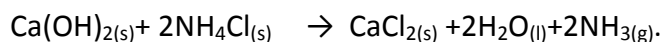
### AMMONIA

Ammonia is a hydride of nitrogen. It is produced in nature when nitrogenous matter decays in the absence of air. Thus, traces of ammonia may be found in the atmosphere but being very soluble in water, it is dissolved by rain water and washed down into the soil.

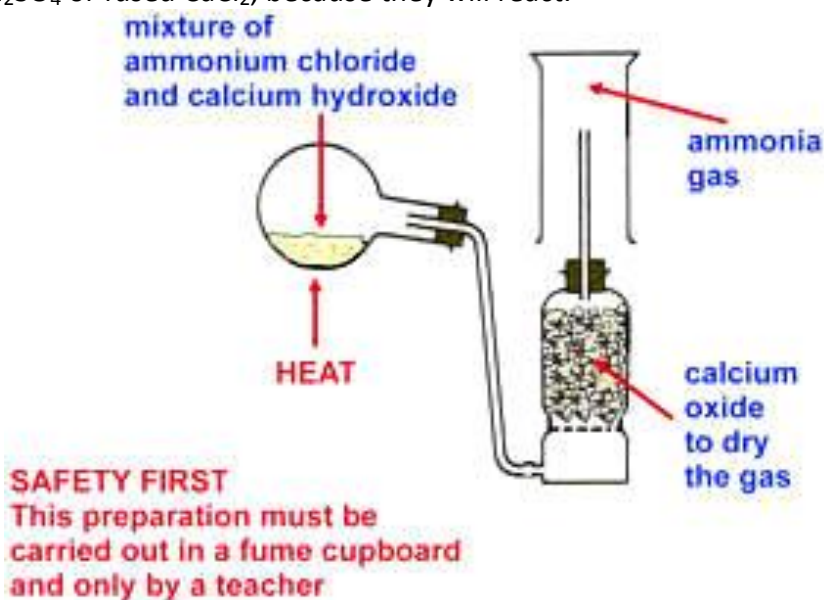
### LABORATORY PREPARATION OF AMMONIA



Ammonia is prepared in the laboratory by heating calcium hydroxide,  $\text{Ca(OH)}_2$  (slaked lime) with ammonium chloride.



Ammonia is dried using calcium oxide,  $\text{CaO}$ . Ammonia being alkaline cannot be dried using Conc.  $\text{H}_2\text{SO}_4$  or fused  $\text{CaCl}_2$ , because they will react.



## INDUSTRIAL PREPARATION

Ammonia is manufactured from nitrogen and hydrogen by the Haber process. It involves mixing nitrogen and hydrogen in ratio 1:3 by volume. The reaction is reversible so special conditions listed below are required for optional yield of ammonia.

- Finely divided iron catalyst is used
- Temperature of about  $450^\circ\text{C}$  is used
- Pressure of about 200atm is used.

The yield is about 15% under this condition

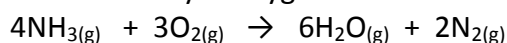


## PHYSICAL PROPERTIES

- It is a colorless gas with a characteristic choking smell.
- Ammonia in large quantity is poisonous as it affects respiratory muscles.
- It is the only known alkaline gas.
- It is about 1.7 times less dense than air.
- Solid ammonia melts at  $-34.4^\circ\text{C}$  and the liquid boils at  $-77.7^\circ\text{C}$ .

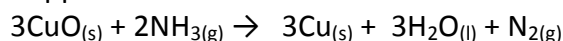
## CHEMICAL PROPERTIES

- Ammonia burns readily in oxygen to form water vapor and nitrogen

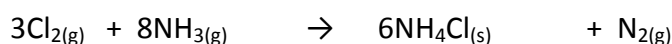


- Ammonia reacts as reducing agents reacting with

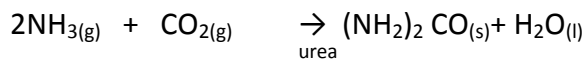
- Copper II oxide



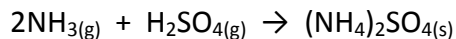
- Chlorine



- Ammonia reacts with carbon IV oxide to form Urea and water vapour.



4. Ammonia reacts with acid to form ammonium salts.



### TEST FOR AMMONIA

Ammonia has a choking smell. It can be confirmed using:

1. Litmus paper: Damped red litmus is dipped into the gas jar containing the unknown gas. If the litmus paper turns blue, then the gas is ammonia.
2. Hydrochloric acid: a glass rod is dipped in concentrated HCl and then inserted in the gas jar containing the unknown gas. If white fumes are observed on the glass rod, then the gas is ammonia.

### USES OF AMMONIA

1. Ammonia is used in the manufacture of trioxonitrate (V) acid and Sodium trioxocarbonate (IV) by the Solvay process.
2. Liquid ammonia is used as a refrigerant.
3. Aqueous ammonia is used in softening temporary hard water.
4. Aqueous ammonia is also used in laundries as a solvent for removing grease and oil stains.

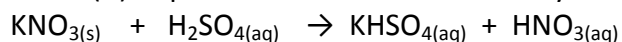
### EVALUATION

1. Briefly describe the laboratory preparation of ammonia.
2. State TWO physical and THREE chemical properties each of ammonia.

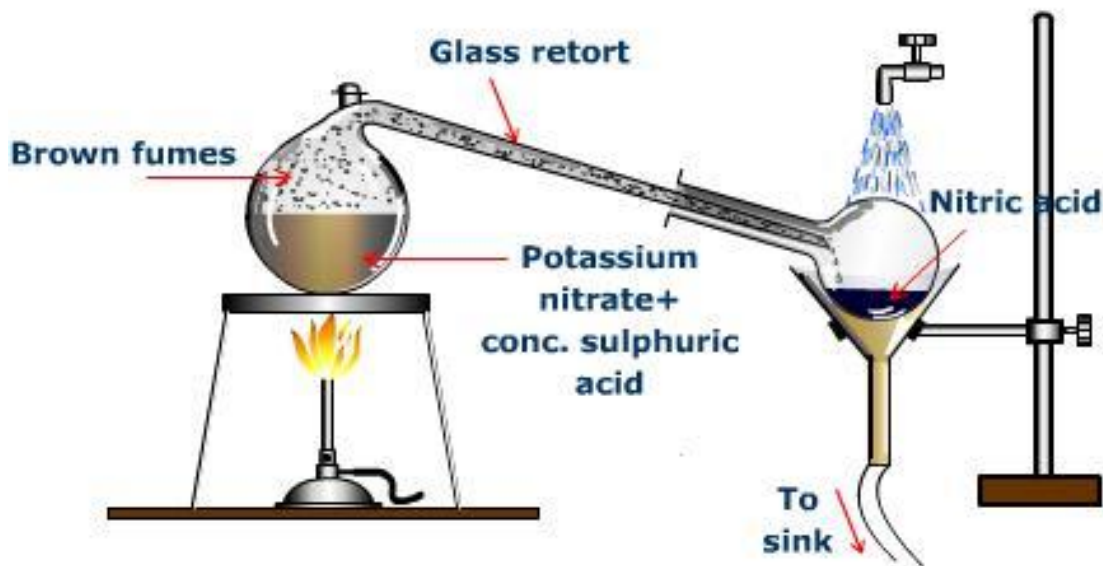
### TRIOXONITRATE (V) ACID, $\text{HNO}_3$

#### LABORATORY PREPARATION

Trioxonitrate (V) acid is a volatile acid and it is prepared in the laboratory by its displacement from any trioxonitrate salt by concentrated  $\text{H}_2\text{SO}_4$  which is less volatile. Trioxonitrate (V) of potassium or sodium is usually used because they are cheap.



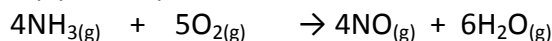
**NOTE:** An all glass apparatus must be used in this preparation because the hydrogen trioxonitrate (V) acid vapour will attack cork or rubber.



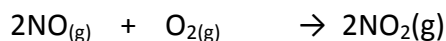
### INDUSTRIAL PREPARATION

Trioxonitrate (V) acid is obtained by the catalytic oxidation of ammonia:

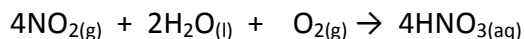
- Ammonia is treated with excess air using Platinum-rhodium catalyst at 700°C to produce nitrogen (II) oxide (96% conversion of NH<sub>3</sub> is obtained)



- Nitrogen (II) oxide formed is cooled and mixed with excess air to produce nitrogen (IV) oxide.



- Nitrogen (IV) oxide formed is dissolved with excess air in hot water to yield trioxonitrate (V) acid solution of up to 50% concentration.

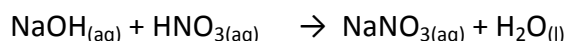


### PHYSICAL PROPERTIES

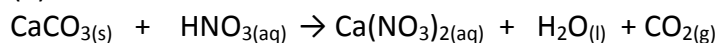
1. The pure acid is a colourless fuming liquid with sharp choking smell. The acid turns yellow due to its decomposition to nitrogen (IV) oxide which redissolves in the acid.
2. The pure acid boils at 86°C and melts at -47°C
3. The density of the pure acid is 1.52 gcm<sup>-3</sup>
4. The pure acid is miscible with water in all proportions and forms constant boiling mixture with it at 121°C
5. The concentrated form of the acid is corrosive.
6. The dilute acid turns blue litmus red.

### CHEMICAL PROPERTIES

1. As an acid it neutralizes bases and alkalis to form metallic trioxonitrate (V) and water only



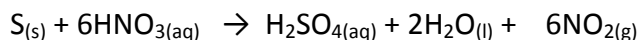
2. As an acid it reacts with metallic trioxocarbonate (IV) to liberate carbon (II) oxide



3. Unlike other acids, it rarely gives out hydrogen with metals except when very dilute solution is reacted with Ca, Mg or Mn.



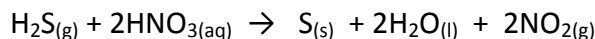
4. As an oxidizing agent, it reacts with non – metal to form the corresponding oxides of the non – metals.



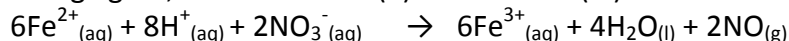
5. As an oxidizing agent, it oxidizes Cu, Pb, Hg and Ag to yield the respective trioxonitrate (V) and nitrogen (IV) oxide if concentrated, but nitrogen (II) oxide if the concentration is moderate.

Aluminum and iron are not oxidized to their oxides by concentrated  $HNO_{3(aq)}$  due to formation of a surface coating of oxide which is passive do not allow further reaction with the metals. Aluminum or iron lined container can be used to transport concentrated  $HNO_{3(aq)}$

6. As an oxidizing agent, it oxidizes hydrogen sulphide to sulphur



7. As an oxidizing agent, it oxidizes iron (II) salts to iron (III) salts



### USES

1. It is used as an acid, oxidizing agent and nitrating agent in the laboratory.
2. It is used in nylon production and Terylene.
3. It is used as rocket fuel.
4. It is used in production of fertilizers, dyes, drugs and explosives.

### GENERAL EVALUATION/REVISION

1. Describe the laboratory preparation of trioxonitrate (V) acid.
2. Write TWO equations of reactions in which trioxonitrate (V) is acting as an acid.
3. Write an equation to show the reaction of nitrogen (IV) oxide as a mixed anhydride.
4. Describe the electrolysis of  $CuSO_4$  solution using platinum electrodes.
5. Classify the following oxides:  $CuO$ ,  $Na_2O$ ,  $PbO$ ,  $NO_2$ ,  $N_2O$

### READING ASSIGNMENT

New School Chemistry for Senior Secondary Schools by O. Y. Ababio (6<sup>th</sup> edition), pages 406-409, 411-419.

### WEEKEND ASSIGNMENT

**SECTION A:** Write the correct option ONLY.

1. Pure trioxonitrate (V) acid is colourless but the product of its laboratory preparation is yellow because of the presence of dissolved a.  $N_2O$  b.  $NO$  c.  $NO_2$  d.  $NH_3$
2. Common laboratory drying agents are not used for drying ammonia because a. ammonia is alkaline b. ammonia forms complexes with them c. ammonia reacts with them and disappears into products d. ammonia is highly soluble in water
3. Ammonia has relatively high boiling point when compared with other similar compounds because a. ammonia is stable b. ammonia is easily liquefied c. ammonia has hydrogen bonding d. ammonia is soluble in water.
4. Aqueous ammonia solution used in the laboratory is referred to as aqueous ammonia and not ammonium hydroxide because a. ammonia dissolves in water without forming bond b. ammonia solution easily decomposes and liberated free ammonia when the temperature of the room rises leaving water in the bottle c. bond between ammonia and  $OH^-$  of water is weakly acidic d. ammonia is less dense than air.



5. Which of the following metals would be in passive state when treated with concentrated  $\text{HNO}_3$ ? a. Zinc b. Sodium c. Tin d. Iron

### SECTION B

1. Give reason for the following
  - a. The flask used for the laboratory preparation of ammonia is mounted in a slanting position
  - b. An all glass apparatus is used for the laboratory preparation of trioxonitrate (V) acid.
2. Give an example of a reaction in which ammonia behaves as a
  - a. reducing agent
  - b. base
  - c. precipitating agent

### WEEK EIGHT

DATE: \_\_\_\_\_

### TOPIC: SULPHUR

#### CONTENT

- General Properties of Sulphur Group.
- Electronic Structure of Sulphur Group.
- Extraction of Sulphur.
- Allotropes of Sulphur.
- Uses of Sulphur

#### GENERAL PROPERTIES OF THE SULPHUR GROUP (GROUP VI ELEMENTS)

The group VI elements include: Oxygen, Sulphur, Selenium, Tellurium and Polonium.

1. Metallic property increases down the group. Oxygen and sulphur are non-metal; selenium and tellurium are metalloid; while polonium is a metal.
2. All the elements are solid except oxygen which is a gas at room temperature.
3. Oxygen and sulphur exhibit allotropy.
4. They have six electrons in their outermost shell. Hence their oxidation number is -2; though sulphur can exhibit -4 and -6 states in some compounds.
5. Electronegativity decreases down the group. Thus, oxygen is a good oxidizing agent.

#### ELECTRONIC STRUCTURE OF SULPHUR GROUP

Members of the sulphur family include: Oxygen, Sulphur, Selenium, Tellurium and Polonium.

Their electronic configurations are shown below:

Oxygen = 8:  $1s^2 2s^2 2p^4$

Sulphur = 16:  $1s^2 2s^2 2p^6 3s^2 3p^4$

Selenium = 34:  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^4$

Tellurium = 52:  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^4$

Polonium = 84:  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 5d^{10} 5f^{14} 6s^2 6p^4$

#### SULPHUR

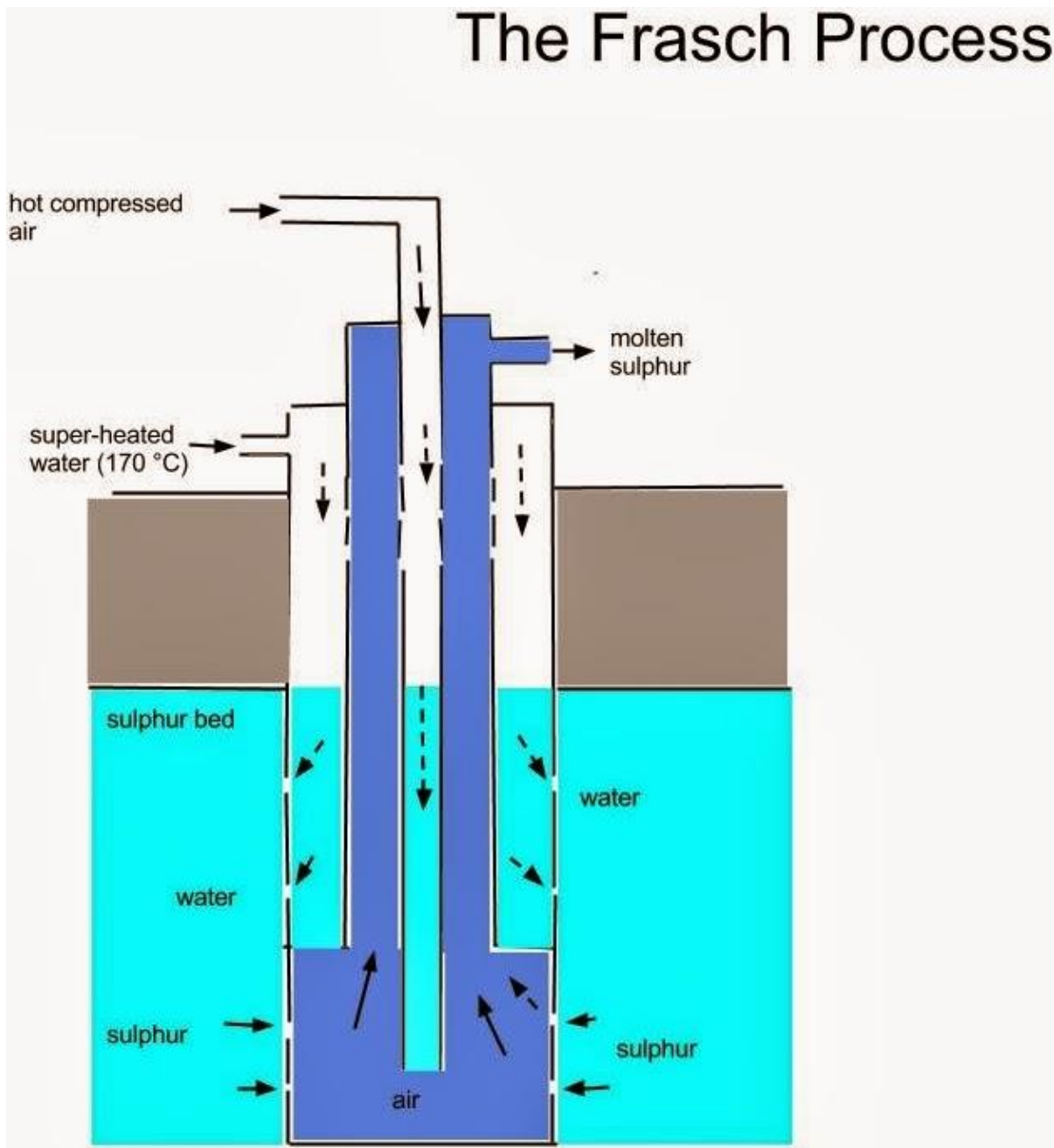
Sulphur is an element. It occurs freely as deposits and in combined state as sulphide and as tetraoxosulphate (IV).

#### EXTRACTION OF SULPHUR

Sulphur is extracted from underground by Frasch process. A three concentric sulphur pump is driven down a hole dug to the sulphur bed. The solid sulphur is melted at  $115^\circ\text{C}$  by super



– heated water at 170°C and 10atms. The molten sulphur is forced out by hot compressed air at 15atm. The molten sulphur is then continuously pumped out and allowed to solidify in a large tank. The sulphur obtained is 99.5% pure.



### ALLOTROPES OF SULPHUR

The two main crystalline allotropes of sulphur are:

- 1 Rhombic sulphur: A bright yellow octahedral crystalline solid. Each crystal is made up of  $S_8$  molecules. Rhombic sulphur is stable below 96°C.
- 2 Monoclinic Sulphur: This is amber coloured solid sulphur consisting of needle shaped  $S_8$  crystal. Stable above 96°C. It easily reverts to Rhombic below 96°C. The transition temperature between Rhombic and Monoclinic is 96°C.



### Comparison of the Physical Properties of Rhombic and Monoclinic Sulphur

1. Rhombic Sulphur melts at 113°C; while monoclinic sulphur melts at 119°C.
2. Rhombic sulphur has bright yellow colour; while monoclinic sulphur has amber colour.
3. Rhombic sulphur has octahedral shape; while monoclinic sulphur is needle-like in shape.
4. Rhombic sulphur is translucent; while monoclinic is transparent.

Sulphur also exists as non – crystalline solid. These are

1. Amorphous sulphur
2. Plastic sulphur

### EVALUATION

1. Briefly explain the Frasch process.
2. Name the two allotropes of sulphur and state their transition temperature.

### PHYSICAL PROPERTIES

1. Sulphur is a yellow solid.
2. It is insoluble in water but soluble in toluene and carbon (IV) sulphide.
3. It is a poor – conductor of heat and electricity.
4. It melts at 119°C and boils at 444°C.

### CHEMICAL PROPERTIES

1. It reacts directly with metals to form sulphide ( $S^{2-}$ )  
$$Fe_{(s)} + S_{(s)} \rightarrow FeS_{(s)}$$
2. It reacts with excess oxygen to form sulphur (IV) oxide  
$$O_{2(g)} + S_{(s)} \rightarrow SO_{2(g)}$$
3. It reacts with hydrogen to form hydrogen sulphide;  
$$H_{2(g)} + S_{(s)} \rightarrow H_2S_{(g)}$$
4. It reacts with coke (carbon) to form carbon (IV) sulphide.  
$$C_{(s)} + 2S_{(s)} \rightarrow CS_{2(l)}$$

### USES

1. Used in manufacturing tetraoxosulphate (IV) acid
2. Used in vulcanization of rubber
3. Used as germicides
4. Used in manufacturing bleaching agent

### GENERAL EVALUATION/REVISION

1. State THREE physical and chemical properties of sulphur.
2. Outline THREE differences between monoclinic and rhombic sulphur.
3. Describe the Frasch process for the extraction of sulphur.
4. State TWO differences between a conductor and an electrolyte.
5. List the steps involved in the treatment of water for municipal supply.

### READING ASSIGNMENT

New School Chemistry for Senior Secondary Schools by O. Y. Ababio (6<sup>th</sup> edition), page 381-384





### WEEKEND ASSIGNMENT

#### SECTION A: Write the correct option ONLY

1. Sulphur is extracted by (a) Haber process (b) Frasch process (c) Solvay process (d) Contact process
2. Which of the following is a crystalline allotropes of sulphur (a) Monoclinic (b) Plastic (c) Amorphous (d) Colloidal
3. The density of rhombic sulphur is (a) 1.2 (b) 1.5 (c) 2.08 (d) 1.98
4. The shape of monoclinic sulphur is (a) needle shape (b) hexagonal (c) octahedral (d) tetrahedral
5. Sulphur is used for (a) making of cellulose (b) cooking rice (c) vulcanizing rubber (d) manufacturing glass

#### SECTION B

1. Give three differences between rhombic sulphur and monoclinic sulphur
2. Briefly describe the extraction of sulphur

### WEEK NINE

DATE: \_\_\_\_\_

#### TOPIC: COMPOUNDS OF SULPHUR

#### CONTENT

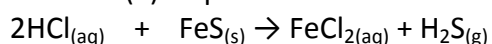
- $\text{H}_2\text{S}$ ,  $\text{SO}_2$  and  $\text{SO}_3$ : Preparation, Properties and Uses
- Tetraoxosulphate (VI) acid: Industrial Preparation (Contact Process).

#### HYDROGEN SULPHIDE, $\text{H}_2\text{S}$

Hydrogen sulphide is found in volcanic gases, sulphur springs, coal gas and natural gas.

#### LABORATORY PREPARATION

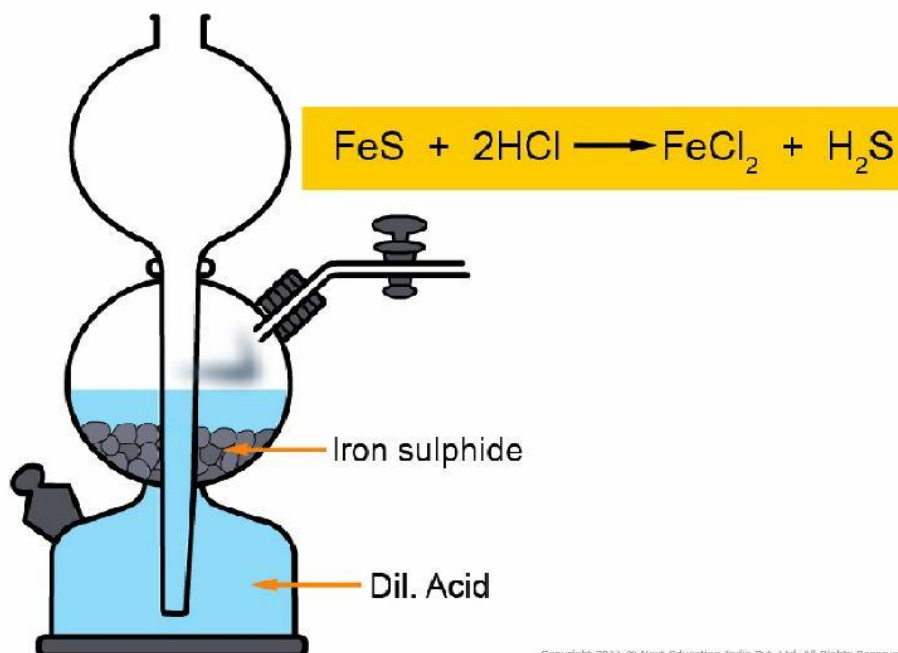
Hydrogen sulphide is prepared in the laboratory by the action of dilute acids on metallic sulphide like Iron (II) sulphide



The apparatus used for regular supply of hydrogen sulphide in the laboratory is Kipp's apparatus.



## Kipp's Apparatus



### PHYSICAL PROPERTIES

1. Hydrogen sulphide is a colourless gas with smell like that of rotten egg.
2. It is a very poisonous.
3. It is about 1.18 times denser than air.
4. It is moderately soluble in water to form very weak acidic solution.
5. It burns with pale blue flame.

### CHEMICAL PROPERTIES

1. As an acid it reacts with alkali to form a normal salt and water
$$2\text{NaOH}_{(aq)} + \text{H}_2\text{S}_{(g)} \rightarrow \text{Na}_2\text{S}_{(aq)} + 2\text{H}_2\text{O}_{(l)}$$
2. It reacts with excess oxygen to form sulphur (VI) oxide but forms deposit of sulphur with limited oxygen
$$2\text{H}_2\text{S}_{(g)} + 3\text{O}_2_{(g)} \rightarrow 2\text{H}_2\text{O}_{(l)} + 2\text{SO}_2_{(g)}$$
$$2\text{H}_2\text{S}_{(g)} + \text{O}_2_{(g)} \rightarrow 2\text{H}_2\text{O}_{(l)} + 2\text{S}_{(s)}$$
3. As a reducing agent, it reacts with many oxidizing agents such as acidified  $\text{KMnO}_4$ , acidified  $\text{K}_2\text{Cr}_2\text{O}_7$ , chlorine gas,  $\text{FeCl}_2$ ,  $\text{SO}_2$ ,  $\text{H}_2\text{SO}_4$  and  $\text{HNO}_3$

### TEST FOR HYDROGEN SULPHIDE

A piece of filter paper is moisten with lead (II) trioxonitrate (V) solution and dropped it into a gas jar of the unknown gas. If the paper turns black, then the gas is  $\text{H}_2\text{S}$ .

### EVALUATION

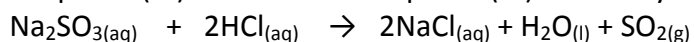
1. Name the reagents used in laboratory preparation of hydrogen sulphide.
2. List TWO physical and chemical properties each of hydrogen sulphide.

### SULPHUR (IV) OXIDE, $\text{SO}_2$

#### LABORATORY PREPARATION



Sulphur (IV) oxide is prepared in the laboratory by heating sodium or potassium trioxosulphate (IV) with tetraoxosulphate (IV) acid or hydrochloric acid.

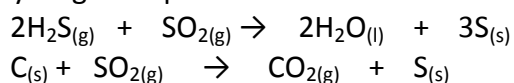


### PHYSICAL PROPERTIES

1. Sulphur (IV) oxide is a colourless poisonous gas with smell like that of burning matches.
2. It is very soluble in water.
3. It is about 2.5 times denser than air.

### CHEMICAL PROPERTIES

1. As an acid, it reacts with alkali to form normal salt of trioxosulphate and water only
$$2\text{NaOH}(\text{aq}) + \text{SO}_2(\text{g}) \rightarrow \text{Na}_2\text{SO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$$
2. As reducing agent, sulphur (IV) oxide reacts with many oxidizing agents such as acidified  $\text{KMnO}_4$ ; acidified  $\text{K}_2\text{Cr}_2\text{O}_7$ ;  $\text{FeCl}_3$ ,  $\text{HNO}_3$ , chlorine gas. It decolorizes acidified purple  $\text{KMnO}_4$  and turns acidified orange  $\text{K}_2\text{Cr}_2\text{O}_7$  to green.
3. It reacts as bleaching agent decolourising dye by its bleaching action. The bleaching action is similar to that of chlorine in that there must be water. But, while chlorine bleaches by oxidation sulphur IV oxide bleaches by reduction.
4. Sulphur (IV) oxide reacts as oxidizing agent in the presence of strong reducing agent such as hydrogen sulphide.



### TEST FOR $\text{SO}_2$

1. If an unknown gas bleaches a coloured flower,  $\text{SO}_2$  can be suspected
2. The unknown gas bubbled through solution of either acidified potassium heptaoxodichromate (VI) or potassium tetraoxomanganate (VII). If orange colour of the acidified  $\text{K}_2\text{Cr}_2\text{O}_7$  turn green or the purple colour of the acidified  $\text{KMnO}_4$  turns colourless, then the unknown gas is  $\text{SO}_2$

### USES

1. It is used in manufacture of tetraoxosulphate (VI) acid.
2. It is used as a germicides and a fumigant especially for destroying termites.
3. It is used as bleaching agent for straw, silt and wood.
4. It is used as preservative in some liquid e.g orange juice.
5. Liquid sulphur (IV) oxide is used as refrigerant.

### EVALUATION

1. Give one method of preparing sulphur (IV) oxide in the laboratory.
2. State THREE physical and chemical properties of sulphur (IV) oxide.

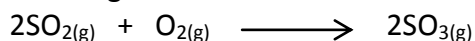
### SULPHUR (VI) OXIDE, $\text{SO}_3$

Sulphur (VI) oxide is prepared by reacting sulphur (IV) oxide and oxygen under special conditions which are:

1. Presence of platinized asbestos or vanadium (V) oxide as catalyst
2. Pressure of 1atm



3. Temperature range of 400°C – 450°C.



#### PHYSICAL PROPERTIES OF SO<sub>3</sub>

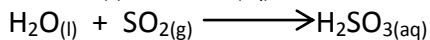
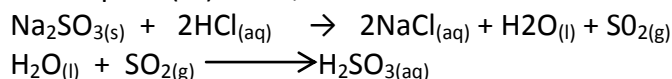
1. It exists as white needle-like crystals at room temperature.
2. It has a low boiling point and vapourizes on gentle heating.
3. It dissolves readily in water to give tetraoxosulphate (VI) acid.

#### TRIOXOSULPHATE IV ACID, H<sub>2</sub>SO<sub>3</sub>

Trioxosulphate (IV) acid is a dibasic acid with a molecular formula H<sub>2</sub>SO<sub>3</sub>

#### LABORATORY PREPARATION OF H<sub>2</sub>SO<sub>3</sub>

It is prepared by the action of dilute hydrochloric acid on heated sodium trioxosulphate (IV) to produce sulphur (IV) oxide, which is then dissolved in water.



Sulphur (IV) Oxide is the acid anhydride of trioxosulphate (IV) acid.

#### PHYSICAL PROPERTIES OF H<sub>2</sub>SO<sub>3</sub>

1. It turns blue litmus paper red.
2. It is colourless liquid.
3. It is mixes readily with water.
4. It has an irritating and choking smell.

#### CHEMICAL PROPERTIES OF H<sub>2</sub>SO<sub>3</sub>

1. It reacts with alkalis to form salt and water.  
$$2\text{NaOH}_{(aq)} + \text{H}_2\text{SO}_{3(aq)} \rightarrow \text{Na}_2\text{SO}_{3(aq)} + 2\text{H}_2\text{O}_{(l)}$$
2. It is oxidized in air to tetraoxosulphate (VI) acid  
$$2\text{H}_2\text{SO}_{3(aq)} + \text{O}_{2(g)} \rightarrow 2\text{H}_2\text{SO}_{4(aq)}$$
3. It reduces oxidizing agent such as potassium tetraoxomanganate (VII) and potassium heptaoxidichromate (VI).
4. It bleaches dyes in the presence of water.

#### TEST FOR SO<sub>3</sub><sup>2-</sup>

Barium chloride solution is added to the solution of the unknown substance. A white precipitate soluble in dilute hydrochloric acid confirms the presence of a trioxosulphate (IV) ion.

#### USES OF H<sub>2</sub>SO<sub>3</sub>

1. It is used for bleaching straw and other fabrics.
2. It is used as a germicide.

#### EVALUATION

1. Write an equation of reaction for the laboratory preparation of trioxosulphate IV
2. State two physical and two chemical properties of trioxosulphate IV

#### TETRAOXOSULPHATE VI ACID, H<sub>2</sub>SO<sub>4</sub>

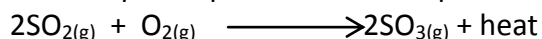


Tetraoxosulphate VI acid is one of the most important chemical compounds known. It is used in almost every manufacturing process; hence it is mostly prepared industrially.

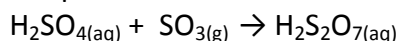
### INDUSTRIAL PREPARATION OF H<sub>2</sub>SO<sub>4</sub>

Industrially, tetraoxosulphate VI acid is manufactured by Contact process. The following steps are involved in Contact process.

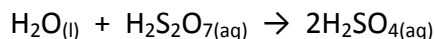
1. Burning sulphur in dry air to obtain sulphur (IV) oxide, SO<sub>2</sub>  
$$S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$$
2. The sulphur (IV) oxide produced is mixed with excess air and passed through an electric chamber to remove impurities and dust which may poison the catalyst. The gaseous mixture is then passed through concentrated H<sub>2</sub>SO<sub>4</sub> to dry it before passing it into the reaction chamber.
3. The dried gaseous mixture is delivered to the contact tower (reaction chamber) where the sulphur (IV) oxide and oxygen combine in the presence of pellets of catalyst, vanadium (V) oxide, V<sub>2</sub>O<sub>5</sub> to yield sulphur (VI) oxide. The reaction takes place at atmospheric pressure and temperature of 450-500°C.



4. The sulphur (VI) oxide is cooled and then dissolved in concentrated H<sub>2</sub>SO<sub>4</sub> to produce a thick liquid called Oleum.



5. The Oleum is then diluted with water appropriately to produce 98% tetraoxosulphate (VI) acid.



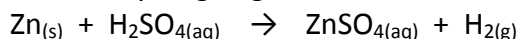
**NOTE:** Sulphur (VI) oxide is not dissolved directly in water to produce the acid because of the large amount of heat that is evolved in the process. The heat is capable of boiling the acid formed to produce mist of droplets which can spread throughout the factory and cause acid burns.

### PHYSICAL PROPERTIES

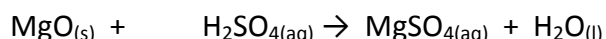
1. It is a colourless, vicious liquid with density of 1.84gcm<sup>-3</sup>
2. It is corrosive and cause burns when in contact with the skin.
3. It is highly soluble in water evolving large amount of heat.

### CHEMICAL PROPERTIES

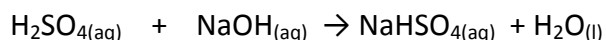
1. As an acid, it reacts with metal which are above hydrogen in the electrochemical series to liberate hydrogen gas



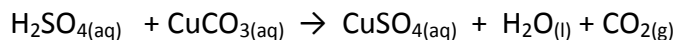
2. It reacts with bases to form salts and water



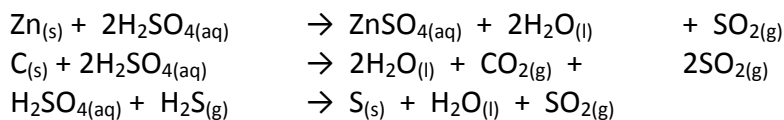
3. It reacts with alkali to form normal and acidic salt



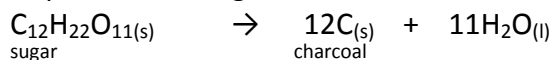
4. As an acid, it reacts with trioxocarbonate (IV) to liberate carbon (IV) oxide



5. As oxidizing agent, concentrated H<sub>2</sub>SO<sub>4</sub> oxidize metals, non –metals and hydrogen sulphide in the following ways.



6. Concentrated tetraoxosulphate (VI) acid is a dehydrating agent, removing water from compounds like sugar, ethanol, methanoic acid and ethanedioic acid



7. Concentrated tetraoxosulphate (VI) displaces volatile acids from their salts



### TEST FOR $\text{SO}_4^{2-}$

Barium chloride solution is added to the solution of the unknown substance. A white precipitate insoluble in excess dilute hydrochloric acid confirms the presence of a tetraoxosulphate (VI) ion.

### USES OF $\text{H}_2\text{SO}_4$

- 1 It is used in production of fertilizers e.g ammonium tetraoxosulphate (VI).
- 2 It is used in purification of crude oil.
- 3 It is used as an electrolyte in lead acid accumulator.
- 4 It is used as drying agent for many gases except  $\text{NH}_3$  and  $\text{H}_2\text{S}$  gas.
- 5 It is used to clean metals before electroplating.

### USES OF TETRAOXOSULPHATE (VI) SALTS

1. Ammonium tetraoxosulphate (VI) used as fertilizers
2. Sodium tetraoxosulphate (VI) is used in paper manufacture and as a purgative
3. Calcium tetraoxosulphate (VI) is mined as gypsum and when heated forms plaster of Paris used to set broken bones.
4. Aluminum tetraoxosulphate (VI) is used to coagulate precipitate in purification of water
5. Iron II tetraoxosulphate (VI) is used to treat anaemia.

### GENERAL EVALUATION/REVISION

1. Using equations only, outline the steps involve in the Contact process.
2. State THREE physical and chemical properties each of tetraoxosulphate (VI) acid
3. Give three uses of tetraoxosulphate (VI) salts.
4. A current is passed through three electrolytic cells connected in series containing solutions of silver trioxonitrate (V), copper (II) tetraoxosulphate (VI) and brine respectively. If 12.7g of copper is deposited in the second electrolytic cell, calculate
  - a. the mass of silver deposited in the first cell,
  - b. the volume of chlorine liberated in the third cell at  $17^\circ\text{C}$  and 800mmHg pressure.  
[Ag = 108, Cu = 63.5, 1F = 96500C, Molar gas volume at s.t.p =  $22.4 \text{ dm}^3$ ]
5.  $1.33 \text{ dm}^3$  of water at  $70^\circ\text{C}$  is saturated by 2.25moles of lead (II) trioxonitrate (V), and  $1.33 \text{ dm}^3$  of water at  $18^\circ\text{C}$  saturated by 0.53mole of the same salt. If  $4.50 \text{ dm}^3$  of the saturated solution are cooled from  $70^\circ\text{C}$  to  $18^\circ\text{C}$ , calculate the amount of solute that will be deposited in
  - a. moles
  - b. grams [ Pb = 207, N= =14 O = 16]



### READING ASSIGNMENT

New School Chemistry for Senior Secondary School by O. Y. Ababio (6<sup>th</sup> edition), pages 384-396

### WEEKEND ASSIGNMENT

**SECTION A:** Write the correct option ONLY.

1. The acid anhydride of tetraoxosulphate (VI) acid is a.  $\text{SO}_2$  b.  $\text{SO}_3$  c.  $\text{SO}_4$  d.  $\text{SO}$
2. Which of the following compounds gives a white precipitate with acidified barium chloride solution? a.  $\text{K}_2\text{SO}_4$  b.  $\text{NaNO}_3$  c.  $\text{KCl}$  d.  $\text{CaCO}_3$
3. Why do we acidify the solution used for testing for the presence of  $\text{SO}_4^{2-}$ ? a. To prevent the precipitation of any other ion that may be present in the solution. b. To acidify the test solution. c. To increase the rate of the reaction d. The acid acts as catalyst.
4. Which of the following is used as catalyst in the Contact process? a.  $\text{V}_2\text{O}_5$  b. Platinum c.  $\text{Fe}_3\text{O}_2$  d. Nickel
5. What is the colour of tetraoxosulphate VI acid? a. Colourless b. White c. Blue d. Pale white

### SECTION B

1. Explain why sulphur (VI) oxide is not dissolve directly in water during the Contact process for preparing tetraoxosulphate (VI) acid.
2. Using balanced equations ONLY, describe the stages involved in the manufacture of tetraoxosulphate (VI) acid using the Contact process.