CHEMISTRY NOTE FOR SS 1 SECOND TERM

SCHEME OF WORK

1. **GAS LAWS**: Kinetic theory of matter. States of matter. Change of state. Latent heat of fusion and vaporization. Phenomena supporting the kinetic theory. Kinetic theory of gases. Deviations from the law. Boyle's law. Charles' law. General gas law. Ideal gas equation.
2. **GAS LAWS:** Gay Lussac's law. Avogadro's law. Graham's law of diffusion. Dalton's law of partial pressure. Molar volume of gases. Avogadro's number and the mole concept. Calculations based on the gas laws.
3. **ACIDS, BASES AND SALTS:** Preparation, properties and uses of acids. Preparation, properties and uses of bases. Types of salts. Preparation of soluble and insoluble salts.
4. **MEASUREMENT OF ACIDITY AND ALKALINITY:** pH scale. Acid-base indicators. Efflorescent, hygroscopic and deliquescent substances. Water of crystallization. Drying and dehydration.
5. **CARBON AND ITS COMPOUNDS:** Occurrence, allotropes, structure and properties of carbon. Amorphous carbon.
6. **COAL:** Types of coal. Industrial distillation of coal. Uses of the product obtained from industrial distillation of coal.
7. **COKE:** Gasefication of coke and uses of its products.
8. **OXIDES OF CARBON:** Occurrence, preparation, physical and chemical properties, uses.
9. **TRIOXOCARBONATES(IV) AND HYDROGEN TRIOXOCARBONATE (IV):** Preparation, properties and uses.
10. **CARBON CYCLE:** Activities that remove carbon (IV) oxide from the atmosphere. Activities that liberate carbon(IV) oxide to the atmosphere.

KINETIC THEORY OF MATTER

Matter is made up of tiny particles called **atoms, molecules or ions.** The kinetic theory postulates that these particles are continually in motion and so possess kinetic energy. Matter is classified into three states:- solid, liquid and gas. Matter can change from one state to another.

Kinetic theory deals with how the particles in a substance is arranged, how it determines the properties of the substance possess and the physical state of the substance under certain conditions

SOLID STATE

Substances in the solid state are made up of particles which are very closely packed and are held firmly together by forces of cohesion. The cohesive forces may be electrovalent, covalent, metallic or even Vander waal forces. These cohesive forces, holding the particles of a solid are strong enough to prevent the movement of translation i.e moving from one place to another. The particles of a solid can only vibrate and rotate about their fixed positions but cannot translate. Hence solids have definite shapes, definite volumes and are difficult to compress. The strength of any solid is determined by the type of bond/forces holding the particles together.

When a solid is heated, the particles acquire greater kinetic energy and vibrate more violently till the crystal collapses into a liquid state

LIQUID STATE

The liquid state is intermediate in character between the complete molecular randomness that characterizes gases and the orderly arrangement of molecules of crystalline solids. The particles in a liquid are further apart than those in a solid and can move about because they have more kinetic energy than solid and are not held in a fixed position. They are still under the influence of cohesive forces and their movements are restricted. They can vibrate, rotate and translate. It has no definite shape but assumes the shape of the container in which it is placed.

GASEOUS STATE

The particles in a gas have more kinetic energy than those in a liquid. The cohesive forces are negligible and the particles are free to move about in all directions at great speed, restricted only by the walls of the container. Gas has no definite shape but occupies the whole volume of the container. Gas particles are relatively apart therefore can be readily compressed together.

COMPARISON OF PROPERTIES OF SOLID, LIQUID AND GAS

Property	**Solid**	**Liquid**	**Gas**
Mass	Fixed	Fixed	Fixed
Volume	Fixed	Fixed	No fixed volume
Movement	Particles can vibrate, rotate about a fixed position	Particles vibrate, rotate and move within a restricted space	Particles move at great speed and at random
Shape	Fixed	No Fixed shape	No fixed shape
Compressibility	Incompressible	Incompressible	Compressible
Density	Very dense	Less dense	Least dense

Orderliness increases from gas to solid

Random motion increases from solid to gas

Kinetic energy increases from solid to gas

Disorderliness or entropy increases from solid to gas

Force of cohesion increases from gas to solid

CHANGE OF STATE

Change of state is brought about by change in temperature. When a substance is heated, its particles acquire more kinetic energy. When cooled, they become less energetic.

Melting

When a solid is heated, the particles acquire more kinetic energy and vibrate more violently. At a certain temperature called the melting point of the solid, the forces of vibration overcome the binding forces and the crystalline structure collapses. The particles are no longer held in a fixed position but are free to move about. We say the solid have melted or liquefied. Impurity lowers the melting point of a solid. Sometimes, a solid changes directly into the gaseous state when it is heated, this is known as **sublimation**.

Evaporation

When a liquid is heated, the liquid particles acquire greater kinetic energy and begins to move randomly. The surface of a liquid is level and behaves like a stretched skin preventing liquid molecules from escaping into the space above the liquid. Some molecules are more energetic than others, they break away from the attractive force of the other nearby molecules when they come near the surface of the liquid body and escape into the space above. (Particles in a liquid are attracted by neighboring particles in all directions equally). Since evaporation results in escape of the energetic particles, the average kinetic energy is lowered and hence the temperature drops. Increase in temperature results in increase in rate of evaporation because the average kinetic energy of the particle is increased. Rate of evaporation is slower in electrovalent liquid than covalent liquids. More energy is needed to vaporize an electrovalent liquid than the volatile covalent liquids.

Vapor Pressure

When a liquid vaporizes in a closed container, the escaped particles will gradually accumulate in the space above the liquid. Hence, the particles collide together frequently with one another and with the walls of the container and consequently exert a pressure known as the vapour pressure. The vapour pressure of a liquid is a measure of the tendency of the liquid to vapourize at a given temperature. Some vapour particles hit the liquid surface and re-enter the liquid i.e condense. Condensation increases as vapour pressure increases.

Liquid particles vapour particles

A state of equilibrium is said to be attained when the rate of evaporation is the same as the rate of condensation. At this point, the vapour pressure stops rising and remains constant. This is called the **saturated vapour pressure** at that temperature. **Saturated vapour pressure** is the pressure at which the number of liquid particles is equal to the number of vapour particles**.** Vapour pressure depends on the temperature and the nature of the liquid.

Boiling

When a liquid is heated, the rate of evaporation as well the vapour pressure also increases. Boiling occurs when the saturated vapour pressure of a liquid is equal to the prevailing atmospheric pressure. The temperature at which the saturated vapour pressure is equal to the prevailing atmospheric pressure is known as the **boiling point** of that liquid. Bubbles of vapour form in the liquid and rise to the surface above the liquid. Impurities increases boiling point. Boiling point increases with increase in atmospheric pressure and vice versa. For example water will normally boil at a temperature of 100°C at a pressure of 1atm but will boil at 98.6°C at a lower temperature of 0.95atm and also at 101.4°C at a higher pressure of 1.05atm.

Freezing and Condensation

Heating causes melting and boiling while cooling causes condensation and freezing. Condensation is a process whereby a vapour looses some of its kinetic energy to a cooler body and changes into a liquid state. This is what happens when a bottle of milk is removed from the refrigerator and placed on the table. The water vapour in the air around the bottle lose some of its kinetic energy to the bottle (cold bottle) and condense as droplets of a liquid water on the surface of the bottle. When a liquid cools, it loses heat energy to the surrounding causing its temperature to drop. If cooling continues, the temperature keeps dropping until it changes to a solid. This is known as the freezing point of a liquid. It is the temperature at which solid and liquid are in equilibrium under a pressure of 1atm. At freezing point, the solid-liquid system remains in equilibrium until all the solid has frozen over.

LATENTS HEAT OF FUSION AND VAPORIZARTION

It is observed that during the process of melting, no heat was supplied to the system but there is hidden (latent) heat energy that weakens the cohesive forces of the liquid. The heat energy needed to overcome the cohesive forces during melting is known as the **latent heat of fusion** while the heat energy needed to overcome the cohesive forces during boiling is known as the **latent heat of vaporization**

Student exercise: Write two differences between (a). boiling and evaporation (b). gas and vapour

What is the relationship between cohesive force and boiling

Explain why evaporation causes cooling

What is triple point

PHENOMENA SUPPORTING THE KINETIC THEORY

1. **Brownian movement**: This is the irregular, zig-zag movement of particles due to bombardment of the solid particles by the surrounding molecules e.g. smoke. The smoke particles are constantly being bombarded by air particles. The movement was described by Brown, a botanist in 1827
2. **Diffusion**: This is the movement of solute particles through a medium, from a region of higher concentration to a region of lower concentration. Solute particles move a more crowded region until the solute particles become evenly distributed throughout the medium. Diffusion is fastest in gases because the particles have more kinetic energy and the cohesive forces between them are negligible. It is slow in liquids and slowest in solids.
3. **Osmosis**: This is the movement of water molecules through a semi-permeable from a region of higher concentration to a region of lower concentration.
4. **sublimation**

KINETIC THEORY OF GASES

Early scientists studied the behavior of gases. They proposed gas laws to describe the behavior of an ideal or perfect gas. The theory postulates the following:

1. The gas molecules move randomly in straight lines, colliding with one another and with the walls of container. The collisions on the walls of the container constitute the gas pressure.
2. The collisions of the gas molecules are perfectly elastic. When molecules collide, individual energies may vary but the total kinetic energy remains the same.

3. The actual volume occupied by the gas molecules is negligible relative to the volume of the container. Gas consists of molecules which are widely apart.
4. The cohesive forces (forces of attraction) between the gas molecules are negligible.
5. The temperature of the gas molecules is a measure of the average kinetic energy of the gas particles. i.e the kinetic energy depends on the temperature

The above theory have been able to describe the gases but real gases (O_2, H_2, N_2, CO_2) show deviations in behavior at low temperature and high pressure because the molecules are close together and intermolecular attractions become appreciable

DEVIATIONS FROM THE KINETIC THEORY OF GASES

1. The molecules of real gases occupy space
2. At low pressure, force of attraction and repulsion are no longer negligible i.e forces of attractions exist between the gas molecules.
3. Real gases liquefy at lower temperatures as opposed to ideal gases which do not liquefy.

The pressure exerted by gases is as a result of collision of the gas molecules with the walls of the container. The larger the number of molecules, the greater the number of collisions, therefore the higher the pressure. The gas pressure is force exerted by unit area of the wall. Gas pressure is measured in atmosphere (atm) or mmHg. The S.I. Unit for measuring pressure is Pascal (Pa) i.e. Newton's per meter squared (Nm^{-2})

1 atm = 760mmHg = 760 torrents = 101325 Nm^{-2} = 1.012bar

BOYLE'S LAW

This law states that the volume of a given mass of a gas is inversely proportional to its pressure provided that the temperature remains constant i.e volume of a gas increases as pressure decreases and vice versa.

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

$$V = \frac{K}{P}$$

$$PV = K$$

Where V= volume, P = Pressure and K= a mathematical constant

At two different conditions, $P_1V_1 = P_2V_2$

Where, P_1 =Pressure at Volume V_1 P_2 =Pressure at volume V_2

Graphical representation of Boyle's law

Pictorial representation of Boyle's law

Explanation of Boyle's law

If a given mass of gas is enclosed in a vessel with a movable piston and kept static by placing a weight on it. At constant temperature, the average velocity of the molecules are constant so also the number of collisions on the wall i.e. pressure.

If the weight is replaced with a lighter one such that the piston moves up and the original volume V is doubled, the gas molecules spread out so the number of collisions is also halved. If the weight is replaced by a heavier one, such that the original volume is halved, the gas molecules will be packed closely and so the number of collisions is doubled. Hence at constant temperature, as the volume of a gas decreases its pressure increases.

Examples on Boyle's law

1. $420cm^3$ of a gas has a pressure of 450mmHg. Find its volume if the pressure is increased to 710mmHg.

Solution

2. Calculate the pressure required to compress 5.0 litres of hydrogen at atmospheric pressure to 2.5 litres (1 atm = 760mmHg = 760 torrents)

Solution

3. 200cm^{3}of a gas has a pressure of 380mmHg. What will be its volume if the pressure is doubled, assuming there is no change in temperature.

   Solution

Student's exercise: 320cm^3 of a given mass of gas has a pressure of 640mmHg. Calculate its volume if the pressure is halved, assuming temperature remains constant.

Absolute Temperature

The **absolute zero or absolute temperature** is the temperature at which there is no motion of any kind of the molecules and kinetic energy is zero.

The **critical temperature** is the highest temperature at which it can exist as a liquid or which a gas can be liquefied, above it, a liquid does not exist or a gas cannot be liquefied

The pressure needed to liquefy a gas at critical temperature is known as the **critical pressure**

The volume occupied by one mole of the gas at critical temperature and pressure is known as the **critical volume**

Scientists discovered that the volume of a gas will decrease or increase by $^1/_{273}$ of its original volume for every 1% rise or fall in temperature provided pressure is constant. The temperature of -273°C is known as absolute zero. The Kelvin temperature scale has -273°C as its starting point. Before we use any of the gas laws in calculations, we must convert them to the Kelvin temperature is K. The symbol for temperature is T

0°C = 273K
-273 °C = 0K
∴ K = °C + 273
°C = K - 273

Absolute zero 0K -273°C
Kelvin Celsius

Fig: Comparison of the Kelvin and Celsius temperatures.

Examples:

1. Convert the following from °C to Kelvin
   (a) 0°C (b) -75°C (c) 224 °C

2. Convert the following from Kelvin to °C

(a) 55K (b) 320K

Solution

Students exercise: (a) Convert the following from Kelvin to °C (i). 112K (ii). 66K (iii) -25K

(b). Convert the following from °C to Kelvin (i). 50°C (ii). 278°C

Charles' Law

This law states that the volume of a fixed mass of gas is directly proportional to its temperature in Kelvin (absolute Temperature) provided that pressure remains constant.

Mathematically: $V \alpha T$

$V = KT$

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

Where V= volume, T= Kelvin Temperature K= a mathematical constant

At two different conditions, $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Where V_1 = volume at temperature T_1, V_2 = volume at temperature T_2

Pictorial representation of Charles' law

Graphical representation of Charles' law

Explanation on Charles' law

If a given mass of gas is enclosed in a vessel with a movable piston and heated, the molecules acquire more kinetic energy, move faster and collide with themselves and the walls of the vessel and thereby increasing the pressure. To maintain the pressure (constant pressure) the piston moves up so that the volume is increased. Therefore, as temperature increases, the volume must also increase the keep the pressure constant.

Examples

1. A sample of hydrogen occupies a volume of $150cm^3$ at 28°C. What will be its volume at 70^oC, if the pressure is kept constant?

Solution

2. A fixed mass of a gas occupies $20cm^3$ at 45^oC. Assuming pressure is constant, at what temperature will it have doubled its volume?

Solution

3. A given sample of a gas occupies 360cm^3 at 15^{o}C. At what temperature will it have its volume reduced by half assuming pressure is unchanged?

Solution

Student's exercise: A sample of a gas occupies 300cm^3 at 50^{o}C. Determine the volume it will occupy at 120°C assuming pressure is unchanged?

General Gas Equation

We know that the volume of a gas depends on temperature and pressure. The relationship between the three variables can be summed up from Boyle's law and Charles law.

If V$\alpha \frac{1}{P}$ (Boyle's law – constant temperature)

And V αT (Charles' law – constant temperature)

V αT $\alpha \frac{1}{P}$ (Temperature and Pressure may vary)

V= $\frac{KT}{P}$

or K = $\frac{PV}{T}$ k = a mathematical constant.

The above equation is known as the general gas equation

At different conditions, $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

Where, *V_1 is volume at temperature T_1 and pressure P_1*

V_2 is volume at temperature T_2 and pressure P_2

The expression above shows the relationship between three variables.

The standard temperature is taken as 0°C or 273K and the standard pressure is 1 atm or 760mmHg.

Examples

1. A certain mass of gas occupies 312cm^3 at 28°C and 720mmHg pressure. What volume will it occupy at -15 °C and 670mmHg.

2. The volume of a given mass of gas is 350cm^3 at 22°C and 650mmHg pressure. What volume will it occupy at 36°C and 740mmHg?

3. A gas has a volume of 150cm^3 under a pressure of 1800Nm^{-2}, What will be its volume if the pressure is changed to 100mmHg at the same temperature (760mmHg =101325 Nm^{-2})

4. What is the volume of a fixed mass of gas that occupies 500cm^3 at 25^{o}C and 0.84 x 10^{5}Nm^{-2} pressure at s.t.p?

Student's exercise: The pressure of a gas which occupies 450cm^3 at 27^{o}C is 700mmHg. What is the pressure of the gas at -48^{o}C if the volume is reduced to 250cm^3

Ideal gas equation

It has been proven that equal volume of all the gases at s.t.p. (Standard Temperature and Pressure) contains equal number of molecules and occupies a volume of 22.4dm^3. In all experimental work, the four quantities are important.

Therefore, for 1 (one) mole of a gas, it can be deduced that PV=RT

For n moles,

PV = nRT

where R is the gas constant at stp for one mole of a gas

R=$\frac{PV}{nT}$ = $\frac{1\ atm\ X\ 22.4\ dm^3}{1\ mole\ X\ 273K}$

= 0.082 atmdm^{3}k^{-1}mol^{-1}

The ideal gas equation is used to solve problems involving a fixed amount of a gas under one set of non-standard conditions

Examples

1. A certain amount of gas occupies 5.0 dm^3 at 2 atm and 10^{o}C. Calculate the number of moles present (R= 0.082 atm dm^3 k^{-1}mol^{-1})

   Solution

2. 3.5 moles of an ideal gas are at a temperature of -23^{o}C and a pressure of 2atm. What volume in dm^3 will the gas occupy at that temperature (R= 0.082 atm dm^3 k^{-1}mol^{-1})

   Solution

Student's exercise:

1. What is the temperature of 0.5 moles of an ideal gas which occupies 800cm^3 at a pressure of 1.5atm? (R= 0.082 atm dm^3 k^{-1}mol^{-1})

2. If a gas occupies 10.0dm^3 at 53270mmHg and 37^{0}C, calculate the number of moles of the gas present. (R= 0.082 atm dm^3 k^{-1}mol^{-1}).

Daltons law of Partial Pressure states that if there are a mixture of gases which do not react chemically together, the total pressure exerted by the mixture is the sum of the partial pressures of the individual gases that make up the mixture if it occupies the whole volume of the container at the same temperature. That is,

$P_{Total} = P_A + P_B + P_c \ldots\ldots\ldots + P_n$

If a gas is collected over water, then the gas is likely to be saturated with water vapour. So that,

$P_{Total} = P_{gas} + P_{water\ vapour}$

Therefore, $P_{gas} = P_{Total} - P_{water\ vapour}$

According to the kinetic theory, the molecules of two or more different gases have the same average kinetic energy and no attractive forces exist between gas molecules that do not react chemically.

Examples

An enclosed vessel contains 2.8g of Nitrogen and 14.2g of chlorine at atmospheric pressure and 0^{o}C. What will be the partial pressure of the nitrogen if the temperature is raised to 180^{o}C? (N = 14, Cl = 35.5)

1. A certain mass of hydrogen gas collected over water at 24^{o}C and 700mmHg pressure has a volume of 170cm^3. Calculate the volume when it is dry at s.t.p. (s.v.p of water at 10^{o}C = 9.2mmHg).

Students exercise:

1. $430cm^3$ of hydrogen gas was collected over water at 30^oC and 630mmHg pressure. If the saturated vapour pressure at that temperature was 50mmHg. Calculate the volume of the dry gas at s.t.p.
2. If $120cm^3$ of Carbon (IV) oxide were collected over water at 13^0C and 700mmHg, determine the volume of the dry gas at s.t.p if the s.v.p of CO_2 at that temperature is 45mmHg.

Gay –Lussac's law of combining volumes states that when gases react /combine, they do so in volumes which are simple ratios to one another and to the volume of the product (if gaseous) provided that temperature and the pressure remain constant. e.g

1. $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$

   2 vol : 1 vol : 2 vol

   2 : 1 : 2
2. $2SO_{2(g)} + O_{2(g)} \rightarrow 2SO_{3(g)}$

2 vol : 1 vol : 2 vol

2 : 1 : 2

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

   1 vol : 3 vol : 2 vol

   1 : 3 : 2

The total volume of the reacting gases need not equal the volume of the gases produced. 2 volumes of hydrogen combined with one volume of oxygen to produce two volume of steam. This law is applicable only to gases.

Examples

1. What is the volume of oxygen required to burn completely 25cm^3 of methane (CH_4)

Solution

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

1 vol 2vol 1 vol 2vol

2. 20cm^3 of Carbon (II) oxide are sparked with 20cm^3 of oxygen. If all the volumes are measured at s.t.p, Calculate the volume of residual gases after sparking

Solution

Equation: $2CO_{(g)} + O_{2(g)} \rightarrow 2CO_{2(g)}$

3. 30cm^3 of Hydrogen combined with 20 cm^3 of oxygen to form steam according to the equation. If all the volumes are measured at s.t.p. Calculate the volume of gaseous mixture at the end of the reaction.

Solution

Equation $2H_2O_{(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$

Students exercise:

1. The combustion of ethene in air is represented in the equation below:

$C_2H_{4(g)} \quad + \quad 3O_{2(g)} \quad \rightarrow \quad 2H_2O_{(l)} \quad + \quad 2CO_{2(g)}$

Calculate the volume of oxygen needed to burn 12.5cm^3 of the ethene.

2. 25.0cm^3 of methane was burnt in 20.0cm^3 of oxygen according to the following equation:

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

(i) Which of the gases was in excess

(ii) Calculate the volume of the excess gas.

AVOGADRO'S LAW

Avogadro's law states that equal volume of all gases at the same temperature and pressure contain the same/equal number of molecules.

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

The Avogadro's number ($6.02 X 10^{23}$) is used to one mole of any substance contains 6.02×10^{23} particles, ions, molecules or atoms.

Therefore,

One mole of nitrogen gas = 6.02×10^{23} molecules

One mole of Carbon (II) oxide gas = 6.02×10^{23} molecules

One mole of glucose = 6.02×10^{23} molecules

Examples

1. How many molecules are there in 4.0moles of glucose ($C_6H_{12}O_6$)

Solution

2. How many atoms are there in 4.0g of carbon

Solution

3. How many fluoride are there in 1.46mole of aluminium fluoride AlF_3

$AlF_3 \rightarrow Al^{3+} + 3F^-$

Solution

Students exercise:

i. Calculate the number of atoms in 7.1g of zinc chloride, $ZnCl_2$
ii. What is the number of hydrogen ions present in 17g of tetraoxosulphate (VI) acid, H_2SO_4 [Zn=65, Cl=35.5, H=1, S=32, O=16]

Molar volume of gases

The molar volume of any gas is the volume occupied by one mole of that gas at s.t.p and it is numerically equal to 22.4dm^3

Example

1. What is the volume of

(a) 2.5 moles of oxygen

(b) 25.5g of ammonia at s.t.p

Solution

2. If 0.8g of a gas Z occupies 0.56 dm^3 at s.t.p, what is its relative molecular mass

3. Find the number of molecules of oxygen required to convert 6.60dm^3 of SO_2 measured at s.t.p to SO_3. (molar volume of a gas at s.t.p = 22.4dm^3, Avogadro's number = 6.02×10^{23})

Solution

$2SO_{2(g)} + O_{2(g)} \rightarrow 2SO_{3(g)}$

Students exercise:

(1). Calculate the volume of the following gases at s.t.p (i) 5.2 moles of nitrogen (II) oxide (ii). 36g of sulphur (IV) oxide

(2). Find the number of molecules in 30g of chlorine gas [Cl =35.5, Avogadro's No=6.02x10^{23}]

Relative Vapour Density

Relative Vapour Density of a gas or vapour is the number of times a given volume of gas (vapour) is as heavy as the same volume of hydrogen at a particular temperature and pressure.

VD = $\frac{mass\ of\ a\ given\ volume\ of\ a\ gas\ /vapour}{mass\ of\ an\ equal\ volume\ of\ hydrogen}$

VD = $\frac{mass\ of\ x\ molecules\ of\ a\ gas\ /vapour}{mass\ of\ x\ molecules\ of\ hydrogen}$

VD = $\frac{mass\ of\ 1\ molecules\ of\ \ gas\ /vapour}{mass\ of\ 1\ molecule\ of\ hydrogen}$

VD = $\frac{mass\ of\ 1\ molecules\ of\ \ gas\ /vapour}{mass\ of\ 2\ atoms\ of\ hydrogen}$

On hydrogen scale, $\frac{mass\ of\ 1\ molecules\ of\ \ gas\ /vapour}{mass\ of\ 1\ atom\ of\ hydrogen}$ = RMM

∴ **2Vapour Density = Relative Molecular Mass**

VD =$\frac{RMM}{2}$

Examples

Calculate the vapour densities of

1. 560cm^3 of oxygen at s.t.p weigh 0.8g
2. 1400 cm^3 of sulphur (IV) oxide at s.t.p weigh 4g [given that hydrogen weighs 0.09g/dm^3]

Solution

Students exercise: 4.34g of a volatile substance when vaporized in a flask displaced 760cm^3 of air measured at s.t.p. Calculate the (i). Vapour density (ii). Relative molecular mass. {Density of hydrogen = 0.09g/dm^3}

<u>Graham's law of diffusion:</u> states that at constant temperature and pressure, the rate of diffusion of a gas is inversely proportional to the square root of its density.

Mathematically,

Where 2 gases are involved

$R = \frac{1}{\sqrt{d}}$ *where R = rate of diffusion* $\frac{R_1}{R_2} = \sqrt{\frac{d_2}{d_1}}$

d= density

The rate of diffusion of a gas is inversely proportional to the square root of its molecular mass

$R=\frac{1}{\sqrt{m}}$

For two gases

$\frac{R_1}{R_2} = \sqrt{\frac{M_2}{M_1}}$

Rate of diffusion of a gas is inversely proportional to the time taken, $R=\frac{1}{t}$

$\frac{R_1}{R_2} = \frac{t_2}{t_1}$

$\therefore \frac{R_1}{R_2} = \sqrt{\frac{d_2}{d_1}} = \sqrt{\frac{M_2}{M1}} = \frac{t_2}{t_1}$

Note: Rate = $\frac{volume}{time}$

Examples

1. If 280cm^3 of hydrogen diffuses in 40sec,. how long will it take 490cm^3 of a gas whose vapour density is 25 to diffuse under the same conditions (H=1)

Solution

2. If $100cm^3$ of oxygen diffused in 4 seconds and $50cm^3$ of gas Y diffused in 3 seconds. Calculate the relative molecular mass of Y (O = 16)

   Solution

3. $120cm^3$ of gas **A** diffused in 15 seconds and $450cm^3$ of another gas **B** diffused in 25seconds. Calculate the rate of diffusion of the two gases.

   Solution

Students exercise: If $360cm^3$ of sulphur (IV) oxide can diffuse through a porous partition in 36 seconds. How long will it take (i) an equal volume (ii) $540cm^3$ of hydrogen sulphide to diffuse through the same partition? [S=32, O=16, H=1]

TOPIC: ACIDS, BASES AND SALTS

THEORIES OF ACID

1. Arrhenius theory of acid

Arrhenius defined an acid is a substance which produces hydrogen ion or hydroxonium ions as the only positive ion when dissolved in water and a base as a substance that produces hydroxyl ions in aqueous solution and reacts with an acid to form water

$KOH_{(aq)} \rightarrow K^{+}_{(aq)} + OH^{-}_{(aq)}$

base

$HCl_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^{+} + Cl^{-}$

Hydroxonium ion

$HCl_{(aq))} \rightleftharpoons H^{+} + Cl^{-}$

Hydrogen ion

$HNO_{3(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^{+} + NO_3^{-}$

Hydroxonium ion

$HNO_{3(aq)} \rightleftharpoons H^{+} + NO_3^{-}$

Hydrogen ion

$H_2SO_{4(aq)} + H_2O_{(l)} \rightleftharpoons 2H_3O^{+} + SO_4^{2-}$

Hydroxonium ion

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

Hydrogen ion

$CH_3COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^{+} + CH_3COO^{-}$

Hydroxonium ion

$CH_3COOH_{(aq))} \rightleftharpoons H^{+} + CH_3COO^{-}$

Hydrogen ion

Therefore, an acid has at least one **ionizable** hydrogen atom in its molecule.

$CH_3COOH_{(aq))} \leftrightharpoons H^+ + CH_3COO^-$ one ionizable hydrogen ion

$HNO_{3(aq))} \leftrightharpoons H^+ + NO_3^-$ one ionizable hydrogen ion

$H_2SO_{4(aq)} \leftrightharpoons 2H^+ + SO_4^{2-}$ two ionizable hydrogen ions

$H_3PO_{4(aq)} \leftrightharpoons 3H^+ + SO_4^{2-}$ three ionizable hydrogen ions

2. Bronsted-Lowry theory of an acid

Bronsted-Lowry defined an acid as a substance which donates a proton while a base is a substance that accepts a proton

$$\underset{\text{Acid}}{CH_3COOH} + \underset{\text{Base}}{H_2O} \rightarrow \underset{\text{Conjugate base}}{CH_3COO^-} + \underset{\text{Conjugate acid}}{H_3O^+}$$

$$\underset{\text{Acid}}{HCl} + \underset{\text{Base}}{H_2O} \rightarrow \underset{\text{Conjugate base}}{Cl^-} + \underset{\text{Conjugate acid}}{H_3O^+}$$

$$\underset{\text{Base}}{NH_3} + \underset{\text{Acid}}{H_2O} \rightarrow \underset{\text{Conjugate base}}{OH^-} + \underset{\text{Conjugate acid}}{NH_4^+}$$

For the forward reaction, acid behaves as an acid but for the backward reaction, the acidic ion behaves as a base. Therefore, for every acid, there is a conjugate base.

3. Lewis theory of an acid

Lewis defined an acid as specie that accepts electron from a base while a base is a substance that donates an electron

A Lewis base has a filled orbital which has an electron pair (lone pair) which is not involved in bonding but may form a dative bond with a Lewis acid which contains an empty orbital to form a Lewis adduct. An adduct is a product of direct addition of two or more distinct molecules resulting in a single reaction product containing all atoms of the components.

Examples of Lewis acids are H^+, K^+, Fe^{3+}, Al^{3+}, BF_3, CO_2, SO_3, Cl_2, Br_2, $BeCl_2$ e.t.c

Examples of Lewis base are NH_3, Cl^-, CaO H_2O, F^-, OH^-, alkanols, amines e.t.c

Organic and inorganic acids

Organic acids are naturally occurring acids found in plants and animals materials. They include:

	Acid	**Source**
1	Ethanoic acid	Vinegar
2	Lactic acid	Milk
3	Citric	Citrus fruits (lime, lemon)
4	Amino acid	Proteins
5	Fatty acid	Fats and oils (vegetable oil)
6	Ascorbic acid	Vitamin C
7	Tartaric acid	Grapes

8	Methanoic acid	Bees, Ants
9	Palmitic acid	Palm oil

Inorganic acids are prepared from mineral elements or inorganic matter e.g.

Acid	**Formula**	**Constituents**
Hydrochloric acid	HCl	Hydrogen and Chlorine
Tetraoxosulphate (VI) acid	H_2SO_4	Hydrogen, Sulphur and Oxygen
Trioxonitrate (v) acid	HNO_3	Hydrogen, Nitrogen and Oxygen
Tetraoxosulphate (VI) acid	H_2SO_4	Hydrogen, Sulphur and Oxygen

Acids in solution

When acids dissolve in water, ionization occurs. It produces positive and negative ions; hydrogen ions or hydroxonium ion is the only positive ion.

e.g. $HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$

$HCl_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$

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

$H_2SO_{4(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + SO_4^{2-}{}_{(aq)}$

$CH_3COOH_{(aq)} \rightarrow CH_3COO^-_{(aq)} + H^+_{(aq)}$

$CH_3COOH_{(aq)} + H_2O_{(l)} \rightarrow CH_3COO^-_{(aq)} + H_3O^+_{(aq)}$

Basicity of an Acid: This is the number of replaceable hydrogen ions in one molecule of an acid. Basicity can be:

1. **Monobasic** if the acid contains one replaceable hydrogen ion,

   $CH_3COOH_{(aq)} \rightarrow CH_3COO^-_{(aq)} + H^+_{(aq)}$
2. **Dibasic** if it contains two,

   $H_2SO_{4(aq)} \rightarrow 2H^+_{(aq)} + SO_4^{2-}{}_{(aq)}$
3. **Tribasic** if it contains three

   $H_3PO_{4(aq)} \rightarrow 3H^+_{(aq)} + PO_4^{3-}{}_{(aq)}$
4. **Polybasic** if it contains more than three.

Acids	**Ions produced**	**Basicity**
$HCl_{(aq)}$	H^+, Cl^-	1
$HNO_{3(aq)}$	H^+, NO_3^-	1
H_2SO_4	$2H^+$, SO_4^{2-}	2
H_2SO_3	$2H^+$, CO_3^{2-}	2
H_3PO_4	$3H^+$, PO_4^{2-}	3
CH_3COOH	H^+, CH_3COO^-	1
$HCOOH$	H^+, $HCOO^-$	1

Propane-1,2,3- triol		3

In ethanoic acid, the ionizable hydrogen ion is the one attached to the oxygen atom and not the carbon atom.

Strong and weak Acid

Strong acids are acids that are completely ionized in water to produce large amount of hydrogen ions and negative radical. Strong acids contain a high amount of hydrogen ions in solution. They are strong electrolytes e.g. HCl, HNO_3, H_2SO_4

$HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$

$HNO_{3(aq)} \rightarrow H^+_{(aq)} + NO_3^-{}_{(aq)}$

Weak acids are acids that are incompletely or partially ionized in water to produce little amount of hydrogen ion and the negative radical. The amount of hydrogen ions present is very low. They are weak electrolytes e.g.

$CH_3COOH_{(aq)} \rightleftharpoons CH_3COO^-{}_{(aq)} + H^+_{(aq)}$

$C_2H_2O_{4(aq)} \rightleftharpoons 2H^+_{(aq)} + C_2O_4^{2-}{}_{(aq)}$

$H_2CO_{3(aq)} \rightleftharpoons 2H^+_{(aq)} + CO_3^{2-}{}_{(aq)}$

$H_2SO_{3(aq)} \rightleftharpoons 2H^+_{(aq)} + SO_3^{2-}{}_{(aq)}$

Note: Complete ionization is represented by a single line (for strong acids) while partial ionization is represented by double lines (weak acids).

Student exercise: Explain why a solution of hydrogen chloride gas in water conducts electricity but a solution of hydrogen chloride gas in toluene does not conduct electricity

Concentrated and Dilute Acids

A concentrated acid is one in which a large amount of acid is added to little water e.g. adding 5 moles of an acid added to $1000cm^3$ of water.

A dilute acid is one in which a little amount of acid is added to a large amount of water e.g. 2 moles of the same acid added to $1000cm^3$ of water.

Physical properties of Acids

1. Dilute acids have sour tastes e.g. especially in unripe fruits, vinegar, rancid milk.
2. Dilute Acids turn blue litmus red
3. Concentrated acids are corrosive

Note: Never add water to acid but acid to water.

Chemical properties of Acids

1. They react with metals to liberate hydrogen gas

   $Zn_{(s)} + HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$

   $Fe_{(s)} + H_2SO_{4(aq)} \rightarrow FeSO_{4(aq)} + H_{2(g)}$

HNO_3 will not produce hydrogen gas because it is a **strong oxidizing agent**. It will produce oxides of nitrogen instead.

Copper and Lead will **not** displace hydrogen from dilute acid because hydrogen is higher than them in the electrochemical series however, they will give similar reaction with hot, concentrated acids.

$Pb_{(s)} + 2HCl_{(aq)} \rightarrow PbCl_{2(s)} + H_{2(g)}$

2. They react with alkali and bases to form salt and water **only**. This reaction is known as **neutralization reaction.**

   $Zn(OH)_{2(aq)} + H_2SO_{4(aq)} \rightarrow ZnSO_{4(aq)} + 2H_2O_{(g)}$

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

3. They react with trioxocarbonates (IV) to liberate carbon (IV) oxide gas

   $CuCO_{3(aq)} + H_2SO_{4(aq)} \rightarrow CuSO_{4(aq)} + CO_{2(g)} + 2H_2O_{(g)}$

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

Preparation of Acids

1. **By dissolving acid anhydrides in water.**

   Acid anhydrides are oxides of non-metals

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

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

   Acid anhydrides are oxides of non-metal which dissolve in water to form acids

   NO_2 is regarded as a mixed anhydride because it dissolves in water to produce two types of acids

2. **By direct combination of constituent elements in the presence of a catalyst.**

   $H_{2(g)} + Cl_{2(g)} \rightarrow HCl_{(g)} \qquad HCl_{(g)} \rightarrow HCl_{(aq)}$

   $H_{2(g)} + Br_{2(g)} \rightarrow HBr_{(g)} \qquad HBr_{(g)} \rightarrow HBr_{(aq)}$

By using a stronger acid(less volatile) to displace a weaker acid(more volatile) from its salt

$2NaNO_{3(s)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(aq)} + HNO_{3(aq)}$

$2HCl + CaCO_{3(s)} \rightarrow CaCl_{2(aq)} + H_2CO_{3(aq)}$

4. **By precipitating insoluble sulphide of a metal from a solution of the metallic salt using hydrogen sulphide gas.**

Hydrogen sulphide gas is passed into a solution of the salt.

$(CH_3COO)_2Pb_{(aq)} + H_2S_{(g)} \rightarrow PbS_{(s)} + 2CH_3COOH_{(aq)}$

$Cu(NO_3)_{2(aq)} + H_2S_{(g)} \rightarrow CuS_{(s)} + 2HNO_{3(aq)}$

Uses of Acids

	Acid	**Uses**
1	Hydrochloric acid	Needed by industries to make chemicals Used to remove rust Used to dissolve metals
2	Tetraoxosulphate (VI) acid	Needed by industries to make chemicals Used as a drying, oxidizing and dehydrating agent Used as electrolyte in lead-acid accumulators Used in refining petroleum Used to manufacture drugs, plastics, fertilizers etc
3	Trioxonitrate (V) acid	Used to make fertilizers, explosives etc Used as fuel in rockets
4	Boric acid	Used as a mild antiseptic or germicide
5	Tartaric acid	Used in making baking soda, soft drinks and health salts
6	Acetic Acid (ethanoic acid)	Used in preserving food Used in dyeing silk and other textiles
7	Citric acid	Used in making fruit juice
8	Fatty acids (palmitic acid, stearic acid)	Fatty acid + caustic soda → soap + water

BASES AND ALKALI

A base is a substance which will neutralize an acid to yield a salt and water only. It turns red litmus paper to blue. Bases are usually metallic oxides or metallic hydroxides e.g. CuO, $Mg(OH)_2$, Na_2O, KOH, $Fe(OH)_2$, $Fe(OH)_3$.

Oxides are formed when metals burn in air or oxygen

$4Na_{(s)} + O_{2(g)} \rightarrow 2Na_2O_{(s)}$

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

Most metallic oxides are insoluble in water. However, some dissolve in water to form hydroxides

An alkali is a soluble base. They are soluble in water e.g. KOH, $NaOH$, NH_4OH, $Ca(OH)_2$

$Na_2O_{(s)} + H_2O_{(l)} \rightarrow 2NaOH_{(aq)}$

Strong and Weak Alkalis

A **strong** alkali is one which ionizes completely in water to produce positive ions and hydroxide ions.

$NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$

$KOH_{(aq)} \rightarrow K^+_{(aq)} + OH^-_{(aq)}$

A **weak** alkali is one which ionizes incompletely or partially in water to produce positive ions and hydroxide ions

$Ca(OH)_{2(aq)} \leftrightharpoons Ca^{2+}_{(aq)} + 2OH^-_{(aq)}$

$NH_4OH_{(aq)} \leftrightharpoons NH_4^+_{(aq)} + OH^-_{(aq)}$

Strong alkalis produce large amount of hydroxyl ions while weak acids produce small amount of hydroxyl ions when dissolved in water.

Physical properties of Bases and Alkalis

1. Alkalis have a bitter taste
2. Alkalis are soapy to touch
3. Alkalis turn red litmus paper blue
4. Concentrated alkalis (NaOH and KOH) are corrosive

Chemical properties

1. They react with acids to form salt and water (neutralization reaction)

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

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

2. They react with ammonium salts to liberate ammonia gas

   $2NaOH + (NH_4)_2SO_4 \rightarrow Na_2SO_{4(aq)} + 2NH_{3(g)} + 2H_2O_{(l)}$

   $Ca(OH)_2 + 2NH_4Cl \rightarrow CaCl_{2(aq)} + 2H_2O_{(l)} + 2NH_{3(g)}$

Preparation of bases

1. By burning metals in air or oxygen. Most metals combine directly with oxygen when heated to form basic oxides. This is dissolved in water to give alkalis or bases

$2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(s)} \longrightarrow 2Mg(OH)_{2(aq)}$

$2Zn_{(s)} + O_{2(g)} \rightarrow 2ZnO_{(s)} \longrightarrow 2Zn(OH)_{2(aq)}$

$4Na_{(s)} + O_{2(g)} \rightarrow 2Na_2O_{(s)} \longrightarrow 2NaOH_{(aq)}$

2. Some metals dissolve in water or steam to produce alkali and hydrogen gas

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

$Ca_{(s)} + 2H_2O_{(l)} \rightarrow Ca(OH)_{2(aq)} + H_{2(g)}$

3. Insoluble basic hydroxides are prepared by precipitation reaction or double decomposition reaction

$CuSO_{4(aq)} + 2KOH_{(aq)} \rightarrow K_2SO_{4(aq)} + Cu(OH)_{2(aq)}$

$FeCl_{2(aq)} + 2NaOH_{(aq)} \rightarrow 2NaCl_{(aq)} + Fe(OH)_{2(aq)}$

Sodium hydroxide is prepared by

(a) Heating slaked lime with dilute sodium trioxocarbonate (IV) solution

$Ca(OH)_{2(aq)} + Na_2CO_{3(aq)} \rightarrow CaCO_{3(s)} + 2NaOH_{(aq)}$

(b) Electrolysis of brine

Ammonium hydroxide is prepared by heating a mixture of ammonium salt and slaked lime to produce ammonia gas which is dissolved in water

$Ca(OH)_{2(s)} + (NH_4)_2SO_4 \rightarrow CaSO_{4(s)} + 2NH_{3(aq)} + 2H_2O_{(l)}$

$NH_{3(g)} + H_2O_{(l)} \rightarrow NH_4OH_{(aq)}$

Metals	**Characteristics of their corresponding hydroxides**
K, Na, Ca	_ Hydroxides are soluble in water forming alkalis _ Hydroxides of sodium and potassium are not decomposed by heat but that of calcium is decomposed by heat $Ca(OH)_{2(aq)} \rightarrow CaO_{(s)} + H_2O_{(l)}$
Mg, Al, Zn, Fe	_ Hydroxides are insoluble in water _ Hydroxides of Zn and Al are amphoteric (i.e have both acidic and basic properties) _ Hydroxides decomposes on heating into oxides and water $Zn(OH)_{2(aq)} \rightarrow ZnO_{(s)} + H_2O_{(l)}$
Cu	_Hydroxide is insoluble in water _ Hydroxides decomposes on heating into oxides and water $Cu(OH)_{2(aq)} \rightarrow CuO_{(s)} + H_2O_{(l)}$
Hg, Ag, Au	No hydroxides formed

Uses of Alkalis

Base/ Alkali	**Uses**
Sodium Hydroxide	Used in manufacture of soap Used petroleum refining. Used to manufacture paper, dyes and rayon from cellulose Used in production of chemicals and as a drying agent
Magnesium hydroxide	Used to manufacture toothpaste (act as anti acid) Used in medicine as a laxative called milk of magnesia
Potassium hydroxide	Used to manufacture shaving creams Used to manufacture soft soaps
Calcium hydroxide	Used for reducing the acidity in the soil Used in the manufacture of cement, mortar white wash and plaster of paris. Used in the refining of sugar
	used in laundry to remove stains (solvent for grease) and for bleaching

Ammonium hydroxide	Used in the manufacture of detergent.

Neutralization

This is a reaction in which an appropriate amount of an acid reacts completely with an appropriate amount of alkali to produce salt and water only. **OR**

It is the combination of hydroxonium ion H_3O^+ or hydrogen ion H^+ and hydroxide ions OH^- to form water molecules and salt.

$$\text{Acid} + \text{base} \rightarrow \text{salt} + \text{water}$$

$$\text{e.g } HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

OR

$$H^+ + OH^- \rightarrow H_2O_{(l)}$$

$$H_3O^+_{(aq)} + OH^-_{(aq)} \rightarrow 2H_2O_{(l)}$$

HEAT OF NEUTRALIZATION, ΔH

The heat of neutralization is the heat evolved when one mole of an acid react with one mole of a base to form one mole of water under standard conditions.

$$NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaOH_{(aq)} + H_2O_{(l)} \qquad \Delta H = -57.3KJ$$

$$NaOH_{(aq)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)} \qquad \Delta H = 2 \times -57.3KJ$$

Heat of neutralization is less for reactions between weak acids and weak bases because they are partially ionized in water.

HYDROGEN ION CONCENTRATION AND pH SCALE

Water is neutral. It has no effect on both blue and red litmus papers. It ionizes slightly to produce hydrogen ions and hydroxide ions. Conductivity measurements showed that at 25°C, the concentration of hydrogen ions $[H^+]$ and the concentration of hydroxide ions $[OH^-]$ are both equal to $10^{-7}moldm^{-3}$

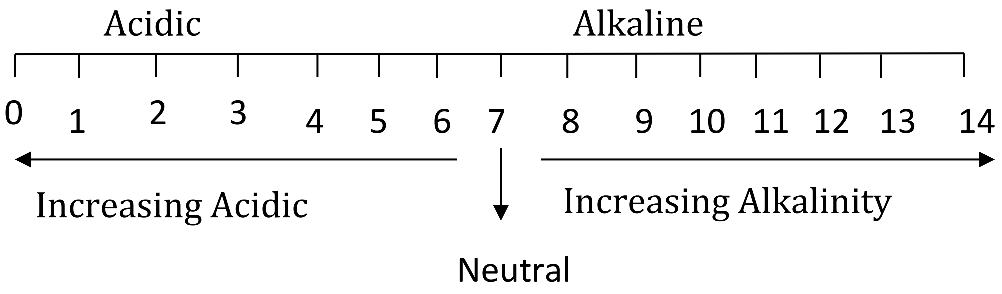
$[H^+] = [OH^-] = 1 \times 10^{-7}moldm^{-3}$ (at 25°C)

The product of these two ionic concentrations is called the **ionic product** of water. It is represented by

$$K_w = [H^+][OH^-]$$
$$= (10^{-7} \times 10^{-7})(moldm^{-3})^2$$
$$= 10^{-14}mol^2dm^{-6}$$

When acids are added, the $[H^+]$ concentration in the solution will increase leading to corresponding decrease in the $[OH^-]$ concentration, so the concentration will decrease below $10^{-7}moldm^{-3}$. If a base is added to the solution, the $[OH^-]$ concentration will increase leading to a decrease in the $[H^+]$ concentration, thereby increasing the concentration above $10^{-7}moldm^{-3}$

The **pH scale** is a numerical measurement of the degree of acidity or alkalinity using a scale of numbers from 0 to 14



The **pH** of a solution is the negative logarithm of the hydrogen ion concentration to the base 10.

$pH = -\log_{10}[H^+]$

It is a measure of the degree of acidity or alkalinity of a solution.

Sorensen in 1909 devised this logarithmic pH

1. Because of the inconvenience of using negative indices and
2. To accommodate the wide range of $[H^+]$ and $[OH^-]$ concentrations encountered in acid-base reactions.

$pH = -\log_{10}[H^+]$

The pH can indicate both acidity and alkalinity

$[H^+]\,[OH^-] = 10^{-14}$ if $pH = pOH = 7$ then,

$pH + pOH = 14$

$pOH = 14 - pH$

Note: $pOH = -\log_{10}[OH^-]$

Examples

(i) Find the hydrogen and hydroxide ion concentrations in:

a. 0.01M H_2SO_4 solution

b. 0.001M KOH solution

Solution

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

(b) $KOH_{(aq)} \rightarrow K^+_{(aq)} + OH^-_{(aq)}$

(ii) The concentration of H^+ in two solutions are 1×10^{-14}moldm^{-3} and 5×10^{-9}moldm^{-3}, what is the pH of the solutions?

Solution

(iii) A solution has a pH of 3.4. What is its hydrogen ion concentration?

(iv) What is the pH and pOH of a solution with hydrogen ion concentration is 5.0×10^{-4} $moldm^{-3}$?

Solution

(v) Calculate the pH of 0.005 $moldm^{-3}$ NaOH solution

$NaOH_{(aq)} \longrightarrow Na^{+}_{(aq)} + OH^{-}_{(aq)}$

(vi) A glass cup of orange juice is found to have a pOH of 11.40. Calculate the concentration of the hydrogen ion in the juice.

Students exercise:

(1). Calculate the hydrogen ion concentration of a bottled drink with pH 10.7.

(2). Calculate the hydrogen and hydroxyl ion concentration of the following solutions:

(i) 0.02M HCl

(ii) 0.005M $Ca(OH)_2$

(3). What is the pH of a solution containing 0.01mol/dm^3 KOH?

Importance of pH

(a) It is required for digestion of food. The enzyme in the stomach work best in acidic medium.

(b) Sharp deviations in blood pH (about 7.4) cause serious ill health

(c) Plants grow best in soils with pH values of between 7 and 8

(d) pH values are important in pharmacy, medicine, water purification, sewage treatment.

ACID –BASE INDICATORS

An indicator is a weak organic acid or base which changes colour according to the pH of the medium (within a specific pH range)

A universal indicator is a mixture of several indicators which work at different pH ranges. The universal indicator shows seven colours from red to violet. Each colour has a pH range of about 2 units. It is prepared by dissolving the following in 500cm^3 of 3-propan-1-ol and diluting it to 1dm^{3}with distilled water - 0.25g of bromothymol blue, 0.025g of thymol blue, 0.0625g methyl red and 0.5g of phenolphthalein.

Universal indicator and its pH range

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Red			Orange		Yellow	Green		Blue	Indigo			Violet		

The pH of a solution can be measured with

1. The universal indicator
2. The pH meter – the pH meter measures accurately the pH of a solution

Students exercise: Given an equal solution 0.1moldm^{-3} HCl and 0.1moldm^{-3} CH_3COOH, which one will have a greater pH value and why?

INDICATORS USED IN ACID-BASE TITRATIONS

The choice of indicator in an acid-base titration (neutralization reaction) depends on the nature of the reacting substances. The indicator determines accurately the amount of acid which will neutralize a given amount of base. This neutral point is called the end-point.

The end point is the point at which the acid has been completely neutralized by a base. This is detected by a colour change (due to pH change).

The table below shows some acid – base reactions and the suitable indicator.

Acid-base reaction	**Change of pH at end point**	**Suitable indicator**
Strong acid versus strong Alkali	3-11	Any indicator
Strong acid versus weak Alkali	3-6	Methyl orange / Litmus
Weak acid versus strong Alkali	8-11	Phenolphthalein / Litmus
weak acid versus weak Alkali	6.5 -7.5	No suitable indicator

Colour of indicators in different medium

	Indicator	**Acidic medium**	**Alkaline medium**
1	Methyl orange	Red/pink	Yellow
2	Litmus	Red	Blue
3	Phenolphthalein	Colourless	Pink

Buffer solution

A buffer solution is one which resists change in pH on dilution or addition of small amounts of acids or bases.

The pH of aqueous solutions is extremely sensitive to small amount of acids or bases e.g. 0.1cm^3 of 1M HCl to 1 dm^3 of distilled water changes the pH from 7.0 to 4.0 such changes would be fatal to living organisms.

Buffers usually consist of a weak acid or weak base in the presence of one of its salts e.g.

(a) Ethanoic acid and sodium ethanoate

(b) Aqueous ammonia and ammonium chloride

(c) Trioxocarbonate (IV) acid and sodium hydrogen trioxocarbonate (IV)

Importance of Buffer solutions

1. In medicine, injections are buffered so that there won't drastic changes in the pH of the blood.

2. In foods and drinks industries, buffer solutions are used to prevent excess acidity.
3. Most fermentation and enzymatic reactions depend on pH which can only vary within narrow limits

SALT

A salt is a compound formed when all or part of the ionizable hydrogen of an acid is replaced by metallic or ammonium ions.

A salt contains a positive metallic or ammonium ions and a negative acid radical.

Salt	Positive or ammonium ion	Negative acid radical
$CuSO_4$	Cu^{2+}	SO_4^{2-}
$ZnSO_4$	Zn^{2+}	SO_4^{2-}
K_2CO_3	K^+	CO_3^{2-}
$Fe_2(SO_4)_3$	Fe^{2+}	SO_4^{2-}
NH_4NO_3	NH_4^+	NO_3^-

Types of Salt

1. **Normal salt:** A normal salt is a salt formed when all of the ionizable hydrogen ions of an acid have been completely replaced by metallic or ammonium ions.

Normal salts are neutral to litmus; however a few salts undergo hydrolysis to give acidic or alkaline solution. This depends on the type of acid or bases that formed the salt e.g.

Na_2SO_4	Sodium tetraoxosulphate (VI)	$\longrightarrow Na^+OH^-\ \ 2H^+SO_4^{2-}$	SB+ SA = Neutral
Na_2CO_3	Sodium trioxocarbonate (IV)	$\longrightarrow Na^+OH^-\ \ 2H^+CO_3^{2-}$	SB+WA = Alkaline
Na_3PO_4	Sodium tetraoxophosphate (V)	$\longrightarrow Na^+OH^-\ \ 3H^+PO_4^{2-}$	SB+WA = Alkaline
$ZnCl_2$	Zinc chloride	$\longrightarrow Zn^{2+}2OH^-\ \ H^+Cl^-$	WB+ SA = Acidic
$Mg(NO_3)_2$	Magnesium trioxonitrate (V)	$\longrightarrow Mg^{2+}2OH^-\ \ 2H^+NO_3^-$	WB+ SA = Acidic
$Bi(NO_3)_3$	Bismuth (III) trioxonitrate (V)	$\longrightarrow Bi^{3+}3OH^-\ \ 3H^+NO_3^-$	WB+ SA = Acidic

2. **Acid Salt:** Acid salts are formed when the hydrogen ions in acids are partially replaced by metallic or ammonium ions.

Dibasic acids can form one type of acid salt while tribasic salts can form 2 types of acid salts.

Acid salts contain replaceable hydrogen ions and have acidic properties e.g. tetraoxosulphate (VI) acid reacts with potassium hydroxide as follows:

1. $H_2SO_{4(aq)} + KOH_{(aq)} \rightarrow KHSO_{4(aq)} + H_20_{(l)}$ Acid salt
2. $KHSO_{4(aq)} + KOH_{(aq)} \rightarrow K_2SO_{4(aq)} + H_20_{(l)}$ Normal salt

H_2SO_4 forms $NaHSO_4$ - Sodium hydrogen tetraoxosulphate (VI)

H_2CO_3 forms $NaHCO_3$ - Sodium hydrogen trioxocarbonate (IV)

H_3PO_4 forms NaH_2PO_4 - Sodium dihydrogen tetraoxophosphate (V)

$NaHPO_4$- Sodium hydrogen tetraoxophosphate (V)and also

Na_3PO_4- Sodium tetraoxophosphate (V)

3. **Basic salt:** Basic salts are formed when the amount of acid needed to completely neutralize a base is insufficient or the hydroxide ions of a base have been partially replaced by the negative ion radical. A basic salt contains a positive metallic ion, a hydroxide ion and a negative ion radical. It has the properties of a basee.g.

   $Mg(OH)NO_3$– Magnesium hydroxide trioxonitrate (V) Mg^{2+}, OH^-, NO_3^-
   $Zn(OH)Cl$ – Zinc hydroxide chloride
   $Ba(OH)Cl$ – Barium hydroxide chloride
   $Bi(OH)_2NO_3$ – Bismuth dihydroxide trioxonitrate (V)
   $CuCO_3.\ Cu(OH)_2$ – Basic Cupper (II) trioxocarbonate (IV)

4. **Double Salt:** Double salts are salts which ionize to produce three different types of ion in solution, usually two are positively charged while one is negatively charged. E.g.

- $(NH_4)_2Fe(SO_4)_2.6H_20$ – Ammonium Iron (II) tetraoxosulphate (VI) hexahydrate - Fe^{2+}, NH_4^+, SO_4^{2-}
- $KAl(SO_4)_2.12H_20$ – Aluminium potassium tetraoxosulphate (VI) dodecahydrate (potash alum) – K^+, Al^{3+}, SO_4^{2-}
- $KCr(SO_4)_2.12H_20$ – Chromium (III) potassium tetraoxosulphate (VI) dodecahydrate (chrome alum) – Cr^{3+}, K^+, SO_4^{2-}

5. **Complex Salts**: These are made by mixing two simple salts such that a complex ion called ligand is formed e.g. if potassium cyanide (KCN) is mixed with an iron (II) Fe^{2+}salt, potassium hexacyanoferrate (II) is formed.

1. Potassium hexacyanoferrate (II)

   $$K_4Fe(CN)_{6(aq)} \rightarrow 4K^+_{(aq)} + \underset{\textit{Complex ion (ligand)}}{[Fe(CN)_6]^{4-}_{(aq)}}$$

2. Tetra amine copper (II) tetraoxosulphate (VI)

   $$Cu(NH_3)_4SO_{4(aq)} \rightarrow \underset{\textit{Complex ion (ligand)}}{(Cu(NH_3)_4)^{2+}} + SO_4^{2-}$$

The complex ion does not exhibit the properties of the central metallic ion nor those of the ligands because they are not free ions but bound up by co-ordinate covalent bonds

Properties of Salts

1. **Action of water on salts**: Salts that dissolve in water are called soluble salts.

   Salts that do not dissolve in water are called insoluble salts.

	Soluble salt	Insoluble salt
1.	All sodium, potassium and ammonium salts	
2.	All trioxonitrates (V) salts	
3.	All chlorides except	$PbCl_2$ (soluble in hot water), AgCl
4.	All tetraoxosulphates except	$PbSO_4$, $BaSO_4$, Ca SO_4 (slightly soluble)
5.	Na_2CO_3, K_2CO_3, $(NH_4)_2CO_3$	All other trioxocarbonates (IV)

2. **Action of acids on salt:** Salts react with acids to liberate gases e.g.

$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + CO_{2(aq)} + H_2O_{(l)}$

$NaCl_{(aq)} + H_2SO_{4(aq)} \rightarrow NaHSO_{4(aq)} + HCl_{(g)}$

3. **Action of alkalis on salts**: Salts react with alkalis to produce gas or a precipitate or a complex ion e.g.

$NH_4Cl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)} + \underset{(gas)}{NH_{3(g)}}$

$Pb(NO_3)_{2(aq)} + 2NaOH_{(aq)} \rightarrow \underset{Precipitate}{Pb(OH)_{2(aq)}} + NaNO_{3(aq)}$

$ZnCl_{2(aq)} + NaOH_{(aq)} \rightarrow Zn(OH)_{2(aq)} \longrightarrow \underset{Complex\ ion}{[Zn(OH)_4]^{2-}}$

4. **Action of heat on salts**: Some salts decompose to their oxides when heated along with evolution of gases.

(a)Trioxonitrate (V) Salts

(i) Trioxonitrate (V) salts of Na or K give Dioxonitrate (III) and oxygen gas.

$2NaNO_{3(s)} \longrightarrow 2NaNO_{2(s)} + O_{2(g)}$

(ii) Trioxonitrates (V) salts of Ca, Mg, Al, Zn, Fe, Pb and Cu decompose to the oxide of the metal, nitrogen (IV) oxide and oxygen on heating

$Pb(NO_3)_{2(s)} \longrightarrow 2PbO_{(s)} + 4NO_{2(g)} + O_{2(g)}$

$Ca(NO_3)_{2(s)} \longrightarrow 2CaO_{(s)} + 4NO_{2(g)} + O_{2(g)}$

(iii)Trioxonitrates of (Mercury) Hg, Ag and Au decompose on heating to give the metal, nitrogen (IV) oxide and oxygen.

$Hg(NO_3)_{2(s)} \longrightarrow 2Hg_{(s)} + 4NO_{2(g)} + O_{2(g)}$

(iv)Ammonium trioxonitrate (V) decompose to give Dinitrogen (I) oxide and water

$NH_4NO_{3(s)} \longrightarrow N_2O_{(g)} + 2H_2O_{(l)}$

<u>(b). Trioxocarbonates (IV) Salts</u>

1. Trioxocarbonate (IV) salts of Na and K are stable to heat i.e do not decompose on heating
2. All trioxocarbonate (IV) salts of metals in the electrochemical series from calcium to copper decompose to give the metallic oxide, and carbon (IV) oxide.

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

$ZnCO_{3(s)} \longrightarrow ZnO_{(s)} + CO_{2(g)}$

3. Trioxocarbonate (IV) salts of Hg and Au decompose to give the metal, carbon(IV) oxide and oxygen.

$2Hg_2CO_{3(s)} \longrightarrow 4Hg_{(s)} + 2CO_{2(g)} + O_{2(g)}$

4. Ammonium trioxocarbonate (IV) will decompose to give ammonia gas, carbon (IV) oxide and Oxygen.

$(NH_4)_2CO_{3(s)} \longrightarrow 2NH_{3(g)} + CO_{2\,(g)} + H_2O_{(l)}$

5. $NaHCO_3$ decompose to give Na_2CO_3, CO_2 and H_2O

$2NaHCO_{3(s)} \longrightarrow Na_2CO_{3(s)} + CO_{2\,(g)} + H_2O_{(l)}$

Note: $KHCO_3$ give similar results as above

(c). Tetraoxosulphate (VI) Salts

i. Tetraoxosulphate (VI) Salts of higher electropositive metals like Na, K, Ca, Mg are thermally stable.

ii. Tetraoxosulphate (VI) Salts of lower electropositive metals like Fe decomposes to the metallic oxide, sulphur (IV) oxide and sulphur (VI) oxide.

$$2FeSO_{4(s)} \longrightarrow Fe_2O_{3(s)} + SO_{2(g)} + SO_{3(g)}$$

iii. Tetraoxosulphate (VI) Salts of weakly electropositive metals decomposes to give sulphur (IV) oxide and oxygen.

$$2HgSO_{4(s)} \longrightarrow 2Hg_{(s)} + 2SO_{3(g)} + O_{2(g)}$$

(d). Chlorides

1. All chlorides are thermally stable except ammonium chloride which sublimes on heating.

$$NH_4Cl_{(s)} \rightleftharpoons NH_{3(g)} + HCl_{(g)}$$

Preparation of Salts

Salts are prepared in a variety of ways. The method of preparation of a particular salt depends largely on its **solubility in water and stability to heat**. Soluble salts are prepared by methods that involve crystallization while insoluble salts are prepared by methods that involve precipitation.

Preparation of Soluble Salts

Salts that are soluble in water are prepared by various methods and recovered from the solutions by evaporation or crystallization.

1. Action of dilute acid on metal

There is displacement of hydrogen atom from an acid by metals that are higher(more reactive) than hydrogen e.g. Ca, Zn, Mg and Fe

$$Zn^{2+}_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$$

$$Ca^{2+}_{(s)} + H_2SO_{4(aq)} \rightarrow CaSO_{4(aq)} + H_{2(g)}$$

2. Action of acid and alkali

This is neutralization reaction and a suitable indicator is used to determine the end point.

$$KOH_{(aq)} + HNO_{3(aq)} \rightarrow KNO_{3(aq)} + H_2O_{(l)}$$

3. Action of acid and an insoluble base

Dilute acid is heated and a base is added until the solution is saturated. The excess base is filtered off.

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

$$2HCl_{(aq)} + MgO_{(s)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$$

4. Action of dilute and trioxocarbonate (IV)

This reaction produces a salt, water and carbon (IV)oxide

$$H_2SO_{4(aq)} + CuCO_{3(s)} \rightarrow CuSO_{4(aq)} + CO_{2(g)} + H_2O_{(l)}$$

Recovering Salts from Solution

Salts in aqueous solution can be recovered by:

1. **Evaporation**: This method is used for salts that can withstand dry heating. The salt solution is put in an evaporating dish and heated over a sand or water bath.
2. **Crystallization**: This is used to recover salts that can decompose or destroyed by dry heating e.g. tetraoxosulphate (VI) and trioxonitrate (V) salts are recovered by crystallization.
   - i. The salt solution is heated to drive off some water.
   - ii. The concentrated solution is then allowed to cool, crystals of the salt will appear in the solution. Crystals can also be induced by adding a crystal of the salt into the solution or scratching the inside of the container with a glass rod.
   - iii. The crystals obtained can be filtered, washed with distilled water and dried between filter papers.

Preparation of Insoluble Salts

Salts that are insoluble in water can be prepared by the following methods.

1. Double decomposition

The reacting substances recombine by exchanging their radicals.

$AB + CD \rightarrow AD + BC$

$AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow AgCl_{(s)} + NaNO_{3(aq)}$

Soluble *Soluble* *ppt* *soluble*

$BaCl_{2(aq)} + K_2SO_{4(aq)} \rightarrow BaSO_{4(s)} + 2KCl$

Soluble *Soluble* *ppt* *soluble*

2. **Direct combination of constituent elements** especially chlorides and sulphides.

$Fe_{(s)} + S_{(s)} \rightarrow FeS_{(s)}$

$Fe_{(s)} + 3Cl_{2(s)} \rightarrow 2FeCl_{3(s)}$

METHOD OF PREPARATION OF SOME SALTS

a. Preparation of Zinc chloride crystals (Action of an acid on a metal)

Procedure: Half-fill a beaker with dilute hydrochloric acid and add zinc granules while stirring with a glass rod. Effervescence occurs and hydrogen gas is evolved. Add more zinc granules until no more zinc dissolves. When the effervescence stops, filter the solution to remove the unreacted zinc granules and other impurities. Heat the filtrate to evaporate some water molecules. Place the beaker in a bowl of cold water to allow the solution to cool and crystallize. Crystals are formed. Filter the crystals and wash with a small quantity of cold water. Allow to dry between filter paper.

$Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$

Students exercise: Describe how you would prepare copper (II) tetraoxosulphate (VI) crystals from copper (II) oxide.

b. Preparation of sodium chloride crystals (Neutralization reaction)

Procedure: Put 25cm^3 of bench sodium hydroxide solution into a conical flask. Add 3 drops of methyl orange indicator. Fill a burette with dilute hydrochloric acid solution and read the acid level. Run the acid slowly into the sodium hydroxide, shaking it frequently to obtain a homogenous solution until the orange solution turns red. Read the new acid level and calculate the exact volume of acid needed to neutralize the known volume of the base. A small quantity of animal charcoal (to remove the colour) is added to the neutral solution. It is filtered and heated over a water bath to evaporate the water molecules. Sodium chloride crystals are left behind in the evaporating dish.

$NaOH_{(aq)} + 2HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

Students exercise: Describe how you would prepare potassium chloride crystals using potassium hydroxide and hydrochloric acid.

c. Preparation of lead (II) chloride (double decomposition)

Procedure: Half-fill a beaker with lead (II) trioxonitrate (V). Add dilute hydrochloric acid stirring with a glass rod. A white precipitate of lead (II) chloride is formed. Filter the solution. The residue which is lead (II) chloride is left on the filter paper while the filterate is dilute trioxonitrate (V) acid. Wash with a small quantity of cold water. Allow to dry between filter paper.

$Pb(NO_3)_{2(aq)} + 2HCl_{(aq)} \rightarrow PbCl_{2(s)} + 2HNO_{3(aq)}$

Students exercise: Describe how you would prepare silver chloride from silver trioxonitrate (V) and sodium chloride solution.

HYDROLYSIS OF SALTS

Hydrolysis is the reaction of salts with water to form a solution. This solution can be acidic, basic (alkaline) or neutral.

1. **Salts formed from strong acids and strong bases.**
   When these salts hydrolyze, they produce solutions that are neither acidic nor basic i.e. neutral; pH is about 7

e.g. $KCl_{(aq)} \longrightarrow HCl_{(aq)} + KOH_{(aq)}$ Neutral

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

$Na_2SO_{4(aq)} \longrightarrow NaOH_{(aq)} + H_2SO_{4(aq)}$ Neutral

2. **Salts formed from strong acids and weak bases**.
   When these salts are hydrolyzed, they form solutions that are acidic in nature – pH is less than 7 e.g.

$CuSO_{4(aq)} \longrightarrow Cu(OH)_{2(aq)} + H_2SO_{4(aq)}$ Acidic

$NH_4Cl_{(aq)} \longrightarrow NH_4OH_{(aq)} + HCl_{(aq)}$ Acidic

$2AlCl_{3(aq)} \longrightarrow Al(OH)_{3(aq)} + 3HCl_{(aq)}$ Acidic

3. **Salts formed from weak acids and strong bases**.
   When these salts are hydrolyzed, they form solutions that are alkaline in nature; pH is greater than 7 e.g.

$Na_2CO_{3(aq)} \longrightarrow NaOH_{(aq)} + H_2CO_{3(aq)}$ Alkaline

$CH_3COONa_{(aq)} \longrightarrow CH_3COOH_{(aq)} + NaOH_{(aq)}$ Alkaline

4. **Salts formed from weak acids and weak bases.**
   When these salts are hydrolyzed, they form solutions that are neither acidic nor alkaline in nature; pH is about 7 e.g.

$CH_3COONH_{4(aq)} \longrightarrow CH_3COOH_{(aq)} + NH_4OH_{(aq)}$ Neutral

Hydrated and Anhydrous Salts

Many salts combine chemically with water to form hydrated salts. **Hydrated** salts are salts which have a definite number of moles of water molecules attached to it. The water molecules attached is called ***water of crystallization***. When hydrated salts are heated, they lose the water of crystallization because they are loosely attached to the salt and the crystalline structure collapses and it becomes powder. The powdered form of the salt which does not have water of crystallization is called the **anhydrous salt or amorphous (shapeless) salt** e.g.

Copper (II) tetraoxosulphate (VI) pentahydrate	$CuSO_4.5H_2O$
Sodium trioxocarbonate (IV) decahydrate	$Na_2CO_3.10H_2O$
Zinc tetraoxosulphate (VI) heptahydrate	$ZnSO_4.7H_2O$
Copper (II) trioxonitrate (V) trihydrate	$Cu(NO_3)_2.3H_2O$
Magnesium tetraoxosulphate (VI) heptahydrate	$MgSO_4.7H_2O$
Zinc trioxonitrate (V) hexahydrate	$Zn(NO_3)_2.6H_2O$

When they are heated, they loose the water molecules attached.

$CuSO_4.5H_2O_{(s)} \longrightarrow CuSO_{4(s)}$

Hydrated salt *anhydrous salt*

$Na_2CO_3.10H_2O \longrightarrow Na_2CO_3$

Hydrated salt *anhydrous salt*

Salts without water of crystallization include NaCl, KCl, KNO_3, $KMnO_4$, $(NH_4)_2SO_4$, K_2SO_4, $Pb(NO_3)_2$ and $AgNO_3$, That means that not all crystalline salts are hydrates

Determination of water crystallization

Procedure

Weigh a clean crucible with lid, place some crystals of the salt and weigh again. Heat the dish and crystals to a constant mass. Ensure that the hot crucible is cooled in a dessicator before weighing. Weigh the dish and its content.

Analysis

Mass of crucible (empty)	xg
Mass of crucible with hydrated salt	yg
Mass of crucible with anhydrous salt	zg
Mass of residue (anhydrous)	(z-x)g
Mass of hydrated crystals	(y-x)g
Mass of water lost	(y-z)g

Let molar mass of anhydrous salt = M

Water of crystallization = $\frac{mass\ of\ anhydrous\ salt}{molar\ mass\ of\ anhydrous\ salt} = \frac{mass\ of\ water\ lost}{molar\ mass\ of\ water}$

OR

$$\frac{mass\ of\ hydrated\ salt}{molar\ mass\ of\ hydrated\ salt} = \frac{mass\ of\ water\ lost}{molar\ mass\ of\ water}$$

OR

Find the number of moles of each constituent (empirical formula)

Example 1

7.47g of hydrated Copper (II) tetraoxosulphate (VI) crystals were heated in a dish to a constant mass. The residue weighed 4.77g. Calculate the moles of water of crystallization in the hydrated salt.

Solution

Example 2

415g of anhydrous barium chloride were obtained when 459g of the hydrated salt were heated. Calculate the moles of water of crystallization in the hydrated salt $BaCl_2.nH_20$.

Solution

Students exercise:

(1). A 4.3g of hydrated sodium tetraoxosulphate (VI) $Na_2SO_4.xH_2O$, was heated to remove the water of crystallization. The remaining anhydrous salt has a mass of 2.12g. Calculate the value of x in the hydrated salt. [H=1, O=16, Na=23, S=32]

(2). 2.5g of hydrate compound of $BaCl_2. xH_2O$ gave on heating a residue of 2.13g of anhydrous compound of it. Calculate the value of x in the hydrated compound. [Ba= 131, Cl= 35.5, O= 16, H=1].

CHARACTERISTICS OF SALTS

When salts are exposed to the atmosphere, some changes take place.

1. **Efflorescent substances**: These are crystalline salts which loose some or all of their water of crystallization when exposed to the atmosphere to form a lower hydrate or anhydrous salt e.g.

$$Na_2CO_3.10H_2O \longrightarrow Na_2CO_3.H_2O_{(s)} + 9H_2O_{(g)}$$

(lower hydrate)

$$Na_2CO_3.10H_2O \longrightarrow Na_2CO_{3(s)}$$

(anhydrous)

Glauber's salt ($Na_2SO_4.10H_2O$) is also efflorescent.

The phenomenon described above is called **efflorescence**

2. **Deliquescent substances**: These are substances that absorb moisture and dissolve in it to form solutions when exposed to the atmosphere e.g sodium hydroxide (NaOH) pellets, potassium hydroxide (KOH) pellets, Iron (III) Chloride, Phosphorus (V) oxide, Magnesium Chloride, Calcium Chloride (Silica gel). There is increase in the mass of the salt

   The phenomenon described above is **Deliquescence**

3. **Hygroscopic substances**: These substances when exposed to the atmosphere, absorbs moisture but does not form solutions it becomes moist or sticky e.g. sodium trioxonitrate (V), copper (II) Oxide CuO, quicklime CaO and concentrated tetraoxosulphate (VI) acid. There is also increase in mass of the salt. Concentrated H_2SO_4 is the only hygroscopic liquid that can absorb moisture from the atmosphere and dilute itself.

USES OF SALTS

Salts	**Uses**
Ammonium Chloride (NH_4Cl)	Used in washing powder Used in electrolyte in dry cell
Calcium trioxocarbonate (IV)	Used as medicine to neutralize stomach acidity
Calcium chloride	Antifreeze (lower freezing point of water)
Fused calcium chloride	As a drying agent
Calcium tetraoxosulphate (VI)	Making plaster of Paris
Copper (II) tetraoxosulphate (VI)	Dyeing and calico printing
Magnesium tetraoxosulphate (V)	As a laxative
Potassium trioxonitrate (V)	For making gunpowder and matches As soil fertilizer
Sodium chloride	In Preservation of food In glazing of pottery In soap making to separate soap from glycerine To recharge water softeners
Zinc chloride	Petroleum refining
Sodium hydrogen trioxocarbonate (IV)	As baking powder
Sodium trioxocarbonate (IV)	To soften water In glass manufacturing In making of paper

DRYING AND DEHYDRATION

DRYING AGENTS / DESSICANTS.

Drying is a process of removing water molecules or moisture from a substance without altering the composition of the substances. The substances involved in drying are called **drying agents**. A drying agent must not react with the substance to be dried. Most hygroscopic substances are drying agents.

Conc. H_2SO_4 cannot be used to dry ammonia gas and hydrogen sulphide gas because it reacts with them. Calcium chloride also cannot be used to dry ammonia gas due to the same reason.

A **dehydrating agent** on the other hand removes water molecules (hydrogen and oxygen atoms) from a substance thereby altering the chemical composition of the substance e.g

$C_6H_{12}O_6 \longrightarrow 12C$

	Drying Agent	**Gases**
1	Conc. H_2SO_4	All gases except $NH_{3(g)}$ and $H_2S_{(g)}$
2	Fused Calcium chloride $CaCl_2$	All gases except $NH_{3(g)}$
3	Silica gel	All gases
4	Quicklime CaO	$NH_{3(g)}$
5	Phosphorus (V) oxide	All gases except $NH_{3(g)}$

WRITING IONIC EQUATIONS

When writing ionic equations:

1. Don't break up solids, gases or weakly ionized substances like water into ions but represent them as molecules.
2. Cancel out ions that are exactly the same on both sides of the equation.
3. The net charge and the atoms of each element must be the same on both sides of the equation (Balanced equation) e.g.
    1. $Zn_{(s)} + CuSO_{4(aq)} \rightarrow ZnSO_{4(aq)} + Cu_{(s)}$
       $Zn_{(s)} + Cu^{2+}\cancel{SO_4^{2-}} \rightarrow Zn^{2+}\cancel{SO_4^{2-}} + Cu_{(s)}$
       $Zn_{(s)} + Cu^{2+}_{(aq)} \rightarrow Zn^{2+}_{(aq)} + Cu_{(s)}$
    2. $AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow AgCl_{(s)} + NaNO_{3(aq)}$
       $Ag^+\cancel{NO_3^-}_{(aq)} + Na^+\cancel{Cl^-}_{(aq)} \rightarrow AgCl_{(s)} + \cancel{Na^+}\cancel{NO_3^-}_{(aq)}$
       $Ag^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)}$
    3. $Na_2SO_{4(aq)} + Pb(NO_3)_{2(aq)} \rightarrow 2NaNO_{3(aq)} + PbSO_{4(s)}$

Students exercise: Write the ionic equations of the following:

(1). $Ca(OH)_{2\,(aq)} + 2HNO_{3(aq)} \rightarrow Ca(NO_3)_{2(aq)} + H_2O_{(l)}$

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

(3). $CaCl_{2(aq)} + 2NaOH_{(aq)} \rightarrow Ca(OH)_{2\,(s)} + 2NaCl_{(aq)}$

TOPIC: CARBON AND ITS COMPOUNDS

Carbon is a solid and a non-metal. A member of group IV in the periodic table and exhibits oxidation states of +2 and +4. Carbon shows little tendency to acquire four electrons to form an anion or loose four electrons to form a cation, rather, it forms four covalent bonds. Carbon is rarely found naturally in the pure form but occurs mostly in the combined and impure form. Organic chemistry is the study (chemistry) of carbon compounds other than trioxocarbonate (IV) salts and oxides. Carbon can form bonds with other carbon atoms to form carbon frameworks (chains or rings); this property is known as **catenation**

Occurrence

Carbon occurs naturally as diamond or graphite which are the pure forms of carbon. Impure forms include coal, petroleum, wood and natural gases. Other sources are mineral deposits like limestone ($CaCO_3$), dolomite ($MgCO_3$) and CO_2 in air and water. Carbon is an essential constituent of all living things.

Allotropes of Carbon

Allotropy is a phenomenon in which an element can exist in two or more different forms in the same physical state. Carbon has three main allotropes:

(1). Diamond (2).Graphite - These are crystalline allotropes of carbon.

(3). Non-crystalline or Amorphous carbon: These are the non-crystalline forms of carbon and they include coal, coke, charcoal, lamp-black, sugar charcoal and animal charcoal.

Diamond, graphite and amorphous carbon consist of the same element (Carbon exists in different forms with respect to shape. - allotropy

DIAMOND

Diamond is the purest form of carbon. It is found as colourless, lusterless solids which can be transformed into brilliant gems.

Properties

1. It is the hardest known substance. Only a diamond can cut a diamond.
2. It is resistant to high temperatures and chemical attack
3. It does not conduct electricity because there are no mobile electrons in the crystal.
4. It is very dense about 3.5g/cm^3
5. It is a colourless, transparent solid which sparkles when polished
6. Burns in air 900°C to form CO_2 and combines with fluorine at 700 °C
7. It is an octahedral crystal with 3-dimensional lattices. It is a giant molecule in which the carbon atoms are closely bonded by covalent bonds.

Uses

(i) They are used individually in drills because they are very hard

(ii) Used as abrasives to sharpen hand tools because they are hard and dense

(iii) Used to cut glass and metals

(iv) Used as pivot supports in precision instruments and dies for chewing wires

(v) It is used as jewelry since it has high refractive index and dispersion brilliance when it is cut and polished.

Artificial diamond

These are obtained when graphite is subjected to high temperature and pressure for several hours in the presence of a catalyst (Nickel or Rhodium).

Graphite → Diamond

GRAPHITE

Graphite exists as black, slippery, hexagonal solids

Occurrence

Found naturally as Plumbago (an opaque black solid) in china, Australia, West Germany, republic of Korea, Mexico, Madagascar, Siberia and Sri Lanka.

Properties

1. It is slippery and so used as dry lubricant in engines where high temperatures will melt ordinary lubricant
2. It is one of the softest materials, can mark paper
3. It conducts electricity because of mobile electrons. Only three out of the four electrons are involved in covalent bond so the extra valence electron enables graphite to conduct electricity.

4. It is less dense than diamond about $2.3gcm^{-3}$
5. More reactive than diamond burns at 700°C to form CO_2. Reacts with oxidizing agents to form oxides and also reacts with H_2SO_4 and Fluorine
6. It has basic 2 dimensional hexagonal units forming parallel layers (one above the other) held together by weak van der Waals forces in-between layers.
7. It is a black opaque solid with a metallic luster.

Uses

1. Graphite is used as a dry lubricant
2. It is used as electrodes in electroplating and dry cells
3. For lining crucibles used in making high grade steel and other alloys
4. Used as lead in pencils when mixed in clay
5. As a black pigment in paints
6. As a neutron moderator in atomic piles because it is soft

Industrial Preparation of Graphite

It is produced industrially by heating coke in an electric furnace to high temperature for about 20 to 30 hours. This is called the **Acheson process**.

General Properties of Carbon

1. They are generally greyish black or black solids except diamond
2. They are tasteless and odourless
3. They are insoluble in all common solvents e.g. water, petrol
4. They can form single or multiple bonds with itself and atoms of other elements (catenation).

Catenation is the ability of carbon atoms to form multiple bond with itself as long chains or rings

5. All allotropes of carbon have similar chemical properties
6. They have high melting points

Students exercise: In a tabular form, enumerate five differences between diamond and graphite

Amorphous Carbon

1. **Coal**: This was formed during the carboniferous era and vegetable materials were converted into stages by decomposition process in the absence of air. It is result of complex chemical and physical changes. There are four types of coal: Peat, lignite (brown coal), bituminous (soft coal) and anthracite (hard coal). Impurities in coal may include nitrogen, sulphur and phosphorus. Coal is used
    - as fuel to power steam engines, factories and electrical plants
    - for making various chemicals
2. **Coke**: This is obtained by heating bituminous coal to very high temperature (about 1300°C) in the absence of air to remove volatile constituents. This is known as the destructive distillation of coal.

- It is used as fuel (it burns with no smoke and leaves little reside)
- It is used as important industrial reducing agent e.g. extraction of metals (iron) from their ore.
- It is used in the production of gaseous fuels like water gas and producer gas.
- It is used for the manufacture of graphite, calcium carbide, carbon (IV) sulphide and silicon carbide

3. **Carbon black or soot**: This is formed when carbonaceous material is burnt in limited supply of air. Lamp black is obtained from vegetable or lamp oils. Carbon black is obtained from coal gas, natural gas or fuel oils. Carbon black is used in manufacturing rubber tyres, black shoe polish, printer's ink type writing ribbons and carbon paper.
4. **Charcoal**: This can be made by heating wood, nut shells, bones, sugar and even blood in a limited supply of air.

a) **Wood charcoal** is made by heating wood in limited supply of air. It may contain sulphur as impurities

- Wood charcoal adsorbs gases, so it is used in gas masks to adsorb poisonous gases
- It is used to recover industrial solvents
- It is used in the purification of noble gases
- Wood charcoal is used mainly as domestic fuel in Nigeria

b) **Sugar charcoal**: This is made when sugar is dehydrated either by burning in limited supply of air or by the action of concentrated H_2SO_4

c) **Animal Charcoal**: This is formed when bones or animal refuse is heated in limited supply of air.

(a) Animal charcoal adsorb colouring matter and so it is used to remove brown colour from crude sugar and to decolorize petroleum jelly.

Carbon fibres

These are formed by heating fibres of materials like poly (propenonitrile) until they char to form carbon. They are incorporated into plastic to form a very light stiff and strong material.

Chemical properties of Carbon

(a) Combustion

All forms of carbon burn in plenty air to form CO_2 but in limited air to form CO

$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$ excess supply of air

$2C_{(s)} + O_{2(g)} \rightarrow 2CO_{(g)}$ limited supply of air

The charcoal fire diagram

Level A

$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$

Level B

$CO_{2(g)} + C_{(s)} \rightarrow 2CO_{(g)}$

Level C

$2CO_{(g)} + O_{2(g)} \rightarrow 2\,CO_{2(g)}$

At level A, air is plentiful and charcoal burns to produce CO_2 only.

At level B, air is limited as a result, the ascending is CO_2 reduced to CO

At level C, air is plentiful and the ascending CO is re oxidized to CO_2

Carbon (II) oxide (CO) is a very dangerous gas. It combines with haemoglobin to form carboxyheamoglobin which prevents the heamoglobin from distributing oxygen round the body

(b). Combination reaction

Carbon combines directly with some elements at high temperatures e.g. Hydrogen, Calcium, Sulphur and Aluminium.

$C_{(s)} + 2S_{(s)} \rightarrow CS_{2(l)}$ Carbon (IV) sulphide

$C_{(s)} + 2H_{2(g)} \rightarrow CH_{4(g)}$ Methane

$2C_{(s)} + 2Ca_{(s)} \rightarrow CaC_{2(s)}$ Calcium carbide

$3C_{(s)} + 4Al_{(s)} \rightarrow Al_4C_{3(s)}$ Aluminium carbide

(b) As a reducing reagent

Carbon is a strong reducing agent. It reduces the oxides of less active metals to the metals and is oxidized to carbon (IV) oxide or carbon (II) oxide

$Fe_3O_{2(s)} + 3C_{(g)} \rightarrow 3Fe + 3CO_{(g)}$

$2CuO_{(s)} + C_{(s)} \rightarrow 2Cu + CO_{2(s)}$

$H_2O_{(l)} + C_{(s)} \rightarrow CO_{(g)} + H_{2(g)}$

$CO_{2(g)} + C_{(s)} \rightarrow 2CO_{(g)}$

(c) Reaction with strong oxidizing agents

Carbon is oxidized to carbon (IV) oxide when it is heated with Conc. HNO_3 or Conc. H_2SO_4.

$C_{(s)} + 4HNO_{3(aq)} \rightarrow 2H_2O_{(l)} + CO_{2(g)} + 4NO_{2(g)}$

$C_{(s)} + 2H_2SO_{4(aq)} \rightarrow 2H_2O_{(l)} + SO_{2(g)} + CO_{2(g)}$

DESTRUCTIVE DISTILLATION OF COAL

Coal is a complex mixture of compounds containing carbon, hydrogen, oxygen and small amounts of sulphur, nitrogen, phosphorus or other impurities.

Destructive distillation of coal means heating coal to a very high temperature in the absence of air so that all the volatile components distil over.

Coal → coke + ammonical liquor + coal tar + coal gas

1. **Coal gas**: This is the volatile compound which contains about 50% hydrogen, 3% methane and 10% carbon (II) oxide and also small amount of other gases like ethene and hydrogen sulphide. Coal gas is used as a gaseous fuel because it is cleaner and more efficient than other sources of fuel.
2. **Ammoniacal liquour**: This is an aqueous liquid consisting mainly of ammonium compounds and benzene. It is used in the manufacture of nitrogenous fertilizers (ammonium compounds) while benzene is used as solvent and for the manufacture of pharmaceutical products.
3. **Coal tar**: Coal tar is a thick, black liquid. It is a mixture of more than 200 different substances which can be separated by fractional distillation. Most of the substances like naphthalene, benzene, phenol and toluene coal tar is used in the manufacture of commercial products like paints, dyes, perfumes, insecticides, explosives, plastic and drugs.
4. **Coke**: This is the non-volatile (solid) residue left behind after destructive distillation with 95% carbon. It is used in the manufacture of gaseous fuels such as water gas and producer gas. It is used as a reducing agent in metallurgy.

DESTRUCTIVE DISTILLATION OF WOOD

Wood is a complex substance like coal except that the percentage composition of elements is different

This process also yields four fractions

Wood → wood charcoal + pyroligenous acid + wood tar + wood gas

Pyroligenous acid is the liquid fraction and contains mainly ethanoic acid, propanone, methanol and some other compounds.

FUEL GASES (gasefication of coke)

1. **Producer gas**: This is obtained by passing air over red hot coke in a furnace. It contains a mixture of nitrogen and carbon (II) oxide. The reaction is exothermic (large amount of heat is released into the environment). The oxygen in air oxidizes the carbon to CO while the nitrogen is unchanged. Producer gas is a mixture of nitrogen and carbon (II) oxide.

   $$\underset{\text{(air)}}{O_{2(g)} + N_{2(g)}} + C_{(s)} \rightarrow \underset{\text{(Producer gas)}}{2CO_{(s)} + N_{2(g)}} + \text{heat}$$

   Producer gas has lower heating power because it contains 67% non-combustible nitrogen and 33% carbon (II) oxide. Producer gas is not expensive and it is used to heat furnaces, retorts and limekilns. It is also used as a source of nitrogen during the manufacture of ammonia (Haber process)

2. Water gas

This is produced by passing steam over white hot coke at 1000°C. It contains equal volumes of hydrogen and carbon (II) oxide

$C_{(s)} + H_2O_{(l)} \rightarrow CO_{(g)} + H_{2(g)}$

(water gas)

Water gas is a combustible gas because its component burns in air to release a lot of heat. It is used as an industrial fuel and to produce hydrogen, methanol and butanol.

Both gases are produced in the same plant by passing both steam and air through the heated coke. **Water gas is a better fuel because its components (hydrogen and carbon(II) oxide) are combustible to release a lot of heat. Water gas production is an endothermic process while that of producer gas is an exothermic process.** In view of this, **both gases can be produced in the same plant by passing air and steam alternately through the heated coke. The heat produced during producer gas formation is enough for water gas formation.** Water gas is used in the manufacture of hydrogen, methanol and butanol.

OXIDES OF CARBON

Carbon forms two important oxides; carbon(IV) oxide (CO_2) and carbon (II) oxide (CO) which depends on the availability of oxygen during combustion.

CARBON (IV) OXIDE, CO_2

CO_2 is found in the atmosphere about 0.03% and also in dissolved form in water. It is found as metallic trioxocarbonates (IV) and hydrogen trioxocarbonates (IV) in the earth's crust (limestone region and coral reefs).

Laboratory preparation of carbon (IV) oxide

1. It is prepared by the action dilute HCl or dil HNO_3 acid with any trioxocarbonate (IV)e.g. $CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$

$NaHCO_{3(s)} + 2HNO_{3(aq)} \rightarrow NaNO_{3(aq)} + H_2O_{(l)} + CO_{2(g)}$

Procedure: When dilute HCl is poured on marble chips by means of thistle funnel, effervesence occurs and a gas is given off. The gas is passed through a solution of potassium hydrogen trioxocarbonate (IV) solution to absorb the excess acid and through a U-tube packed with anhydrous calcium chloride to dry it. The gas is collected by downward delivery (because it is heavier/denser than air). Conc. H_2SO_4 cannot be used to prepare the gas because it reacts to form $CaSO_4$ which coats the surface of the marble chips and prevent further reaction.

2. By heating metallic trioxocarbonate (IV) and hydrogen trioxocarbonates (IV) like $NaHCO_3$ and $KHCO_3$ e.g trioxocarbonates (IV) of sodium and potassium will not decompose on heating

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

   $2NaHCO_{3(s)} \rightarrow Na_2CO_{3(s)} + H_2O_{(l)} + CO_{2(g)}$

Physical properties of CO_2

1. It is a colourless and odourless gas
2. It is soluble in water
3. It is a weak acidic gas which turns moist blue litmus paper
4. It is denser than air
5. On cooling, it liquefies and solidifies (-78°C) to form a white solid known as dry ice.

Chemical properties of CO_2

1. It ionizes slightly in water to form weak dibasic acid known as soda water

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

2. It reacts with alkalis to yield trioxocarbonates (IV)

   $2NaOH_{(aq)} + CO_{2(g)} \rightarrow Na_2CO_{3(aq)} + H_2O_{(l)}$

   $2KOH_{(aq)} + CO_{2(g)} \rightarrow K_2CO_{3(aq)} + H_2O_{(l)}$

   Solutions of alkali absorb CO_2 and are used to remove it from a mixture of gases.

3. It burns with magnesium ribbon, though CO_2 does not burn nor support combustion but it decomposes CO_2 to release oxygen for oxidation of the magnesium

   $CO_{2(g)} + Mg_{(s)} \rightarrow MgO_{(s)} + C_{(s)}$

4. It is reduced to carbon (II) oxide when it reacts with red hot carbon. The reaction is reversible and is of great commercial importance.

   $CO_{2(g)} + C_{(s)} \rightleftharpoons 2CO_{(g)}$

Test for CO_2

When the unknown gas is bubbled through lime water ($Ca(OH)_2$). It turns milky due to precipitation of insoluble calcium trioxocarbonate (IV) $CaCO_3$, if more of the gas is bubbled through the solution, the milkiness will disappear leaving a clear solution. This is because the $CaCO_3$ formed reacts with CO_2 to form soluble calcium hydrogen trioxocarbonate (IV). If the clear solution is heated, it turns milky again due to the decomposition of $Ca(HCO_3)_2$.

$Ca(OH)_2 + CO_{2(g)} \rightarrow CaCO_{3(s)} + H_2O_{(l)}$

$CaCO_{3(s)} + CO_{2(g)} + H_2O_{(l)} \rightarrow Ca(HCO_3)_{2(aq)}$

$Ca(HCO_3)_2 \rightarrow CaCO_{3(s)} + H_2O_{(l)} + CO_{2(g)}$

Uses of CO_2

1. It is used in fire extinguishers since it does not support combustion. It is used for putting out petrol fires since its floats on water.
2. It is used for making carbonated drinks e.g coco-cola, mirinda etc. It is dissolved in the drinks under high pressure, when the pressure is released, the gas is liberated.
3. Many health salts contain a solid mixture of sodium trioxocarbonate (IV) and citric acid or tartaric acid, when they are dissolved in water, effervescence occurs and CO_2 is given out
4. Solid CO_2 (dry ice) is used as a refrigerant for perishable goods e.g. ice cream. It sublimes on warming and provides lower temperature for the food.
5. Gaseous CO_2 is used to preserve fruits.
6. CO_2 is used as a coolant in nuclear reactors.
7. It is used to manufacture many chemicals like sodium trioxocarbonate (IV) (washing soda) by solvay process.
8. It is used to make sodium hydrogen trioxocarbonate (IV) which is used as baking soda (Yeast and baking produce CO_2 which causes the dough to rise) and with lead (II) trioxonitrate, urea and ammonium tetraoxosulphate (VI) as fertilizers

Carbon(II) oxide(Carbon Monoxide), CO

This is produced by incomplete combustion of carbon compounds e.g. octane C_8H_{18} found in petrol. It exhibits oxidation state of +2. It is present in coal gas and other gaseous fuels. It occurs in trace amount as impurity in the atmosphere but the percentage is higher in cities where the gas is released from exhaust of motor cars and in industrial areas.

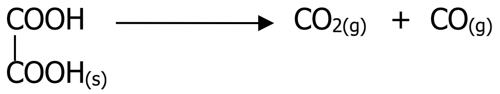
CO is a very poisonous gas. As little as 0.5% of CO can cause a person to die when inhaled.

Laboratory Preparation

1. It can be prepared by passing carbon (IV) oxide over red hot carbon. The CO_2 is reduced to Carbon (II) Oxide. Unchanged CO_2 is removed by passing it over concentrated sodium hydroxide or potassium hydroxide solution. The pure CO is collected over water.

   $$CO_{2(g)} + C_{(s)} \rightarrow 2CO_{(g)}$$

2. It can also be prepared by dehydrating ethanedioc or methanoic acid with concentrated H_2SO_4. The mixture of CO and CO_2 liberated is passed over concentrated KOH or NaOH to remove CO_2 and finally passed through conc. H_2SO_4 to dry the gas



$$\begin{matrix}\text{COOH} \\ | \\ \text{COOH}_{(s)}\end{matrix} \longrightarrow CO_{2(g)} + CO_{(g)}$$

Ethanedioc acid

$$HCOOH_{(l)} \longrightarrow CO_{(s)}$$

Methanoic acid

Carbon (II) oxide is prepared in the fume cupboard because it is a poisonous gas

Physical properties of CO

1. It is colourless, tasteless and odourless gas
2. It is insoluble in water but dissolves in a solution of ammonical copper (I) chloride
3. It is a neutral gas (no effect on moist litmus paper)
4. It is slightly less dense than air

Chemical properties of Carbon (II) Oxide

1. It is a strong reducing agent. It reduces metallic oxides to their metals

$$PbO_{(s)} + CO_{(g)} \rightarrow Pb_{(s)} + CO_{2(g)}$$

$$I_2O_{5(s)} + 5CO_{(g)} \rightarrow I_{2(s)} + 5CO_{2(g)}$$

Iodine (V) oxide

$$H_2O_{(g)} + CO_{(g)} \rightarrow H_{2(g)} + CO_{2(s)}$$

steam

2. It undergoes combinations reaction

a. **With oxygen**: It burns in air with a faint blue flame to give carbon (IV) oxide.

$$2CO_{(g)} + O_{2(g)} \rightarrow 2CO_{2(g)}$$

b. With heamoglobin

It reacts with heamoglobin in the red blood cells to form carboxyheamoglobin (a stable compound)

$$CO + Hb \rightarrow COHb$$

This compound prevents heamoglobin from transporting oxygen to the red blood cells. A person who inhaled large concentration of carbon(II) oxide may die from lack of oxygen.

Test of carbon (II) oxide, CO

Procedure: Bubble the unknown gas through a test tube containing lime water. Next apply a lighted splinter to a test tube containing the gas. Then add some lime water to the test tube and shake.

Result: Carbon (II) oxide burns in air with a blue flame and then turns lime water milky after burning but not before.

Uses of CO

1. It is used for extraction of metals from their ores as an important reducing agent.
2. It is used to produce gaseous fuels (producer gas and water gas).
3. It is used in the commercial production of methanol using Zinc chromate as catalyst

   $CO_{(g)} + 2H_{2(g)} \rightarrow CH_3OH_{(aq)}$

TRIOXOCARBONATES (IV)

Trioxocarbonate (IV) acid forms two types of salt:

(a) Acid salt – hydrogen trioxocarbonate (IV) – HCO_3^-

(b) Normal salt –trioxocarbonate (IV)- CO_3^{2-}

Metallic trioxocarbonate (IV) are usually found as natural deposits or ores.

Preparation

1. **Soluble trioxocarbonate (IV)** are prepared by bubbling CO_2 through a solution of the corresponding alkali. The soluble trioxocarbonates (IV) are Na_2CO_3, K_2CO_3 and $(NH_4)_2CO_3$

   $2KOH_{(aq)} + CO_{2(g)} \rightarrow K_2CO_{3(aq)} + H_2O_{(l)}$

   Since K_2CO_3 and Na_2CO_3 are not decomposed by heating, they can be prepared by heating the corresponding hydrogen trioxocarbonate (IV)

   $2KHCO_3 \rightarrow K_2CO_{3(s)} + H_2O_{(l)} + CO_{2(g)}$

2. **Insoluble trioxocarbonate (IV)** can be prepared as precipitates by adding a solution of sodium trioxocarbonate (IV) or sodium hydrogen trioxocarbonate (IV) to a solution of the corresponding metal salt.

   $CaCl_{2(aq)} + Na_2CO_{3(aq)} \rightarrow CaCO_{3(s)} + 2NaCl_{(aq)}$

   $CaCl_{2(aq)} + 2NaHCO_{3(aq)} \rightarrow CaCO_{3(s)} + 2NaCl + H_2O_{(l)} + CO_{2(g)}$

   $AgNO_{3(aq)} + Na_2CO_{3(aq)} \rightarrow Ag_2CO_{3(s)} + 2NaNO_{3(aq)}$

   $AgNO_{3(aq)} + 2NaHCO_{3(aq)} \rightarrow Ag_2CO_{3(s)} + 2NaNO_{3(aq)} + H_2O_{(l)} + CO_{2(g)}$

   Aluminium trioxocarbonate (IV) does not exist.

Sodium trioxocarbonate (IV) [Na_2CO_3]

(a) Laboratory preparation

By passing carbon (IV) oxide into a solution of sodium hydroxide

$2NaOH_{(aq)} + CO_{2(g)} \rightarrow Na_2CO_{3(aq)} + H_2O_{(l)}$

If excess is $CO_2$is passed into the solution, insoluble white precipitate of $NaHCO_3$ is formed.

$Na_2CO_{3(aq)} + CO_{2(g)} + H_2O_{(l)} \rightarrow 2NaHCO_{3(aq)}$

(b) Industrial preparation - Solvay process

Ammoniacal brine (brine saturated with NH_3) is poured into the solvay tower from the top. Carbon (IV) oxide is forced up the tower. The tower is fitted with dome-shaped baffle plates to slow down the flow of liquid and gas and also to provide large surface area for reaction. Carbon (IV) oxide reacts with ammonia to form ammonium hydrogen trioxocarbonate (IV) which in the presence of sodium chloride produces sodium hydrogen trioxocarbonate. Sodium hydrogen trioxocarbonate is formed as a precipitate which is washed, filtered and heated to give anhydrous sodium trioxocarbonate (IV).

$NH_{3(g)} + CO_{2(g)} + H_2O_{(l)} \rightarrow NH_4HCO_{3(aq)}$

$NH_4HCO_{3(aq)} + NaCl_{(aq)} \rightarrow 2NaHCO_{3(s)} + NH_4Cl_{(aq)}$

$2NaHCO_{3(s)} \rightarrow Na_2CO_{3(aq)} + H_2O_{(l)} + CO_{2(g)}$

The solvay process is economical because the CO_2 is recycled and ammonia produced is also recycled into system.

Physical properties of Na_2CO_3

(a) The solution is alkaline i.e. turns red litmus paper blue

(b) Anhydrous Na_2CO_3 isa soluble powder (soluble in water).

(c)It occurs as a large transparent crystal.

Chemical properties of Na_2CO_3

(1) It reacts with dilute acids to produce carbon (IV) oxide and the salt of the acid

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

(2) It undergoes effervescence to give the monohydrate of the salt

$Na_2CO_3.10H_2O \rightarrow Na_2CO_3.H_2O_{(s)} + 9H_2O_{(l)}$

(3) It is stable to heat i.e. does not decompose

Uses

1. To soften hard water
2. To manufacture sodium hydroxide
3. To manufacture glass
4. To precipitate metallic trioxocarbonates (IV) in qualitative analysis.

Calcium trioxocarbonate (IV) [$CaCO_3$]

It occurs naturally in chalk, limestone and marble

Preparation

1. By double decomposition

$Ca(NO_3)_{2(aq)} + Na_2CO_{3(aq)} \rightarrow CaCO_{3(s)} + NaNO_{3(aq)}$

2. By adding calcium chloride to a solution of sodium trioxocarbonate (IV)

$CaCl_{2(aq)} + Na_2CO_{3(aq)} \rightarrow CaCO_{3(s)} + 2NaCl_{(aq)}$

$CaCO_3$ is decomposed by heat to form calcium oxide and carbon (IV) oxide.

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

$CaCO_3$ reacts with dilute acids to liberate CO_2 gas

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

Copper (II) trioxocarbonate (IV) [$CuCO_3$]

It is a green salt prepared by double decomposition

$Cu(NO_3)_{2(aq)} + Na_2CO_{3(aq)} \rightarrow CuCO_{3(s)} + NaNO_{3(aq)}$

It is insoluble in water and decomposed by heat to give black CuO and CO_2

$CuCO_{3(s)} \rightarrow CuO_{(s)} + CO_{2(g)}$

$CaCO_3$ reacts with dilute acids to liberate CO_2 gas

Zinc trioxocarbonate (IV) [$ZnCO_3$]

A white solid formed by double decomposition

$Zn(NO_3)_{2(aq)} + Na_2CO_{3(aq)} \rightarrow ZnCO_{3(s)} + NaNO_{3(aq)}$

It is insoluble in water and decomposed by heat to give zinc oxide and CO_2

$ZnCO_{3(s)} \rightarrow ZnO_{(s)} + CO_{2(g)}$

(ZnO is yellow when hot and white when cold)

$ZnCO_3$ reacts with dilute acids to liberate CO_2 gas

$ZnCO_{3(s)} + HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$

Lead trioxocarbonate (IV) [$PbCO_3$]

A white salt formed by double decomposition

$Pb(NO_3)_{2(aq)} + Na_2CO_{3(aq)} \rightarrow PbCO_{3(s)} + NaNO_{3(aq)}$

$Pb(NO_3)_2$ is insoluble in water

It is decomposed when heated to give lead (II) oxide and CO_2

PbO is red when hot and yellow when cold.

$PbCO_{3(s)} \rightarrow PbO_{(s)} + CO_{2(g)}$

$PbCO_3$ reacts with dil. acids to liberate CO_2 gas

$PbCO_{3(s)} + HCl_{(aq)} \rightarrow PbCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$

Insoluble

Potassium trioxocarbonate (IV) [K_2CO_3]

A white salt prepared by passing CO_2 into potassium hydroxide solution.

$2KOH_{(aq)} + CO_{2(g)} \rightarrow K_2CO_{3(aq)} + H_2O_{(l)}$

K_2CO_3 is soluble in water to form alkali solution

It cannot be decomposed by heating

K_2CO_3reacts with dilute acids to liberate CO_2 gas

$K_2CO_{3\ (s)} + 2HCl_{(aq)} \rightarrow 2KCl_{(aq)} + H_2O_{(l)} + CO_{2(g)}$

Hydrogen trioxocarbonate (IV) [HCO_3]

These are acid salts prepared by passing excess carbon (IV) oxide to an aqueous solution of a trioxocarbonate (IV) salt.

$Na_2CO_{3(aq)} + H_2O_{(l)} + CO_{2(g)} \rightarrow 2NaHCO_{3(aq)}$

They are soluble in water. They decomposed by heating to liberate CO_2 gas

$K_2CO_{3\ (s)} + 2HCl_{(aq)} \rightarrow 2KCl_{(aq)} + H_2O_{(l)} + CO_{2(g)}$

Only $(NH_4)HCO_{3(aq)}$, $KHCO_3$and $NaHCO_3$ can be isolated as solids.

Calcium hydrogen trioxocarbonate (IV) is responsible for hardness of water.

Test of Hydrogen trioxocarbonate (IV)

1. When the salt is heated, CO_2 is given off and the test for CO_2 is positive (turns lime water milky).
2. When the salt is warmed with dilute acids, CO_2 is given off and the test for CO_2 is positive (turns lime water milky).

CARBON CYCLE

The level of carbon in living matter is kept constant and continuously circulated in nature by a series of changes known as the carbon cycle.

The level of carbon (IV) oxide in the air is kept constant at 0.03% by volume i.e rate of formation and rate of removal of CO_2 is naturally balanced.

The carbon cycle

Process that liberate CO_2 into the atmosphere

1. Respiration of living organism
2. Combustion of organic substances (wood, coal, petrol, etc)
3. Decay of organic material
4. Heating of trioxocarbonates (IV) and hydrogen trioxocarbonates (IV)
5. Eruption of volcanoes
6. Fermentation of sugars and other carbohydrates.

Process that remove CO_2 into the atmosphere

1. Photosynthesis
2. Hardening of mortar and white-wash
3. Build–up of calcium deposits (sea shell, chalk, limestone etc)

Activities that upset the natural balance of the carbon cycle

1. Increase in combustion of fossil fuel in industries home and vehicles
2. Deforestation