SS2 FIRST TERM CHEMISTRY NOTE, 2024/2025 SESSION.

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STOICHIOMETRY (I)

MASS-VOLUME RELATIONSHIPS IN REACTIONS

Stoichometry is the study of quantitative relationships of the amounts of reactants to one another and to the product as implied by chemical reactions. Stoichometry deals with definite ratio in which substances combine. A chemical equation is a statement of both qualitative and quantitative chemical change. It is used by scientists to describe calculations involving mass-volume relationships.

IUPAC CONVENTIONS AND S.I UNIT

Quantity	Symbol	Unit
Mass	M	g or Kg
Molar mass	M	g/mol
Volume	V	cm^3 or dm^3
Molar volume	Vm	dm^3mol^{-1}
Amount (mole)	N	Mol
Molar concentration	C	$moldm^{-3}$
Mass concentration	P	$g\ dm^{-3}$
Avogadro's constant	L	mol^{-1}
Number	N	-

RELATIONSHIP BETWEEN QUANTITIES

$$\text{Mole} = \frac{\text{volume}}{\text{Molar Volume}} \qquad \text{mole} = \frac{\text{mass}}{\text{molar mass}}$$

$$\text{Amount (mole)} = \frac{\text{Number of entities}}{\text{Avogadro's constant}}$$

$$\text{Avogadro's constant} = \frac{\text{Number of entities}}{\text{Amount}}$$

MOLE RATIO

A mole is the amount of a substance which contains as many elementary particles as there are carbon atoms in 0.012Kg of carbon-12

A mole is the amount of substance which contains as many formular units as there are atoms in 12g of carbon-12. The numerical co-efficients of a balanced equation represent the number of moles of reactants and products.

Mole = molar mass = molar volume of a gas at s.t.p = Avogadro's number

The mole ratio in which reactants combine and products are formed gives the stoichiometry of the reaction.

	$Mg_{(s)}$	+ $2HCl_{(aq)}$	→ $MgCl_{2(aq)}$	+ $H_{2(g)}$
No of moles	1	: 2	: 1	: 1
Mole ratio	1	: 2	: 1	: 1
Molar mass	24	: 2 x 36.5	: 95	: 2
reacting mass	24g	: 2 x 36.5g	: 95g	: 2g

$$\text{number of moles} = \frac{\text{reacting mass}}{\text{molar mass}} \quad \textbf{OR} \quad \text{number of moles} = \frac{\text{mass of element}}{\text{atomic mass of element}}$$

Examples

1. Calculate the number of moles of calcium chloride $CaCl_2$ that can be obtained from 20g of limestone $CaCO_3$ in the presence of excess hydrogen chloride? (Ca=40, Cl=35.5, C=12, H=1, O=16)

Solution

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

2. What mass of lead (II) trioxonitrate (V) will be required to yield 18g of lead (II) chloride on addition of excess sodium chloride solution? (Na=23, Pb=207, N=14, O=16, Cl=35.5).

Solution

$$Pb(NO_3)_{2(aq)} + 2NaCl_{(aq)} \rightarrow PbCl_{2(aq)} + 2NaNO_{3(aq)}$$

3. Calculate the mass of ammonia required to produce 3 x10^{23} molecules of nitrogen according to the equation? $4NH_{3(g)} + 3O_{2(g)} \rightarrow 2N_{2(g)} + 6H_2O_{(l)}$

Solution

4. 20g of copper (II) oxide was warmed with 0.05 moles of tetraoxosulphate(VI) acid. Calculate the mass of copper (II) oxide that was in excess? (Cu=64)

Solution

5. What mass of sodium trioxocarbonate (IV) is needed to prepare 500cm^3 of 0.2M solution? (Na=23, C=12, O=16)

Solution:

REACTIONS INVOLVING GAS VOLUMES

Equal volumes of all gases at the same temperature and pressure contain the same number of molecules provided that the gases are under the same conditions of temperature and pressure. The co-efficients of a balanced gaseous reaction/ equation gives the mole ratios as well as the volume relations among the gases.

$$4NH_{3(g)} + 5O_{2(g)} \rightarrow 4NO_{(g)} + 6H_2O_{(g)}$$

No of moles 4 : 5 : 4 : 6

4 vol : 5 vol : 4vol : 6 vol

One mole of a gas at s.t.p occupies 22.4dm^3 and contains 6.02×10^{23} molecules

Examples

1. In the industrial preparation of ammonia gas, nitrogen combines with hydrogen in the presence of a catalyst according to the equation.

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

(a). How many moles of hydrogen gas will react with 2.0 moles of nitrogen?

(b). What volume of ammonia gas will be produced from with 450cm^3 of hydrogen?

Solution

2. Calculate the volume of carbon (IV) oxide at 30°C and 770mmHg pressure which could be obtained by heating 20g of limestone? (Ca=40, C=12, O=16, molar volume of a gas at s.t.p =22.4dm ^{3}.

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

1 : 1 : 1

3. 50 cm^3 of CO was mixed and sparked with 200cm^3 of air containing 21% of oxygen. if all the volumes were measures at s.t.p. calculate the total volume of the residual gases?

Solution

4. What volume of dry oxygen gas would be produced from the decomposition of 15.5g of potassium trioxochlorate (V)? [K=39, Cl=35.5, O=16, I mole of a gas at s.t.p =22.4dm^3]

Solution

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

5. Calculate the maximum volume of ammonia gas which could be obtained by boiling 5dm^3 of 0.05M solution of ammonia (molar volume of a gas at s.t.p = 22.4dm^3)

Solution

6. When 10.0g of razor blade completely reacted with an excess solution of hydrochloric acid, 0.15 moles of $FeCl_2$ was obtained. Calculate the mass of iron in the razor blade? (molar volume of a gas at s.t.p = 22.4dm^3)

Solution

7. Calculate the volume of 0.1M ammonia gas which could be obtained by heating 2.72g of ammonium chloride with excess sodium hydroxide and absorbing all the ammonia gas produced?

Solution

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

8. What volume of 1.0M HCl will be required to react with completely with 3.25g of zinc?

Solution

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

9. Calculate the volume of 2M hydrochloric acid which could be obtained by dissolving 560cm^3 of hydrogen chloride in water? (molar volume of a gas at s.t.p = 22.4dm3)

Solution

10. Calculate the mass of carbon (IV) oxide produced when 105g of ethyne in burned in air? (C=12,H=1, O=16)

Solution

$$2C_2H_{2(g)} + 5O_{2(g)} \rightarrow 4CO_{2(g)} + 2H_2O_{(g)}$$

11. 100cm^3 of 1M sulphuric acid is added to an excess of sodium hydrogen trioxocarbonate (IV). Calculate (a). The mass of sodium tetraoxosulphate (VI) produced (b). volume of carbon (IV) oxide evolved at 25°C and 740mmHg (Na_2SO_4 = 142g/mol, molar volume of a gas at s.t.p = 22.4dm^3)

Solution

$$H_2SO_{4(aq)} + 2NaHCO_{3(aq)} \rightarrow Na_2SO_{4(aq)} + 2CO_{2(g)} + H_2O_{(l)}$$

Mole ratio 1 : 2 : 1 : 2 : 1

STOICHIOMETRY (II)

STUDY OF STOICHIOMETRY

Stoichiometry is the act of measuring chemical elements in quantitative relationship in chemical reactions. Reactions used to study stoichiometry include:

1. Precipitation reaction
2. Displacement of hydrogen from acids
3. Displacement of metallic oxides
4. Synthesis of metallic oxides
5. Reduction of metallic oxides

1. **Precipitation Reaction:** Stoichiometry of the reaction between Barium chloride and potassium tetraoxosulphate (VI) solution.

Method: Prepare 1 molar solution of K_2SO_4 solution and Barium chloride solution. Add $5cm^3$ of $BaCl_2$ to 7 different test tubes and add different volumes of K_2SO_4. Shake the test tubes and measure the height of the precipitate in each test tube.

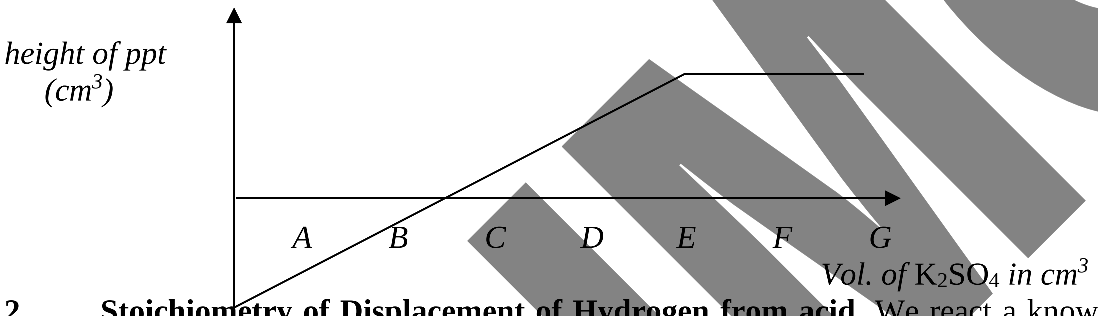
Result: The amount of precipitate formed increases with increasing volume of potassium tetraoxochromate (VII). After sometime, further increase in the volume of K_2SO_4 does not result in an increase in the amount of precipitate.

Vol. of $BaCl_2$	5	5	5	5	5	5	5
Vol. of K_2SO_4	1	2	3	4	5	6	7
Test tube	A	B	C	D	E	F	G

In test tube E, 5 mole of $Bacl_2$ react with 5 mole of $K_2Cr_2O_4$

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

Graph of height of precipitate against volume of K_2SO_4



2. **Stoichiometry of Displacement of Hydrogen from acid**. We react a known mass of magnesium with excess acid e.g. Hydrochloric acid and measure the volume of hydrogen gas liberated.

In the set up above, the test tube is tilted and HCl reacts with magnesium and hydrogen gas is given off. It will displace its own volume of water from the bottle into the cylinder. The volume is obtained by deducting the initial reading from the final reading. The temperature is measured to be 25^0C and pressure 755mmHg. The volume is $378cm^3$ while the mass of magnesium was 0.36g

Using general gas equation.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$P_1 = 755mmHg$

$P_2 = 760mmHg$

$V_1 = 378cm^3$

$T_1 = 25 + 273 = 298K$

$T_2 = 0 + 273 = 273K$

$V_2 = ?$

To calculate the moles of Mg and H_2 evolved

	Mg	H_2
No of moles	mass	volume

Molar mass *molar volume*

Therefore the mole of magnesium displaces one mole of H_2

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

$1 : 2 : 1 : 1$

3. Stoichiometry of displacement metallic oxides: Place a known amount of Zinc dust in a test tube and pour concentrated Copper (II) tetraoxosulphate (VI) solution, little at a time until all the zinc has reacted. Filter the solution and dry the copper residue and find its mass.

Mass of Zinc dust = 3.93g

Mass of copper residue = 3.84g

Zn *Cu*

No of moles= $\frac{mass}{Molar\ mass}$

Therefore one mole of Zinc displaces one mole of copper from a solution of its ions

$Zn_{(s)} + Cu^{2t} \rightarrow Cu_{(s)} + Zn^{2t}$

4. Stoichiometry of synthesis and reduction of metallic oxides: When copper (II) oxide is reduced to copper by passing hydrogen gas over it

Mass of copper (II) oxide = 3.50g

Mass of copper = 2.80g

CuO *Cu*

No of moles = $\frac{mass}{Molar\ mass}$

Therefore one mole of copper (II) oxide is reduced to 1 mole of copper

$CuO \rightarrow Cu + ½O_2$

Examples:

1. 5.0cm^3 of 2.0M solution of $BaCl_2$ required 6.0cm^3 of 1.7M $K_2Cr_2O_4$ solution. Suggest a possible equation for the reaction

Solution:

$BaCl_2$ ***$K_2Cr_2O_4$***

No of moles = CV

Therefore 1 mole of $BaCl_2$ reacted with one mole of $K_2Cr_2O_4$

$$BaCl_{2(aq)} + K_2Cr_2O_{4(ag)} \rightarrow BaCr_2O_{4(s)} + 2KCl_{(aq)}$$

1 : 1 : 1 : 2

2. 1.65g of Zinc foil was added to a solution of Copper (II) tetraoxosulphate (VI). The solution is filtered and dried, at the end, 1.5g of copper was collected. What is the stoichometry of the reaction.

Solution:

Zn *Cu*

No of moles

One mole of Zn displace one mole of copper

$Zn_{(s)} + Cu^{2t} \rightarrow Cu_{(s)} + Zn^{2t}$

3. 2.47g of dry copper (II) oxide was completely reduced to copper using laboratory procedures. The mass of the residue obtained was 1.97g. Write a chemical equation for the reaction.

Solution

Cu ***O***

No of moles

Therefore the balanced equation is

Students exercise: The main component of egg shells is $CaCO_3$. If $25.0cm^3$ of $0.700moldm^{-3}$ HCl with all the $CaCO_3$ in a sample of egg shells, calculate the

(i). Write a balanced equation for the equation

(ii). Mass of $CaCO_3$ in the egg shells

(iii). Volume of CO_2 evolved at s.t.p [C=12, O=16, Ca=40, 1 mole of a gas = $22.4dm^3$]

VOLUMETRIC ANALYSIS

Chemist analyse substances to determine their composition either qualitatively or quantitatively.

In qualitative analysis, we identify the elements or compounds present in a given sample of substance. In quantitative analysis, we calculate the amount or quantity of element or compound present in a given sample. There are two methods of quantitative analysis

(a) **Volumetric analysis:** This is based on volume measurement of solution. It is most commonly used but it is less accurate

(b) **Gravimetric analysis:** This is based on direct mass measurement of the substances.

TITRATION

This is a method employed in volumetric analysis where a solution from a graduated vessel is added to a known volume of a second solution, until the chemical reaction between the two is just completed. This is shown by a colour change of the added indicator.

TERMS USED IN VOLUMETRIC ANALYSIS

1. **Standard solution**: Is a solution whose concentration is accurately known and used to react with a solution of unknown concentration.
2. **Mass concentration** is the amount of solute present in one dm^3 or $1000cm^3$ of a solution. It is expressed in g/dm^3 or gdm^{-3}
3. **Molar concentration**: is the number of modes of solution in one dm^3 or $1000cm^3$ of a solution. It is expressed in mol per dm^3 ($moldm^{-3}$) or mol/dm^3
4. **Molar solution** of a compound is a solution which contains one mole or molar mass of the compound in one dm^3 of solution.
5. **Standardization:** This is determining the unknown concentration of given solution by titrating it with another solution of known molar concentration.

FORMULAS EMPLOYED IN QUANTITATIVE CALCULATIONS

$$\textit{No of moles} = \frac{\textit{Volume} \times \textit{molar concentration}}{1000}$$

Number of specified entities = molar conc. x Avogadro's Number

$$\textbf{Mass concentration } (\mathbf{gdm^{-3}}) = \frac{\text{mass} \times 1000}{\text{volume}}$$

$$\textbf{Molar concentration } (\mathbf{moldm^{-3}}) = \frac{\text{mass concentration } (g/dm^3)}{\text{molar mass } (g/mol)}$$

Students exercise:

$25.00cm^3$ of a solution of Sodium trioxocarbonate (IV) containing 1.3g in $250cm^3$ of solution was titrated against a solution of $22.40cm^3$ of Hydrochloric acid. Calculate

i. Concentration of the base in $moldm^{-3}$

ii. Concentration of the acid in $moldm^{-3}$ and in gdm^{-3}

iii. Number of moles in $2dm^3$ of the base

(Na=23, C=12, O=16, H=1, Cl=35.5)

MATERIALS FOR ACID-BASE TITRATION

Materials used in acid-base Titration include

(1) Weighing bottle
(2) Chemical Balance
(3) Pipette
(4) Burette
(5) Retort stand
(6) Filter paper
(7) Funnel
(8) White tile
(9) Standard Volumetric Flask
(10) Conical flask

Indicators used in acid base titrations

Indicator	pH range	Acid	Alkali	Endpoint	Acid vs Base
Litmus	5.0-8.0	Red	Blue	Purple	Strong acid vs strong base
Methyl Orange	2.9-4.6	Pink	Yellow	Orange	Strong acid vs weak base
Methyl Red	4.4-6.3	Red	Yellow	Orange	Strong acid vs strong base
Phenolphthalein	8.3-10.0	Colourless	Pink	Colourless	Strong base vs weak acid

Precautions during titration

1. Pipette

(a) Rinse the pipette with the solution is should be used to measure
(b) Avoid air bubbles in the pipette
(c) Take reading at eye level

2. Burette

(a) Rinse the burette with acid before filling up
(b) Make sure that the burette jet is filled
(c) Avoid bubbles in the burette
(d) Take reading at eye level to avoid error due to parallax
(e) Make sure the burette is not leaking
(f) Remove the funnel before taking your reading or titrating
(g) Avoid inconsistent burette reading

3. Conical Flask

(a) Rinse only with distilled water
(b) Wash down any solution that sticks to the side of the flask

Standardization (determining the concentration) of hydrochloric acid using standard sodium hydroxide solution.

Reagents/materials: Hydrochloric acid, standard NaOH Solution, 50cm^3 burette, 25cm^3 pipette, methyl orange indicator

Method:

- Fill the burette with Hydrochloric acid and adjust it to zero mark.
- Pipette 25cm^3 of NaOH solution into conical flask and add two drops of methyl orange.
- Titrate the acid against the alkali, swirling the flask to mix the solution.
- Titrating continues till the end point is just reached (indicator turns orange).
- Carry out two or more accurate titrations.

Note: The acid is added drop wise when approaching end point so that the end point is not exceeded.

Result: Record your reading as follows

Burette readings (cm^3)	1st	2nd	3rd
Final readings(cm^3)	$21.80cm^3$	$21.50cm^3$	$22.00cm^3$
Initial readings(cm^3)	$0.00cm^3$	$0.50cm^3$	$1.00cm^3$
Volume of acid used(cm^3)	$21.80cm^3$	$21.00cm^3$	$21.00cm^3$

Average volume of acid used is $\frac{21.00cm^3 + 21.00cm^3}{2}$

$= 21.00cm^3$

It is better to use values that are not more than $0.2cm^3$ difference in calculations.

Calculation:

$25cm^3$ of 0.1M NaOH is needed to neutralize $21cm^3$ of HCl acid (HCl = 36.5, NaOH = 40)

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

$$1 \quad : \quad 1 \qquad 1 : 1$$

To determine the concentration of the acid.

$$\frac{C_AV_A}{C_BV_B} = \frac{n_A}{n_B}$$

C_A	= *concentration of Acid*	C_B	= *concentration of Base*
V_A	= *volume of Acid*	V_B	= *Volume of Base*
n_A	= *No of moles of Acid*	n_B	= *No of moles of Base*

To calculate the mass concentration of acid

Molar concentration $= \frac{\text{mass concentration}}{\text{Molar mass}}$

STATEMENTS OF EQUIVALENCE IN CONCENTRATION.

$$H_2SO_{4(aq)} + 2NaOH_{(aq)} \rightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)}$$

$$1 \quad : \quad 2 \qquad 1 : 2$$

1 mole 2 mole

98g 2 x 40g

1 mole H_2SO_4 ≡ 2 mole NaOH

98g H_2SO_4 ≡ 80g NaoH

$1dm^3$ 1mole H_2SO_4 ≡ $1dm^3$ 2mole NaOH

98g H_2SO_4 ≡ $1dm^3$ 2M NaOH

$1dm^3$ 0.1mole H_2SO_4 ≡ $1dm^3$ 0.2mole NaOH

1 dm^3 0.1mole H_2SO_4 ≡ $2dm^3$ 0.1mole NaOH

If 1mole and 2 mole solutions of NaOH are prepared separately

$1dm^3$ 2 moles NaOH ≡ $2dm^3$ I mole NaOH

$20cm^3$ 2 mole NaOH ≡ $40cm^3$ 1mole NaOH

$10cm^3$ 1mole NaOH ≡ $20cm^3$ 0.5mole NaOH

$75cm^3$ 0.1mole NaOH ≡ $150cm^3$ 0.05 mole NaOH

Examples:

1. Calculate (a) the mass of anhydrous sodium trioxocarbonate (IV) present in 300cm^3 of 0.1 moldm^{-3} (b) the number of Na_2CO_3 particles present (Na=23, C=12, O= 16)

<u>Solution</u>

2. Calculate the volume of 0.25 moldm^3 solution of H_2SO_4 acid that will contain a mass of 4.5g of the raw acid

Solution

3. Calculate the volume of hydrogen chloride gas at s.t.p that would yield 1.2dm^3 of 0.15moldm^{-3} aqueous hydrogen chloride solution
(molar volume of gases at s.t.p = 22.4dm^3).

Solution

4. Xcm^3 of hydrogen chloride gas at s.t.p were passed into 50cm^3 of 0.2M Na_2CO_3(IV) solution. The excess trioxocarbonate (IV) was neutralized by 25cm^3 of 0.1M H_2SO_4 acid. Calculate

(a) the mass of excess sodium trioxocarbonate (IV) in g/dm^3

(b) the value of x

(Molar volume of a gas at s.t.p = 22.4dm^3 Na_2CO_3 = 106)

Solution

PURITY OF SUBSTANCE

Volumetric analysis is often used to determine percentage purity of substances. It is useful when determining the amount of impurities present in water.

5. 16g of anhydrous sodium trioxocarbonate(IV) containing some sodium chloride as impurity were made up to $1000cm^3$ of aqueous solution. $25cm^3$ of the solution was neutralized by $23.5cm^3$ of 0.2M hydrochloride acid. Calculate the mass of the sodium chloride impurity in the mixture.

Solution:

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

Using

$\frac{C_AV_A}{C_BV_B} = \frac{n_A}{n_B}$

$C_A = 0.2m$ $C_B = ?$

$V_A = 23.5cm^3$ $V_B = 25cm^3$

$n_A = 2$ $n_B = 1$

6. A piece of limestone $CaCO_3$ was added to $1dm^3$ of $0.1moldm^3$ hydrochloric acid HCl. After the effervescence stopped, $31.25cm^3$ of the resulting solution required $25cm^3$ of $0.05moldm^{-3}$ sodium hydroxide solution for complete neutralization. Calculate the mass of $CaCO_3$ added ($CaCO_3 = 100$, $HCl = 36.5$, $NaOH = 40$)

Solution:

$CaCO_3 + 2HCl \rightarrow CaCl_{2(aq)} + H_2O_{(g)} + CO_{2(g)}$

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

Using,

$\frac{C_AV_A}{C_BV_B} = \frac{n_A}{n_B}$

$C_A = ?$ $C_B = 0.05$

$V_A = 31.25$ $V_B = 25$

$n_A = 1$ $n_B = 1$

DETERMNATION OF MOLAR MASS, WATER OF CRYSTALLIZATION AND SOLUBILITY OF SUBSTANCES.

Volumetric analysis can be used to calculate

a. The molar mass of a metal or acid
b. The number of molecules of water of crystallization
c. The solubility of a substance in water

7. $30.0cm^3$ Hydrochloric acid of concentration $4.85g/dm^3$ neutralized $25.0cm^3$ of an unknown alkali XOH whose concentration was $6.4g/dm^3$. Calculate

(a) Molar concentration of XOH
(b) Relative atomic mass of element X. Name element X.

Solution:

$HCl_{(aq)} + XOH_{(aq)} \rightarrow XCl_{(aq)} + H_20_{(g)}$

Molar Conc. $= \frac{\text{mass conc.}}{\text{Molar mass}}$

8. Some crystals of washing soda on exposure to the atmosphere effloresced. 5.88g of this washing soda $Na_2CO_3.xH_2O$ were then dissolved in $500cm^3$ of distilled water. $25.0cm^3$ of this trioxocarbonate (IV) solution required $30.00cm^3$ of 0.1M Hydrochloric acid for complete neutralization. Calculate x and write the formular of the effloresced salt.

(Na = 23, H = 1, C = 12, Cl = 35.5, O = 16)

Solution:

$Na_2CO_3.xH_2O_{(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + CO_{2(aq)} + H_2O_{(l)} + xH_2O$

Using

$\frac{C_AV_A}{C_BV_B} = \frac{n_A}{n_B}$

$C_A = 0.1$ $V_A = 30$

$C_B = ?$ $V_B = 25$

$n_A = 2$ $n_B = 1$

9. A saturated solution of lead (II) trioxonitrate (V) was prepared at 25^0C. $30.0cm^3$ of the solution required $48.0cm^3$ of sodium containing $93g/dm^3$ for complete precipitation. Find the solubility of lead(II) trioxonitrate (V) at 25^0C in $moldm^{-3}$ and g/dm^3

Solution:

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

Students exercise: 1.2g of a mixture containing Magnesium powder and sodium chloride. If 50.0cm^3 of 0.1moldm^{-3} HCl were required to react with all the magnesium powder.

(i). Write a balanced equation for the reaction

(ii). Calculate the mass of magnesium powder in the mixture

(iii). Calculate the percentage purity of the magnesium powder

CHEMICAL REACTION

Chemical reactions are chemical changes in which some new chemical substances are formed. The chemical substances which undergo chemical change are called REACTANTS which the new substance formed are called PRODUCTS.

Chemical reactions are grouped into

1. Combination
2. Decomposition
3. Displacement
4. Double decomposition
5. Catalytic
6. Reversible
7. Thermal dissociation
8. Oxidation and reduction

1. COMBINATION

Combination reactions occur when two or more substances combine to form a single compound. It can be

(a) **Element + Element → Compound**

(i) $Fe_{(g)} + S_{(s)} \rightarrow Fes_{(s)}$

(ii) $Zn_{(s)} + Cl_{2(g)} \rightarrow Zncl_{2(s)}$

(iii) $2Fe_{(s)} + 3Cl_{2(g)} \rightarrow 2Fecl_{3(s)}$

(b) **Compound + Compound → Bigger compound**

(i) $PbO_{(s)} + SO_{2(g)} \rightarrow PbSO_{4(s)}$

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

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

Many organic compounds like ethyne undergo a type of combination reaction called polymerization

2. THERMAL DECOMPOSITION

In decomposition, a single compound splits up into two or more simple substances. When heat is needed to bring about decomposition, it is known as **thermal** decomposition.

(i) $2Pb(NO_3)_{2(s)} \xrightarrow{heat} PbO_{(s)} + 4NO_{2(g)} + 0_{2(g)}$

(ii) $2A1(OH)_{3(s)} \xrightarrow{heat} Al_2O_{3(s)} + 3H_2O_{(l)}$

(iii) $2AgNO_{3(s)} \xrightarrow{heat} 2Ag_{(s)} + O_{2(g)} + 2NO_{2(g)}$

3. DISPLACEMENT

In displacement reaction, one element (radical) replaces another element or radical in a compound

$AB + Y \rightarrow AY + B$

The ability of an element or radical to displace another is determined by their positions in the electrochemical series e.g Zinc being more electropositive will displace copper which is less electropositive from an aqueous solution of its salt.

(i) $Zn_{(s)} + CuSO_{4(aq)} \rightarrow ZnSO_{4(aq)} + Cu_{(s)}$

(ii) $Cl_{2(g)} + 2KBr_{(aq)} \rightarrow KCl_{(aq)} + Br_{2(g)}$

Displacement reaction are irreversible.

4. DOUBLE DECOMPOSITION

In this reaction, the reactants decompose/ react to form new substance by exchanging radicals/ ions.

$AB + CD \rightarrow AD + BC$

The two reactants are soluble and one of the products is soluble while the other is insoluble or volatile

(i) $AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow AgCl_{(s)} + NaNO_{3(aq)}$ - precipitation reaction

(ii) $KNO_{3(aq)} + H_2SO_{4(aq)} \rightarrow HNO_{3(g)} + KSO_{4(aq)}$ - formation of volatile acids

(iii) $BaCl_{2(aq)} + Na_2SO_{4(aq)} \rightarrow BaSO_{4(s)} + NaCl_{(aq)}$ - precipitation reaction

This type of reaction is used to prepare insoluble or volatile compounds since it can be easily separated from the other compounds

5. CATALYTIC

A reaction which involves the use of a catalyst. The rate of the reaction is altered by a catalyst. There are different types of catalysis reaction:

- catalytic reversible reaction
- catalytic redox reaction
- catalytic combination reaction
- catalytic decomposition reaction and
- catalytic displacement reaction
  A catalyst is a substance which alters the rate of a chemical reaction but itself remains chemically and quantitatively unchanged at the end of the reaction.

There are two types of catalysed reactions

(i) **Homogenous catalysis**: The catalyst, reactants and products are in the same phase e.g. oxidation of sulphur (IV) oxide using nitrogen(II) oxide as catalyst occurs in the gaseous phase

$$2SO_{2(g)} + O_{2(g)} \xrightarrow[NO_{(g)}]{} 2SO_{3(g)}$$

(ii) **Heterogenous catalysis**: The catalyst, reactants and products are in different phase e.g. hydrogenation of oil uses nickel as a catalyst.

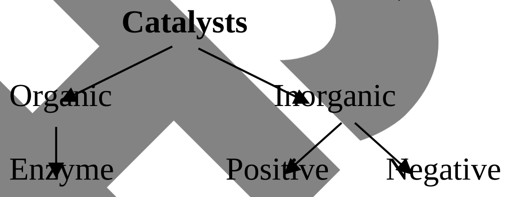
(i) $N_{2(g)} + 3H_{2(g)} \xrightarrow[Fe_{(s)}]{} 2NH_{3(g)}$

(ii) $H_2 + I_2 \xrightarrow{Pt_{(s)}} 2HI_{(s)}$

(iii) Vegetable oil + $H_2 \xrightarrow{Nickel_{(s)}}$ Margarine

Characteristics of a catalyst

1. It alters the rate of a chemical reaction
2. It remains chemically unchanged in nature and mass at the end of a reaction. Physical nature may change
3. A catalyst is specific in action i.e. a specific catalyst will act on a given reactions
4. A catalyst cannot start a reaction. It is effective on reactions that are already in progress.
5. A catalyst has no effect on the equilibrium of a reversible reaction
6. It does not affect the types of product formed in a reaction
7. It is required in very small quantity
8. The effect of a solid catalyst is improved by increasing its surface area.
   Since catalyst does not affect the overall reaction, it is written above the arrow in the equation.



Types of catalyst

1. **Inorganic catalysts**: which may be further classified into

(a) **Positive catalyst** is one that increases the rate of a chemical reaction e.g. Manganese (IV) oxide increases the decomposition of potassium trioxochlorate (V)

$$2KClO_{3(s)} \xrightarrow{MnO_{(s)}} 2KCl_{(s)} + 3O_{2(g)}$$

(b) **A negative catalyst** is one that decrease the rate of a chemical reaction e.g tetraoxophosphate (V) acid decrease the rate of decomposition of hydrogen peroxide

$$2H_2O_{2(l)} \xrightarrow[by\ H_3PO_4]{hindered} 2H_2O_{(g)} + O_{2(g)}$$

2. **Organic Catalysts:** These are called enzymes. They control the rate of biochemical reactions in living organisms. An enzyme is a biological catalyst which brings about chemical reactions in living cells. Enzymes bring about many biochemical processes like digestion of food, clotting of blood etc.

$2(C_6H_{10}O_5)n + nH_2O_{(l)}$ $nC_{12}H_{22}O_{11}$

$C_{12}H_{22}O_{11} + H_2O \xrightarrow{diastase} 2C_6H_{12}O_6$

$\xrightarrow{Maltose}$

$C_6H_{12}O_6$ *maltose* $\xrightarrow{zymase}$ $2C_2H_5OH + 2CO_{2(g)}$ *glucose*

PROMOTERS AND INHIBITORS

a. **Promoters**: These are substances which are not catalyst but improve the efficiency of a catalyst e.g Iron catalyst used in the Haber process can be activated by the addition of trace amount of Aluminium oxide or Molybdenum.

b. **Inhibitors**: these are substances that decrease the efficiency of a catalyst. They are called catalyst poisons e.g. Hydrogen sulphide, Arsenic(III)oxide, Hydrogen cyanide and mercury salts are catalyst poisons which inhibit important enzymatic process in the body

6. REVERSIBLE REACTIONS

A reversible reaction is a chemical or physical process that can be made to proceed either forward or backward different conditions of temperature and pressure. This reaction can go on simultaneously in both directions i.e. on both reactant and product sides. It is denoted by the symbol(opposing arrows) ⇆ between reactants and products. The arrow painting to the right is called forward reaction while the other half of the arrow pointing to the left is called backward reaction

$A + B \rightleftharpoons C + D$

The condition for the backward reaction (reverse reaction may not be the same as forward reaction e.g.

$3Fe_{(s)} + 4H_2O_{(l)} \rightleftharpoons Fe_3O_{4(s)} + 4H_{2(s)}$
$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$
$N_{2(g)} + O_{2(g)} \rightleftharpoons 2NO_{(g)}$

When a reaction proceeds in only one direction, it is called an irreversible reaction. It can only go in the forward direction. In most reversible reactions, more of the products are removed from the reaction mixture. The ways by which a product is removed from the reaction mixture are:

(1) When it is insoluble and precipitates out of the solution e.g. when a solution of sodium chloride is added to a solution of silver trioxonitrate(V), an insoluble salt silver chloride is formed and precipitates out of the solution

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

(2) When it is unionized or poorly ionized and so cannot participate in the reaction e.g. when hydrochloric acid is added to sodium hydroxide, neutralization reaction occurs and water is formed, since water is weakly ionized, the OH^- and H^+ ions present water molecules formed is removed from the reaction mixture

(3) When it is a gas and so escape from the reaction mixture e.g. when dilute HCl is added to calcium trioxocarbonate (IV), carbon (IV) oxide CO_2 is formed and escapes into the atmosphere.

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

7. THERMAL DISSOCIATION

This is a type of reversible reaction in which a molecule of a substance dissociates into two or more simpler molecules or atoms on the application of heat. Unlike thermal decomposition, thermal dissociation is reversible.

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

At high temperature, NH_4Cl dissociates into NH_3 and HCl but when cooled, ammonium chloride is formed

$N_2O_{4(g)} \rightleftharpoons 2NO_{2(g)}$

When Dinitrogen (IV) oxide at 20⁰C is heated to 140⁰C, it is converted to nitrogen (IV)oxide, on cooling, the nitrogen (IV) oxide recombine to form Dinitrogen (IV) oxide

OXIDATION AND REDUCTION REACTIONS (REDOX REACTIONS)

This is a reaction that involves two opposing yet complementary process; oxidation and reduction, which occur simultaneously in the same reaction. **Red**uction – **Ox**idation reactions are abbreviated as redox reaction

Oxidation

Oxidation can be defined as

(a) Addition of oxygen to an atom e.g. $2Cu_{(s)} + O_{2(g)} \rightarrow 2CuO_{(s)}$

(b) Removal of hydrogen e.g. $H_2S + Cl_{2(g)} \rightarrow 2HCl_{(g)} + S_{(s)}$

Hydrogen sulphide has been oxidized by the removal of hydrogen from it to form sulphur.

(c) Addition of electronegative (non-metals) elements and removal of electropositive (metals) elements.

$2Na_{(s)} + Cl_{2(g)} \rightarrow 2NaCl_{(s)}$

(d) Removal of electrons/ loss of electrons $FeCl_{2(s)} + Cl_{2(g)} \rightarrow FeCl_{3(s)}$.

Iron (II) ion has been increased to Iron (III) by the loss of an electron.

(e) Gain in oxidation number. (Increase in oxidation number)

$4FeO + O_{2(g)} \rightarrow 2Fe_2O_{3(s)}$ Fe^{2+} (+2) → Fe^{3+}(+3)

Reduction

Reduction can be defined as

(a) Removal of oxygen $Mg + H_2O \rightarrow MgO + H_2$

Oxygen is removed from steam to form Hydrogen

(b) Addition of Hydrogen $H_2S + Cl_{2(g)} \rightarrow 2HCl_{(g)} + S_{(s)}$

Addition of hydrogen to chlorine is a reduction reaction

(c) Removal of electronegative (non metals) element and addition of electropositive (metal) elements

$H_2S_{(g)} + Br_{2(g)} \rightarrow 2HBr_{(g)} + S_{(s)}$

Bromine is more electronegative than sulphur and so it is removed while sulphur is added

(d) Gain of electrons

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

$Fe^{3+} + e^- \rightarrow Fe^{2+}$

(e) Reduction in oxidation number of an atom or ion

$H_2S_{(g)} + Cl_{2(g)} \rightarrow 2HCl_{(g)} + S_{(s)}$

$$\begin{array}{ll} & \xrightarrow{\text{Oxidation}} \\ \text{Oxidation} & -3\ \ -2\ \ -1\ \ 0\ \ +1\ \ +2\ \ +3 \\ \text{Number} & \xleftarrow[\text{Reduction}]{} \end{array}$$

Oxidation is a process involving a loss of electrons while reduction is a process involving gain of electrons. An oxidizing agent is a substance which accepts electron(s). A reducing agent is a substance which donate electron(s)

<u>OXIDISING AND REDUCING AGENTS</u>

In any redox reaction, there must be oxidizing and reducing agents.

An oxidizing agent (OA) is the substance that gains electron and it becomes reduced with a decrease in oxidation number.

A reducing agent (RA) is the substance that loses electron and becomes oxidized with an increase in oxidation number.

Metals are generally reducing agents because they denote electrons while non metals are generally oxidizing agents because they accept electrons.

Oxidation

(a) $Mg + O_2 \rightarrow MgO$

Reduction

(b) $H_2S + Cl_2 \rightarrow S_{(s)} + 2HCl_{(g)}$

R.A O.A

Ionically,

$S^{2-} + Cl_2 \rightarrow S + 2Cl^-$

$S^{2-} \rightarrow S + 2e^-$ (oxidation)

$Cl_2 + 2e^- \rightarrow 2Cl^-$ (Reduction)

(c) $CuO_{(s)} + CO_{(g)} \rightarrow Cu_{(s)} + CO_{2(g)}$

OA RA

CuO → Cu (reduction)

CO → CO_2 (oxidation)

BALANCING REDOX REACTION

Half cell reaction method.

Half reaction is when an ionic equation for a redox reaction is split into two. Each of these reactions (oxidation and reduction) are written separately e.g.

$2Kl + Fe_2(SO_4)_3 \rightarrow I_{2(s)} + K_2SO_{4(aq)} + 2FeSO_{4(aq)}$

Ionically,

$2I^-_{(aq)} + 2Fe^{3+}_{(aq)}) \rightarrow I_2 + 2e^- 2I^-_{(aq)}2I^-_{(aq)} + 2Fe^{3+}_{(aq)}2Fe^{3+}_{(aq)}) \rightarrow I_2 + 2e^-$

$2I^-_{(aq)} \rightarrow I_{2(g)} + 2e^-$ (Oxidation half reaction)

$2Fe^{3+} + 2e^- \rightarrow 2Fe^{2+}$ (reduction half reaction)

The steps involved are:

1. Identify the oxidizing agent and reducing agent and deduce what the product will be
2. Write the half equation for each of oxidation and reduction, then balance the atoms and charges for each half equation by

(a) adding the correct number of H_2O, H^+ or OH^- to the appropriate side

(b) adding the correct number of electrons on the right hand side for the oxidation half-equation and in the left hand side for the reduction half equation

3. Ensure that the electron in the oxidation half equation is balanced by electron gain in the reduction half equation
4. Add the two half equation to eliminate the electrons and get the overall redox equation

Example 1:

Write a balanced ionic equation for the redox reaction between acidified heptaoxodichromate (IV) ion and chloride ion.

Solution:

$Cr_2O_7^{-2}O_7^{-2}O_7^{-2} \rightarrow 2Cr^{3+}$

This is the oxidizing agent and so is reduced to chromate in

$2Cl^- \rightarrow Cl_2$

This is the reducing agent and so is oxidized to chlorine atom

Next,

$Cr_2O_7^{-2}O_7^{-2}O_7^{-2} + 14H^+ \rightarrow 2Cr^{3+} + 7H_2O$

Changes on right hand is +12, changes in EHS is +6 so we add 6e- to the LHS

$Cr_2O_7^{-2}O_7^{-2}O_7^{-2} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$

For oxidation half reaction

$2Cl^- \rightarrow Cl_{2(g)}$

The above are balanced, so we balance the charges

$2Cl^- \rightarrow Cl_2 + 2e^-$

The number of electrons lost must be equal the number of electrons gained, so we multiply through by 3

$6Cl^- \rightarrow 3Cl_2 + 6e^-$

The final equation is

$Cr_2O_7^{-2}O_7^{-2}O_7^{-2} + 6Cl^- + 14H^+ \rightarrow 2Cr^{3+} + 3Cl_2 + 7H_2O$

The 6e- on the RHS cancels out the 6e- on the LHS

Example 2

Write a balanced ionic equation for the redox reaction between tetraoxomanganate (VII) ion MnO_4^- and hydrazine N_2H_4 in alkaline solution

Solution:

$MnO_4^-O_4^-O_4^- \rightarrow MnO_2$ (Reduction)

$N_2H_4 \rightarrow N_2$ (oxidation)

Reduction half equation

$MnO_4^-O_4^-O_4^- + 2H_2O \rightarrow MnO_2 + 4OH^-$

Balance the charges (we add 3e- to the RHS)
$MnO_4^- O_4^- O_4^- + 2H_2O + 3e^- \rightarrow MnO_2 + 4OH^-$
Oxidation half equation
$N_2H_4 + 4OH^- \rightarrow N_2 + 4H_2O$
Balance the charges
$N_2H_4 + 4OH^- \rightarrow N_2 + 4H_2O + 4e^-$
To balance the number of electrons, multiply reduction half equation by 4 and oxidation half equation by 3.
$4M_nO_4^- O_4^- O_4^- + 8H_2O + 12e^- \rightarrow 4MnO_2 + 16OH^-$
$3N_2H_4 + 12OH^- \rightarrow 3N_2 + 12H_2O + 12e^-$
Add the two equations together
$4MnO_4^- O_4^- O_4^- + 8H_2O + 12e^- + 3N_2H_4 + 12OH^- \rightarrow 4MnO_2 + 3N_2 + 16OH^- + 12H_20 + 12e^-$
$4MnO_4^- O_4^- O_4^- + 3N_2 H_4 \rightarrow 4MnO_2 + 3N_2 + 4H_20 + 4OH^-$

Example 3
Write a balance equation for the ionic reaction between acidified potassium tetraoxomangnate VII and Iron (II) tetraoxosulphate(IV)
Solution:

Oxidation Number method
(a) The oxidation numbers of the atoms in the equation are determined to identify oxidizing and reducing agent.
(b) Numerical co-efficient are places before the appropriate formular so that the total decrease in oxidation number is equal to the total increase in oxidation number
(c) Balance the equation by placing correct number of H_20, H^+ on the appropriate side to ensure that the number of atoms of elements on both sides are the same.
Example 1:
Write a balance equation for the redox reaction between trioxonitrate (V) acid and hydrogen sulphide
Solution:
$HNO_3 + H_2S \rightarrow NO_2 + S + H_2O_{(l)}$
Get the oxidation number of each element
+5 -2 +2 0 +3
O N of nitrogen changes from +5 to +2 (decrease by 3)
O N of sulphur changes from – 2 to 0 (increase by 2)
So we multiply each element by the factor of the other element e.g sulphur is multiplied by 3 while nitrogen is multiplied by 2
$2HNO_3 + 3H_2S \rightarrow 2NO_2 + 3S + H_2O$
There are 8 atoms of hydrogen on the LHS
So we add 4 to the water

$2HNO_{3(aq)} + 3H_2S_{(g)} \rightarrow 2NO_{(g)} + 3S_{(g)} + 4H_2O_{(g)}$

Some oxidizing and reducing agents

Oxidizing agents and reduction change		Reducing agents and oxidation change	
Oxygen	$O_2 \rightarrow 2O^{2-}$	Hydrogen	$H_2 \rightarrow 2H^+$
Manganese(IV)oxide	$MnO_2 \rightarrow Mn^{2+}$	carbon	$C \rightarrow CO$ $CO \rightarrow CO_2$
Hydrogen peroxide	$H_2O_2 \rightarrow 2H_2O$	Hydrogen sulphide	$H_2S \rightarrow S^2$
Acidified $K_2Cr_2O_7$	$Cr_2O_7^{2-} O_7^{2-} O_7^{2-} \rightarrow 2Cr^{3+}$	Sulphur(IV)oxide	$SO_2 \rightarrow SO_4^{2-} SO_4^{2-} SO_4^{2-}$
Acidified $KmnO_4$	$MnO_4^- \rightarrow Mn^{2+} O_4^- O_4^- \rightarrow Mn^{2+}$	Ammonia	$NH_3 \rightarrow N_2$
Chlorine	$Cl_2 \rightarrow 2Cl^-$	Iron (II) Salt	$Fe^{2+} \rightarrow Fe^{3+}$
Conc HNO_3	$NO_3^- \rightarrow 2NO_2^0 NO_2^0 NO_2^0$	Potassium lodide	$2Cl^- \rightarrow I_2$
Hot Conc. H_2SO_4	$SO_4^{2-} \rightarrow SO_2$	Sodium or any metal high in ECS	$Na \rightarrow Na^+$
Silver (any metal low in ECS)	$Ag^+ \rightarrow Ag$		

TEST FOR OXIDISING AGENT

(a) **Action on iron(II) chloride**: When a green solution of iron(II) chloride is added to an oxidizing agent, it turns to brown iron (III) solution

$Fe^{2+} \rightarrow Fe^{3+} + e^-$
Green brown

The Fe^{2+} ion denotes an electron to the oxidizing agent and becomes oxidized to Fe^{3+}

(b) **Action on hydrogen sulphide**: When hydrogen sulphide is passed through a solution of an oxidizing agent, a yellow deposit of sulphur is seen due to the oxidation of the sulphide ions to suphur

$S^{2-} \rightarrow S + 2e^-$

(c) **Action on potassium iodide**: when potassium iodide is added to an oxidizing agent, a brown coloured solution is formed which turns blue-black on addition of starch

$2I^- \rightarrow I_2 + e^-$

TEST FOR REDUCING AGENTS

1. **Action on acidified potassium tetraoxomagnanate (VII):** When reducing agent are warmed with acidified $KMnO_4$ solution, the purple colour is decolorized because the purple coloured MnO_4^- is reduced to Manganese (II)ion Mn^{2+} which is colourless.

$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$
Purple *colourless*

2. **Action on acidified potassium heptaoxodichromate(VI)**: When reducing agents are warmed with acidified $K_2Cr_2O_7$ solution, the orange colour changes to green. This is because the orange coloured $Cr_2O_7^{2-} O_7^{2-} O_7^{2-}$ is reduced to green coloured Cr^{3+}

$Cr_2O_7^{2-} + 14H^+ + 6e \rightarrow 2Cr^{3+} + 7H_2O$
Orange *green*

3. **Action on iron (III) salts**: When reducing agent is added to brown coloured iron (III) solution, it turns to green iron (II) ions.

$Fe^{3+} + e^{-} \rightarrow Fe^{2+}$

ELECTRON TRANSFER IN REDOX REACTIONS

A half reaction cannot occur by itself unless oxidation and reduction occurs simultaneously, a substance donates electrons while another one accepts the electron.

Experiment to show electron transfer between iron (III) tetraoxosulphate (VI) and potassium iodide

The solution of potassium iodine and iron (III) tetraoxosulphate VI are kept in separate beaker in which a platinum electrode is dipped into. The two electrodes are connected to a milliammeter to detect the presence of an electric current. On connecting the two solutions with a salt bridge (filter paper soaked in NaCl solution). The milliameter moves indicating the flow of electricity (flow of electrons)

Result: After some time, a brown colour appears around electrode A indicating the presence of iodine, and at the same time green colour appears around electrode B indicating the presence of iron (II) ions.

$2I^{-} \rightarrow I_2 + 2e^{-}$ (oxidation)

$2Fe^{3+} + 2e^{-} \rightarrow 2Fe^{2+}$ (reduction)

$2I_{(aq)} + 2Fe^{3+}_{(aq)} \rightarrow I_{2(aq)} + 2Fe^{2+}_{(aq)}$

OXIDATION NUMBER

The oxidation number of any element (molecule) or ion is the electrical charge it has

Rules governing oxidation numbers are:

1. Oxidation number of elements in the uncombined state i.e free state is shown as zero e.g. Na^0, Cl_2^0, Mg^0, P_4^0
2. The oxidation number of a simple ion has the same charge and sign as the charge of the ion eg oxidation number of Al^{3+} is +3, Cl^{-} is -1, S^{-2} is -2, Mg^{2+} is +2 etc
3. The oxidation number of ion consisting of more than one element is the algebraic sum of the oxidation numbers of all the elements present e.g. OH- is -1 CO is -2+ H is +1(-2+1 = -1); NO_3^{-}, - 1, SO_4^{2-} = -2, NH_4^{+} is +1 PO_4^{3-} is -3, MnO_4^{-} is -1, etc
4. The algebraic sum of the oxidation number of all elements in a compound is zero.
   Eg. $MgCl_2$ = O: i.e +2 + (-2) = O

In a compound more electronegative elements will have negative oxidation numbers while the more electropositive elements will have positive oxidation number.

Exceptions

1. The oxidation number of oxygen in most compound is -2 but it is -1 in peroxides
2. The oxidation number of hydrogen in most compound is +1 but in hydrides it is -1

Example:

1. Find the oxidation number of manganese atom in Potassium tetraoxomagnanate(VI) $KMnO_4$

Solution:

2. Find the oxidation number of chromium atom in potassium heptaoxodichromate(VI) $K_2Cr_20_7$

Solution:

3. Find the oxidation number of chlorine atom in $KCl0_3$

Solution:

Students exercises:

1. Define oxidation in terms of electron transfer

2. Consider the reaction represented by the following equation:

   $2MnO_4^-{}_{(aq)}$ + $5C_2O_4^{2-}$ +$16H^+$ $Mn^{2+}{}_{(aq)}$ + $8H_2O_{(l)}$ + $10CO_{2(g)}$

   Write down

   (i) The specie undergoing reduction with reasons

   (ii) The reducing agent with reasons

   (iii) The reduction half-equation

   (iv) One observation made during the reaction

3. Calculate the oxidation number of each of the elements in the compounds

   (i). CO_2

   (ii). $S_2O_3^{2-}$

   (iii). NH_3

ELECTROLYSIS

1. **Electrolysis**: This is the chemical decomposition of a compound brought about by a direct current passing through either a solution of the compound or the molten compound

2. **Electrolyte**: This is a compound in aqueous or molten form which conducts electricity and is decomposed in the process. They conduct electricity by movement of ions. A non-electrolyte does not conduct/allow passage of electricity.

3. Electrodes: These are the poles/plates through which an electric current enters or leaves the electrolyte. These can be in form of wires, rods or plates

(a) **Anode**: This is the positive electrode by which the conventional current enters the electrolyte (or by which electrons leave an electrolyte). It is joined to the positive terminal of the electric supply/ battery.

(b) **Cathode**: This is the negative electrode by which the conventional current leaves the electrolytes (or by which electrons enters an electrolyte). It is the negative terminal of the electric supply/ battery.

4. Electrolytic cell: This is an assembly of two electrodes dipping into an electrolyte and is used for electrolysis of a substance.

Oxidation occurs at the anode (positive electrode) while reduction occurs at the cathode (negative electrode). In earlier days, it is called a voltameter

5. Electrochemical cell: This is a device that converts chemical energy to electrical energy. It consists of two electrodes dipped into different ionic solutions and connected by means of a salt bridge. The solutions have different electrode potentials. It is also called a galvanic cell or voltaic cells. The anode is the negative electrode while the cathode is the positive electrode

ELECTROLYTES AND NON ELECTROLYTES

Electrolytes are of three different classes

1. Strong electrolytes
2. Weak electrolytes
3. Non electrolytes

1. Strong electrolytes: These are substances when in molten or liquid state (in solution) will conduct large amount of electric current and be decomposed by it. They ionize completely in water. Most electrovalent compounds are good electrolytes e.g aqueous solution of NaCl, dilute H_2SO_4, dilute HCl, and sodium hydroxide solution.

2. Weak electrolytes: These are substances which ionize slightly in solution and so do not conduct electricity readily. They are poor conductors of electricity e.g ethanoic acid

3. Non electrolytes: These are substances that do not ionize at all in solution and so do not conduct electricity. They are non conductors of electricity. They are covalent and mainly organic compounds e.g. sugar, ethanol, tricholoroethene, ether, benzene, tetrachloromethane.

IONIC THEORY

Swante Arrhenius in 1887 explained the ionic theory which proposed that when an electrolyte is melted or dissolved in water, some or all of the molecules of the substance dissociate into freely moving charged particles called ions. The process of dissociation is called ionization. The metallic ions, ammonium ions and hydrogen ions are positively charged while the non-metallic ions and hydroxide ions are negatively charged. The presence of electric charges makes the properties of the ions to be different from that of the corresponding atom which are electrically neutral when electric current pass through an electrolyte, the free ions loose their random movement i.e the positive ions become attracted to the cathode (negative electrode) and are known as cations (cathode ions). The negative ions moves to the anode (positive electrode) and are known as anions (anode ions). Current flow through the electrolyte is by a **movement of ions** to the electrodes not by **electron flow**.

The modern theory proposes that the ions in the solids are pulled away from one another, either by heat energy applied when the solid melts or with the help of solvent molecules when the solid dissolves.

Arrhenius theory $NaCl_{(aq)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)}Na^+_{(aq)}Na^+_{(aq)} \underline{+} Cl^-_{(aq)}Cl^-_{(aq)}$

Modern theory $Na^+Cl^- \rightarrow Na^+_{(aq)} + Cl^-_{(aq)}Na^+_{(aq)}Na^+_{(aq)} \underline{+} Cl^-_{(aq)}Cl^-_{(aq)}$

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

To prove the existence of ion during electrolysis, we can

1. Use a compound with a coloured cation/anion and show the migration of coloured ions
2. Show the formation of a coloured compound when the ions meet

e.g. MnO_4^- *- purple* , $Cr_2O_4^{2-}\ O_4^{2-}\ O_4^{2-}$ *- yellow*, $Ag_2Cr_2O_4$*- Red*, $Cu\ (NH_4)^{2+}$ *- Blue*

Movement of ions in an electrolyte

Metallic conductor	Electrolyte
conduct electricity in solid state	conduct electricity only in the liquid or molten state
Electric current is by flow of electrons	Electric current is by flow of mobile ions
Not decomposed by the process	decomposed by the process

The only non-metal that conducts electricity is graphite.

MECHANISM OF ELECTROLYSIS

Before the passage of current, the ions move about randomly in an electrolyte but when the battery or generator pumps electrons from the anode to the cathode of the electrolytic cell. The negatively charged cathode attracts cations to itself. The cations accept electrons to become electrically neutral and eventually discharged. The positively charged anode attracts anions itself. They give up their electrons to become electrically neutral and are finally discharged. Hence an electric current passes though the complete circuit. Electrolytic reactions are redox reactions which involve electron transfer through a path outside the chemical system. Oxidation occurs at the anode hence anodic half reaction reduction occurs simultaneously at the cathode hence cathodic half reaction. The overall reaction is the algebraic addition of the two half reactions. In general, metals or hydrogen gas are discharged at the cathode while non metals (except H_2 gas) are discharged at the anode.

PREFRENTIAL DISCHARGE OF IONS

The products formed during electrolysis depends on the ions that are preferentially discharged. The discharge of ions is controlled by some factors. They are

1. Relative position of ions in the electrochemical series
2. Concentration of the ions
3. Nature of the electrode

1. Relative position in the electrochemical series: if the cations migrate to the cathode, to accept electrons, the cation lower in the series (less electropositive) will show greater tendency to be discharged than the one higher in the series (more electropositive). The less electropositive cation accepts electrons more readily and so becomes discharged as a neutral atom e.g. Cu^{2+} is discharged before H^+ in the solution. For anions the one higher in the series (least electronegative) will have the tendency to be discharged than the one lower in the series (more electronegative).

To Cathode
K^+
Na^+
Mg^+
Al^{3+}
Zn^{2+}
Fe^{2+}
Sn^{2+}
Pb^{2+}
H^+
Cu^{2+}
Hg^{2+}
Ag^+

Increasing preference for discharge of ions

Decreasing electro positivity

To Anode
SO_4^{2-}
NO_3^-
Cl^-
Br^-
I^-
OH^-

Decreasing Electronegativity

Increase preference fir discharge of ion

2. Concentration of ions

If one of the ions is present in greater concentrations than the other, the ion of higher concentration may be discharged in preference to the other. This is effective only when the two competing ions are closely positioned in the ECS. The effect of concentration is less important for those far apart in the ECS e.g. during electrolysis of concentrated sodium chloride

Electrolyte	NaCl	H_2O
Cations	Na^+	H^+
Anion	Cl^-	OH^-
Concentration	High	Low

Cathode

H^+ is preferentially discharged because H^+ and Na^+ are far apart in the ECS (the effect of concentration is less important)

$H+ + e^- \rightarrow H$

$H + H \rightarrow H_2$

Anode

Cl^- is preferentially discharged because Cl^- and OH^- are close in the ECS (Effect of concentration is important)

$Cl^- \rightarrow Cl + e^-$

$Cl + Cl \quad Cl_2$

3. Nature of Electrodes

(a) Inert electrodes are electrodes which do not take part in electrolytic reactions eg. Platinum and carbon are inert electrodes but platinum is attached by chlorine gas and carbon is attacked by oxygen

(b) Electrodes which have strong affinity for certain ions may influence their discharge e.g when platinum electrodes are used for electrolysis of aqueous sodium chloride, H^+ are preferentially discharged but if a mercury cathode is used, the mercury associate with Na^+ to form sodium amalgam (Na/Hg) and so Na^+ is discharged in preference to H^+

(c) Electrodes which posses similar characteristics of those in the electrolyte, it may influence their discharge from the electrolyte e.g in the electrolysis of a solution of copper (II) tetraoxosulphate (VI), neither the SO_4^{2-} nor OH^- are will be discharged but Cu atoms from the anode will go into solution as Cu^{2+} because they give up their electrons more readily than SO_4^{2-} or OH^-

Example on Electrolysis

1. **Electrolysis of acidified water/dilute tetraoxosulphate (VI) acid using platinum electrode**. Acidified water is made by adding few drops of tetraoxosulphate (VI) acid to water. The set up for this electrolysis is known as Hoffman's voltameter which is designed for collection of gaseous product at the two electrodes

Electrolyte	H_2SO_4	H_20
Cations	H^+	H^+
Anion	SO_4^{2-}	OH^-
Concentration	Low	High
Position in ECS	OH^- are higher than SO_4^{2-}	

Cathode

H^+ are the only positive ions, they migrate to the cathode where they gain an electron to form neutral hydrogen atom. These atoms combine to form diatomic hydrogen molecule.

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

$H + H \rightarrow H_2$

Anode

Both SO_4^{2-} and OH^- migrate to the anode but OH^- are preferentially discharged. Each OH^- looses an electron and becomes a neutral –OH group. Two –OH group react to form one atom of oxygen and one molecule of water. Two atoms of oxygen combine to form one molecule of oxygen combine to form one molecule of oxygen gas

$OH^- \rightarrow OH + e-$

$OH + OH \rightarrow H_2O + O$

$0 + 0 \rightarrow 0_2$

Summary

Cathodic half reaction	$4H^+_{(aq)} + 4e^- \rightarrow 2H_{2(g)}$
Anodic half reaction	$4OH- \rightarrow 2H_20 + 0_2 + 4e^-$
Overall reaction	$4H_20 \rightarrow 2H_{2(g)} + 0_{2(g)} + 2H_20_{(l)}$
	$2H_20 \rightarrow 2H_2 + 0_2$
	2 vol 1vol 1vol

The electrolysis of acidified water yield 2 volumes of hydrogen at the cathode and I volume of oxygen at the anode.

Since the ionization of water is very low, the discharge of OH^- during electrolysis disturbs the ionic equilibrium of water. To restore the equilibrium more water ionize. The total amount of acid remains unchanged but the concentration increases due to the removal of water molecules.

2. **Electrolysis of Copper (II) tetraoxosulphate (VI) using carbon or platinum electrodes.** The set up (electrolytic cell) is designed to collect solid at the cathode and gas at the anode.

When electricity is passed into the solution, the ions migrates

Electrolyte	$CuSO_4$	H_20
Cations	Cu^{2+}	H^+
Anions	SO_4^{2-}	OH^-
Concentration	High	Low
Position in ECS	Cu^{2+} is just below H^+	OH^- higher than SO_4^{2-}

Cathode (platinum, carbon, copper)

Cu^{2+} and H^+ migrate to the cathode but Cu^{2+} are discharged preferentially because of concentration. Cu^{2+} gain 2 electrons to be deposited as metallic copper, as a result the cathode grow thicker because of the deposition of copper on it.

$Cu^{2+} + 2e^- \rightarrow Cu_{(s)}$

Anode (platinum or carbon)
Both SO_4^{2-} and OH^- migrate to the anode but OH are preferentially discharged as oxygen gas
$OH^- \rightarrow OH + e^-$
$OH + OH \rightarrow H_20_{(g)} + 0$
$O + O \rightarrow O_{2(g)}$

Summary

Cathode half reaction $2Cu^{2+} + 4e^- \rightarrow 2Cu_{(s)}$
Anodic half reaction $4OH \rightarrow 2H_20 + 02 + 4e^-$
Overall reaction $2Cu^{2+}_{(aq)} + 40H^- \rightarrow 2Cu_{(s)} + 2H_20 + 0_{2(g)}$

As Cu^{2+} and OH^- are discharged and removed from the solution, it becomes gradually acidic because of the H^+ and SO_4^{2-} in the solution. The blue colour of solution gradually fades away. If the electrolysis of the solution continues it yields results as that of acidified water.

3. **Electrolysis of Copper (II) tetraoxosulphate (VI) solution using copper electrodes**

This electrolysis is used in the purification of impure copper. The impure copper is used as the anode.

Electrolyte	$CuSO_4$	H_20
Cations	Cu^{2+}	H^+
Anions	SO_4^{2-}	OH^-
Concentration	High	Low
Position in ECS	Cu^{2+} is just below H^+	OH^- higher than SO_4^{2-}

At Cathode
Cu^{2+} and H^+ migrate to the cathode but Cu^{2+} is preferentially discharged due to concentration. Cu^{2+} gains 2 electrons to become metallic copper.
$Cu^{2+} + 2e^- \rightarrow Cu_{(s)}$

Anode
SO_4^{2-} and OH^- migrate to the anode but the metallic copper go into solution as copper ions.
$Cu_{(s)} \rightarrow Cu^{2+} + 2e^-$
Because of the nature of the electrode, no ions are discharged but copper dissolved from the anode is deposited at the cathode

$$\overset{\text{anode}}{Cu_{(s)}} \xrightarrow{-2e-} \overset{\text{electrolyte}}{Cu^{2+}} \xrightarrow{+2e-} \overset{\text{cathode}}{Cu_{(s)}}$$

The colour of the solution remains unchanged because as the anode dissolves forming solution, it is deposited on the cathode.

4. Electrolysis of concentrated sodium chloride solution (brine) using platinum or carbon electrodes.

The set up used is Hoffman's Voltameter

Electrolyte	NaCl	H_20
Cations	Na^+	H^+
Anions	Cl^-	OH^-
Concentration	High	low
Position in ECS	H^+ is lower than Na^+ OH^- is close to Cl^-	

Cathode

Both Na^+ and H^+ migrate to the cathode but H^+ is preferentially discharged due the position in the ECS. Hydrogen atoms, H^+ acquire an electron to form a neutral Hydrogen atom. Two atoms combine to form gaseous hydrogen molecule

$H^+ + e^- \rightarrow H$

$H + H \rightarrow H_2$

Anode

Both Cl^- and OH^- migrate to the anode but concentration of Cl^- is great so Cl^- is preferentially discharged since Cl^- and OH^- are close to each other. Cl^- loose an electron to become a neutral chlorine atom. Two atoms combine to form a chlorine molecule and is released as gas.

$Cl^- \rightarrow Cl + e^-$

$Cl + Cl \rightarrow Cl_{2(g)}$

Since Cl^- and H^+ are removed from the solution, the solution becomes a concentrated solution of sodium hydroxide. The electrolysis of brine is a very important economical process because of the usefulness of the three products

(a) Sodium hydroxide
(b) Hydrogen
(c) Chlorine

5. **Electrolysis of concentrated Sodium Chloride solution (Brine) using graphite anode and mercury cathode.** This is known as the industrial electrolysis of brine. The electrolytic cell is known as Kellner–Solvay process.

Electrolyte	NaCl	H_20
Cations	Na^+	H^+
Anions	Cl^-	OH^-
Concentration	High	low
Position in ECS	H^+ is lower than Na^+ Cl^- is close to OH^-	

Cathode

Both Na^+ and H^+ migrate to the cathode but Na^+ is discharged due to the nature of the electrode. Mercury has high affinity for Na^+ and so form sodium amalgam (Na/Hg) and concentration of Na^+ is high

$Na^+ + e- \rightarrow Na$

$Na + Hg \rightarrow Na/Hg$

Anode

Both Cl^- and OH^- migrate to the anode but Cl^- is preferentially discharged because of the concentration of Cl^- is high

$Cl^- + e^- \rightarrow Cl$

$Cl + Cl \rightarrow Cl_2$

When amalgam is treated with water, it decomposes to produce sodium hydroxide, hydrogen and mercury, mercury is recycled for use again making the process economical

$2Na/Hg(g) + H_{2}0_{(l)} \rightarrow 2NaOH_{(aq)} + H_{2(g)} + 2Hg_{(l)}$

Summary of electrolysis of common electrolytes

Electrolyte	**Cathode**	**Product at Cathode**	**Anode**	**Product at anode**	**Effect on electrolyte**
Acidified water (dil H_2S0_4)	Platinum	H_2	Platinum	Oxygen	Electrolyte becomes acidic
Conc. $CuS0_4$	Copper	Cu	Carbon	Cl_2	Electrolyte becomes dilute
Dilute $CuCl_2$	Copper	Cu	Carbon	O_2	Electrolyte become acidic
Conc. $CuCl_2$ or dil $CuSO_4$	Copper	Cu	Copper	Copper dissolves	Electrolyte remains unchanged
Conc. HCl	Carbon	H_2	Carbon	Cl_2	Electrolyte become dilute
Conc. NaCl	Carbon	Na	Carbon	Cl_2	Electrolyte becomes alkaline
Molten NaCl	Carbon	Na	Carbon	Cl_2	Electrolyte becomes unchanged
Conc. NaOH	Platinum	H_2	Platinum	O_2	Electrolyte becomes alkaline
Conc. $CuSO_4$	Carbon	Cu	Platinum	O_2	Electrolyte become acidic

LAWS OF ELECTROLYSIS

Since there are products at the electrodes, the quantities were investigated by a scientist called Micheal Faraday in 1833 and put forward two laws based on some factors. These factors are

(i) The magnitude of steady current passed
(ii) The time of flow of steady current
(iii) The ionic charge of the liberated element

Faraday's first law of Electrolysis states that the mass (m) of an element discharged during electrolysis is directly proportional to the quantity of electricity (Q) passing through it

Mathematically,
$M \propto Q$ M = Mass Q = Quantity of electricity
But Q is derived from the measured flow of electricity which is current (I in amperes) and t (time in seconds)
$Q = It$
So $M \propto It$
$M = EIT$ where E is a constant

The first law can also be stated as the mass of an element discharged during an electrolysis is directly proportional to the magnitude of the current and the time of flow of the current through an electrolyte.
E is known as the electrochemical equivalence when 1g (m) of a substance is liberated by passing of 1 coulomb (C) of electricity (1 ampere passed for 1 seconds).

To verify Faraday's first law

1. Weigh a copper cathode. Pass a steady current of 1A for 10 minutes. Switch off the current supply weigh the cathode and find the gain in mass.

Repeat the procedure using different time intervals. Plot a graph of gain in mass against time. A straight line graph passing through the origin is obtained showing that the mass of copper deposited is directly proportional to the time duration of current flow

2. Repeat the above experiment with a fixed time but varying the current. Plot a graph of gain in mass against magnitude of current. A straight line graph passing though the origin shows that the mass of copper obtained is directly proportional to the magnitude of current.

Faraday’s second Law of Electrolysis states that when the same quantity of electricity is passed through different electrolytes, the relative number of moles of the elements discharged are inversely proportional to the charges on the ions of the elements.

The minimum energy needed to discharge one moles of univalent ion is one Friday which is equivalent to 96500C.

IF = one mole of univalent ≡ Avogadro’s No
IF ≡ $M^+ \equiv 6.02 \times 10^{23}$

One Faraday discharges one mole of a univalent ion.
Two Faradays discharge one mole of a divalent ion
Three Faradays discharge one mole of trivalent ion
IF = $M^+ + e^- \rightarrow M$
2F = $A^{2+} + 2e^- \rightarrow A$
3F = $X^{3+} + 3e^- \rightarrow X$

To verify Faraday’s second law.

Two electrolytic cells are set up above, one cell with copper(II) tetraoxosulphate(VI) solution and copper electrode and the other with silver trioxonitrate(V) solution and silver electrodes.

The electrode (cathodes) are weighed before the experiment. Pass a steady current of 1A through the solutions for 25 minutes. Switch off the current. Find the gain in mass of each cathode, it will be discovered that although the same current was passed but the number of moles of silver deposited is double that of the copper. Charge on copper is +2 while that of silver is +1. The numbers of moles deposited is inversely proportional to the charges on the ions.

Specimen Results

Current flow - 0.45A
Duration - 25 minutes
Mass of Copper deposited - 0.221g
Mass of silver deposited - 0.755g

No of moles = $\frac{\text{mass deposited}}{\text{Molar mass}}$

For copper = $\frac{0.221g}{63.5g/mol}$ = 0.0035 moles

For silver = $\underline{0.755g}$ = 0.070moles

108g/mol

OR

Q = 14

= 0.45 x (25 x 60) = 675C

If 675C of electricity liberate 0.755g of Ag^+

:. 96500C of electricity will liberate $\frac{96500 \times 0.755}{675}$

= 108g

Ag^+ = 108g

For copper

675C of electricity liberate 0221g of Cu^{2+}

96500C of electricity will liberate $\frac{96500 \times 0.221}{675}$ = 31.75g

Since Copper is divalent

One mole of electron will liberate ½ mole of copper

So one mole of copper will be 31.75 x 2 = 63.5g

Cu^{2+} = 63.5g

Examples:

1. What mass of sodium metal is obtained when 1.85A is passed through molten sodium for 34minutes and 40 seconds.

Solution:

2. For how long must a current of 1.5A be passed through a solution of copper salt to deposit 2.50g of copper (Cu = 63.5)

Solution:

3. Calculate the current needed to deposit 12g of chromium when current is passed for one hour (Cr = 51)

Solution:

4. Calculate the volume of oxygen evolved at 285K and 0.91 x $10^5 Nm^{-2}$ when a current of 2.5A is passed through acidified water for 1.5mins.

(molar volume of a gas at s.t.p = $22.4dm^3$, std pressure = 1.01x $10^5 Nm^{-2}$ 1 Faraday = 96500C)

Solution:

5. A given quantity of electricity was passed through three electrolytic cells connected in series containing solutions of silver trioxonitrate(V), Copper (II) tetraoxosulphate (VI) and sodium chloride respectively. If 10.5g of copper are deposited in the second electrolytic cell. Calculate

(i) Mass of silver deposited in the first cell

(ii) The volume of chloride liberated in the third cell at 18^0C and 740mmHg pressure.

(Ag = 108, Cu = 63.5, IF = 96500C, molar volume of gas = $22.4dm^3$)

Solution:

6. A solution of Copper (II) tetraoxosulphate (VI) solution was electrolysed between pure copper electrode and the following results were obtained.

Mass of anode before experiment = 7.20g
Mass of copper anode after experiment = 4.00g
Mass of copper cathode before experiment = 5.75g

From the information above calculate

- (i) The mass of cathode after the experiment
- (ii) Write an equation for the reaction at the anode and cathode
- (iii) State whether the colour of solution would change during the electrolysis. Give a reason for your answer.
- (iv) If the electrolysis was carried out for 1 hour 20 mins with a current of 2.0 amperes. Determine the value of Faraday if 3.2g of copper was deposited.

Solution:

Students exercise:

(i). State Faraday's first law of electrolysis

(ii). Mention two factors that influence the preferential discharge of ions during electrolysis

(iii). Calculate the time taken to deposit 1 mole of silver if a current of 6A is passed through a solution of silver trioxonitrate (V) [1F=96500C]

(iv). Give three applications of electrolysis

(v). A concentrated solution of sodium chloride was electrolysed during using graphite electrodes. I. state the ions in the electrolyte

II. Write the anodic reaction and hence the product

III. Write the cathodic reaction and hence the product

IV. Give the by-product of the reaction and the fate of the electrolyte after electrolysis

USES OF ELECTROLYSIS

1. **Extraction of metals (e.g Na, Mg, Al, Ca)** and non metals e.g H_2, F_2, Cl_2) by electrolysis of their ores or fused compounds or aqueous solutions e.g in the purification of copper, an electrolytic cell is used and the impure copper serves as the anode, a pure copper plate serves at the cathode and soluble copper salt serves as the electrolyte e.g $CuSO_4$. During electrolysis, the impure anode dissolves and goes into solution and the impurities settle at the base of the container. Copper ions are attracted to the cathode where they receive electron to become deposited on the pure copper plate as neutral copper atom.

Copper atoms are transferred from the impure ore to the cathode similar arrangements are employed in the extraction and purification of silver, mercury and gold.

2. **Purification of metals** e.g Cu, Hg, Ag and Au.
3. **Electroplating**: This is the coating of a metal with another meant by means of electrolysis in order to improve its appearance or greater resistance to corrosion. Articles which are plated include jewelries, cutleries, table ware, iron or steel. The object to be coated is first cleaned to make sure that anode deposits sticks. It is a non conductor, it is first coated with graphite. The cathode is the object to be plated. The anode is a strip of plating metal and the electrolyte is the soluble salt of the plating metal e.g in the silver plating of a spoon, the cathode is the spoon, the anode is a silver rod and the electrolyte is the soluble silver salt. When current is passed through the cell, the silver ions dissolves at the anode and migrate to the cathode where the gain electron and is deposited as silver metal on the spoon.

The thickness of the plating is directly proportional to the magnitude of the current and duration of the process sometimes a series of plating is necessary, e.g in chromium plating a steel, chromium does not adhere well to steel and allows moisture to pass through it such that it eventually strips off. So it is first coated with copper to provide adhesion, then coated with nickel to prevent corrosion. Finally, it is coated with chromium for a tarnish-free finish.

Many cathodes can be placed at the same time to increase the quantity plated at a time.

4. Preparation of some important chemicals compounds like sodium hydroxide, sodium trioxochlorate e.t.c the electrolysis of Brine

ELECTRODE POTENTIAL

Electrode potential is the potential difference set up between an element and a solution of its ions. When a metal rod/plate is dipped into a solution containing its ions, some of the metal plate will ionize and go into solution as positively charged ion, leaving behind their valence electron on the surface of the plate. At the same time, some of the metallic ions in the solution will take up electrons from the metal plate and deposit as neutral atoms on the plate leaving behind an excess of anions in the salt solution.

Metal(s) $\leftrightharpoons$ metal ion + electrons.

If the forward reaction is favoured, the metal plate becomes positively charged with respect to the solution or electrolyte, if the backward reaction is favoured, the electrode becomes negatively charged with respect to the electrolyte.

A potential difference known as electrode potential for the metal ion/metal system is set up between the metallic electrode and electrolyte solution

COPPER(II) IONS/ COPPER SYSTEM

If a copper plate is immersed in a solution of copper (II) tetraoxosulphate (VI) solution, Cu^{2+} acquired 2 electrons from the copper plate to become deposited as neutral metallic copper atom on the plate.

$$Cu^{2+} + 2e^- \rightarrow Cu$$

As a result, the copper plate becomes positively charged due to a deficit of electron and the solution becomes negatively charged due to an excess of negatively solutions. A potentials difference known as the electrode potential of copper is set up between the copper metal and the solution containing its ions.

ZINC ION/ZINC SYSTEM

If a zinc plate is dipped into a zinc tetraoxosulphate (VI) solution, the neutral zinc atoms on the plate give up electrons and go into solutions as positively charged zinc ions. As a result, zinc plate becomes negatively on the surface due to an excess of elements and the solution becomes positively charged due to excess zinc ions. A potential difference known as electrode potential of zinc is set up between the zinc metal and the solution containing its ions.

Electrode potentials vary from one metal ion/metal system to another. This depends on

i. Overall energy change
ii. Concentration of ions in the solution
iii. The temperature at which measurement was made

STANDARD ELECTRODE POTENTIAL

The standard electrode potential of a metal ion/metal system is the potential difference set up between the metal and one-molar solution of its ions at 25^0C. Hydrogen has been chosen as the arbitrary standard with electrode potential of zero at all temperatures. The standard electrode potential of a given metal ions/metals system is then expressed as the potential difference which exists between the metallic electrode and the standard hydrogen electrode. This is the standard electrode potential of the metal ion/metal system on the hydrogen scale. The value of electrode potential is

(a) positive if electrons flow from hydrogen electrode to the metal electrode

(b) negative if electrons flow from the metal electrode to the hydrogen electrode.

The standard hydrogen electrode consists of hydrogen gas at 25^0C and one atmosphere pressure, bubbling around an inert platinum electrode in contact with a one molar solution of hydrogen ion is $2H^+_{aq}/H_{2(g)}$ system.

MEASURING STANDARD HYDROGEN ELECTRODE

The standard electrode potential of copper is being measured the $Cu^{2+}_{(aq)}/Cu_{(s)}$ half system cell is connected to the $2H^+_{(aq)}/H_{2(g)}$ system half cell by a salt bridge, the voltmeter shows a reading of 0.34V. This is the potential difference between the two half cells. It is known as the electromotive force (emf) of the cell. As the electrode potential of hydrogen is taken to be zero, the standard electrode is either +0.34V or -0.34V. The half cell reactions show that electrons flow from the hydrogen electrode to the copper electrode, making the electrode potential to be +0.34V.

Platinum in hydrogen electrode (oxidation)

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

Copper electrode

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

Overall reaction

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

Some standard electrode potentials

Metal ion/metal	**Half reaction**	**E^0 in volts**	**Redox properties**
L_1^+/L_1	$Li^+ + e^- \rightarrow Li$	-3.03	Increasing strength of oxidizing agent Increasing strength of reducing agent ↓
K^+/K	$K^+ + e- \rightarrow K$	-2.92	
Ca^{2+}/Ca	$Ca^{2+} + 2e^- \rightarrow Ca$	-2.87	
Na^+/Na	$Na^+ + e^- \rightarrow Na$	-2.71	
Mg^{2+}/Mg	$Mg^{2+} + 2e^- \rightarrow Mg$	-2.37	
Al^{3+}/Al	$Al^{3+} + 3e^- \rightarrow Al$	-1.67	
Zn^{2+}/Zn	$Zn^{2+} + 2e^- \rightarrow Zn$	-0.76	
Fe^{2+}/Fe	$Fe^{2+} + 2e^- \rightarrow Fe$	-0.44	
Sn^{2+}/Sn	$Sn^{2+} + 2e^- \rightarrow Sn$	-0.14	
Pb^{2+}/Pb	$Pb^{2+} + 2e^- \rightarrow Pb$	-0.13	
$2H^+/H_2$	$2H^+ + 2e^- \rightarrow H_2$	0.00	
Cu^{2+}/Cu	$Cu^{2+} + 2e^- \rightarrow Cu$	+0.34	
Hg^+/Hg	$Hg^+ + e^- \rightarrow Hg$	+0.70	
Ag^+/Ag	$Ag^+ + e^- \rightarrow Ag$	+0.80	
Au^+/Au	$Au^+ + e^- \rightarrow Au$	+1.68	
Cu^+/Cu	$Cu^+ + e^- \rightarrow Cu$	+0.52	
Fe^{3+}/Fe^{2+}	$Fe^{3+} + e^- \rightarrow Fe^{2+}$	+0.77	

Increase in electrode potential value leads to decrease in reactivity of the element lithium is the most reactive while gold is the least reactive.

ELECTROCHEMICAL CELLS

This is a device in which chemical energy is converted to an electrical energy. It is also known as galvanic or voltaic cell. It consists of two half cell(s) an oxidation half cell reaction and a complementary reduction half cell reaction. The overall redox reaction results in a flow of electrons i.e. an electric current. For example when a zinc electrode dipped into a solution of zinc tetraoxosulphate (VI) solution connected to a copper electrode dipped in a solution of copper (II) tetraoxosulphate (VI) solution. The two cells are separated by a porous partition which allows electrical contact but prevents excessive mixing of the electrolytes by diffusion. The zinc electrode undergo oxidation and loose 2 electrons which go into the solution, the zinc electrode becomes negatively charged and acts as the anode or negative electrode. The copper electrode undergoes reduction by gaining 2 elections each to form the metallic copper to be deposited on the electrode the copper electrode becomes positively charged and acts at the cathode.

Anode (oxidation)

$Zn_{(s)} \rightarrow Zn^{2+} + 2e^-$

Cathode (reduction)

$Cu^{2+} + 2e^- \rightarrow Cu_{(s)}$

Overall reaction

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

The flow of electrons from the zinc to the copper electrode is equivalent to the flow of conventional current in the opposite direction.

The anode slowly becomes depleted while the cathode increases in size.

SALT BRIGDE

This is a porous partition in an electrochemical cell which completes the circuit. It allows passage of ions from one half cell to the other without actual mixing of the two solutions. It also maintains electrical neutrality in the solution when a current flows in the set-up.

Feasibility of the electrochemical system.

Calculations of Electromotive force (EMF)

The electromotive force of a cell = electrode potential cathode - electrode potential anode

E^0 cell = E^0 right – E^0 left

E^0 cell = E^0 cathode – E^0 anode

EXAMPLE

Given that the electrode potential of copper to be +0.34V and that of zinc to be -0.76V. Calculate the e.m.f of the cell.

Solution:

E^0 cell = E^0Cu - E^0Zn

= +0.34 – (-0.76)

= +0.34 + 0.76

= +1.10V

When a cell has positive emf, it means that the system is spontaneous but if it is has negative emf, it is not spontaneous.

The half cells should be interchanged so that the cells will have positive emf. When it is negative, it means that the anode will not be able to reduce the cathode.

E^0 cell = E^0Zn - E^0Cu

= -0.76 – (+0.34)

= -0.76 – 0.34

= -1.10V

An electrochemical cell is represented by

Electrode1/ Electrolyte 1 // Electrolyte 2/Electrode 2
Anodic Reaction// cathodic reaction
Negative electrode// positive electrode
Zn/Zn^{2+} // Cu^{2+}/Cu

The single stroke represents the boundary between the metal electrode and its ion in solution Zn/Zn^{2+}. The double stroke // represents the junction between the two half cells (salt bride/porous partition/muslin bag)

Similarities between the electrolytic cell and the electrochemical cell

i. Oxidation occurs at the anode
ii. Reduction occurs at the cathode
iii. Electrons flow from anode to cathode

Differences between electrolytic and electrochemical cell

Electrolytic cell	**Electrochemical cell**
Anode is the positive electrode	Anode is the negative electrode
Cathode is the negative electrode	Cathode is the positive electrode
Electrical energy is used to force a chemical reaction that is not occurring spontaneously	Chemical reaction occurs spontaneously to produce electrical energy.

DANIELL CELL

This is a simple electrochemical cell which consists of a copper vessel filled with a saturated solution of copper (II) tetraoxosulphate (VI) and a porous pot filled with a zinc tetraoxosulphate (VI) solution. Immersed in the $ZnSO_4$ solution is a zinc rod. The initial emf of Daniell cell is about 1.1 volts. This cell has to be replaced once the chemicals in it are depleted.

The zinc goes into solution as Zn^{2+} ions

$Zn \rightarrow Zn^{2+} + 2e^-$ and the electrons produced flow in the external current to the copper electrode where Cu^{2+} ions in solution accept them and deposit

$Cu^{2+} + 2e^- \rightarrow Cu$

Daniell Cell

LECLANCHE CELL

Leclanche cell consists of a zinc metal container as the anode and a carbon rod or graphite rod surrounded by Manganese (IV) oxide as the cathode. The electrolyte is a paste of ammonium chloride (dry cell) or a solution of ammonium chloride (wet cell)

The zinc atoms loose two electrons each and dissolves in the electrolyte as positively charged zinc ions.

$Zn_{(s)} \rightarrow Zn^{2+} + 2e^-$

The electrons which are released passed through an external circuit. The ammonium ions accept electrons and become reduced to Ammonia and hydrogen gas. The latter is removed by manganese (IV) oxide to prevent it from adhering to the cathode.

$2NH^{4+}_{(aq)} + 2e^- \rightarrow 2NH_{3(g)} + H_{2(g)}$ (oxidation)

The Lechanche cell has to be replaced once the chemical has been used up. It is used in many small appliances like torches, radios and bicycle lamps.

LEAD ACID ACCUMULATOR

This is commonly used as a car battery. It is a secondary cell which must be recharged by passing direct current through it. The charged cell can produce and electric current when required.

For a charged cell, the cathode is lead (IV) oxide PbO_2 and the anode is metallic lead. The electrolyte is dilute tetraoxosulphate (VI) acid solution. When the two electrodes of an external circuit, it produces electricity by discharging e.g. for starting the engine of a car or lighting the car lamps.

At the anode (discharging cell)

Lead atoms release two electrons each to become oxidized to lead (II) ions Pb^{2+} which combine with tetraoxosulphate (VI) ions SO_4^{2-} in the electrolyte to become deposited on the anode as lead (II) tetraoxosulphate (VI) $PbSO_4$

$Pb_{(s)} \rightarrow Pb^{2+} + 2e^-$

$Pb^{2+} + SO_4^{2-} \rightarrow PbSO_{4(s)}$

The electrons pass around an external circuit as an electrtic current.

At the cathode (discharging cell)

The electrons are accepted at the cathode where lead(IV) oxide and hydrogen ions from the electrolyte undergo reduction to produce lead (II) ions and water.

$PbO_2 + 4H^+_{(aq)} + 2e^- \rightarrow Pb^{2+} + 2H_2O_{(l)}$

The lead ions combine with tetraoxosulphate (VI) ions from the electrolyte to become deposited at the cathode as lead (II) tetraoxosulphate(VI)

$Pb^{2+} + SO_4^{2-} \rightarrow PbSO_{4(s)}$

During discharging

The density of the acid decreases to 1.15gcm^{-3} due to the absorptio of hydrogen and tetraoxosulphate(VI) ions from the electrolyte and the emf of the cell drops to 1.8V when both electrode are completely covered with lad (II) tetraoxosulphate (VI) deposits, the lead accomulator will stop discharging a current. It has to be recharged to make it continue toproduce a current

During recharging, the redox reactions in the cell are reversed because it is an electrolysis. The anode becomes the cathode in the charged cell while the cathode becomes the anode.

Cathode (Recharging cell)

$$PbSO_{4(s)} \left\langle \begin{array}{l} Pb^{2+} \rightarrow Pb_{(s)} \\ \\ SO_4^{2-}{}_{(aq)} \end{array} \right.$$

Anode (Recharging cell)

$$PbSO_{4(s)} \left\langle \begin{array}{l} Pb^{2+} \rightarrow PbO_2 + 4H^+_{(aq)} \\ \\ SO_4^{2-} \end{array} \right.$$

After recharging

1. The density of the acid in the cell returns to an initial value of 125gcm^{-3} due to a release of the same amount of ions.

2. The e.m.f of the cell return to 2.2V

Lead accumulator – recharging

Differences between primary and secondary cells

Primary cell	**Secondary cell**
Cannot be recharged	Can be recharged
Need to be replaced once its contents are used up	They do not need to be replaced.

Both cells are electrochemical cells which converts chemical energy into electrical energy.

SIGNIFICANT FEATURES OF THE ELECTROCHEMICAL SERIES

The standard electrode potentials of different half-cell have been arranged in order, starting with the most negative values to give the electrochemical series.

The good reducing agents (electropositive elements) are at the top while the good oxidizing agents (electronegative elements) are at the bottom

The series is very useful in predicting the properties and chemical behavior of elements and their respective compounds.

.;.:.: $K^{+}_{(aq)} + e^{-}$ ⇌	$K_{(s)}$	-2.92
$Ca^{2+}_{(aq)}Ca^{2+}_{(aq)}Ca^{2+}_{(aq)}$ + 2e⁻ ⇌	$Ca_{(s)}$	-2.87
$Na^{+}_{(aq)}Na^{+}_{(aq)}Na^{+}_{(aq)}$ + e⁻ ⇌	$Na_{(s)}$	-2.71
$Mg^{2+}_{(aq)}Mg^{2+}_{(aq)}Mg^{2+}_{(aq)}$ + 2e⁻ ⇌	$Mg_{(s)}$	-2.37
$Al^{3+}_{(aq)}Al^{3+}_{(aq)}Al^{3+}_{(aq)}$ + 3e⁻ ⇌	$Al_{(s)}$	-1.66
$Zn^{2+}_{(aq)}Zn^{2+}_{(aq)}Zn^{2+}_{(aq)}$ + 2e⁻ ⇌	$Zn_{(s)}$	-0.76
$Fe^{2+}_{(aq)}Fe^{2+}_{(aq)}Fe^{2+}_{(aq)}$ + 2e⁻ ⇌	$Fe_{(s)}$	-0.44
$Sn^{2+}_{(aq)}Sn^{2+}_{(aq)}Sn^{2+}_{(aq)}$ + 2e⁻ ⇌	$Sn_{(s)}$	-0.14
$Pb^{2+}_{(aq)}Pb^{2+}_{(aq)}Pb^{2+}_{(aq)}$ + 2e⁻ ⇌	$Pb_{(s)}$	-0.13
$2H^{+}_{(aq)}2H^{+}_{(aq)}2H^{+}_{(aq)}$ + 2e⁻ ⇌	$H_{2(g)}$	-0.00
$Cu^{2+}_{(aq)}Cu^{2+}_{(aq)}Cu^{2+}_{(aq)}$ + 2e⁻ ⇌	$Cu_{(s)}$	+0.34
$O_2^{(aq)}O_2^{(aq)}O_2^{(aq)}$ + $2H_2O$ ⇌ + 4e⁻	$4OH^{-}_{(aq)}4OH^{-}_{(aq)}4OH^{-}_{(aq)}$	+0.40
$2I^{-} + 2e^{-}$ ⇌	$I_{2(s)}I_{2(s)}I_{2(s)}$	+0.34
$Fe^{3+}_{(aq)} + e^{-}$ ⇌	$Fe^{2+}_{(aq)}$	+0.71$Fe^{3+}_{(aq)}Fe^{3+}_{(aq)}$ + e⁻
$Fe^{2+}_{(aq)}Fe^{2+}_{(aq)}$	+0.71	
$Ag^{-}_{(aq)}Ag^{-}_{(aq)}Ag^{-}_{(aq)}$ + e⁻ ⇌	$Ag_{(s)}$	+0.80
$Br^{-}_{(aq)}Br^{-}_{(aq)}Br^{-}_{(aq)}$ + e⁻ ⇌	$2Br^{-}$	+1.06

$Cr_2O_7\ {}^{2-}_{(aq)}\ {}^{2-}_{(aq)}\ {}^{2-}_{(aq)} + 14\cancel{H_{(aq)}} \rightleftharpoons H_{(aq)}H_{(aq)} + 6e^-$ $2Cr^{3+}_{(aq)}2Cr^{3+}_{(aq)}2Cr^{3+}_{(aq)} + 7H_2O_{(l)}$ +1.33

$Cl_{2(aq)} + 2e^- \rightleftharpoons 2Cl^-$ +1.36

$MnO4^-_{(aq)} + 8H^+_{(aq)}O4^-_{(aq)} \rightleftharpoons \cancel{O4}^-_{(aq)} + 8H^+_{(aq)}8H^+_{(aq)} + 5e^-$ $Mn^{2+} + 4H_2O$ +1.52

$F_{2(g)} + 2e^- \rightleftharpoons 2F^-_{(aq)}2F^-_{(aq)}2F^-_{(aq)}$ +2.87

1. **CURRENT FLOW AND E.M.F OF A CELL:** The metal higher up will serve as the negative electrode while the metal lower down will serve as the positive electrode. The e.m.f is the algebraic difference between the electrode potential of the two cells. A big e.m.f or a powerful cell means that the electrode must be far apart in the series.

2. **CHEMICAL REACTIVITY OF ELEMENTS:** The ECS is sometimes known as the activity series of the metals. The metals are arranged in decreasing order of reactivity (exception is calcium which is above sodium but less reactive than sodium). Strong electropositive metals like sodium and potassium are more reactive than weak electropositive metals like gold and silver.
The non-metals are arranged in increasing order of chemical reactivity (since their reactivity is based on readiness to form negative ions. Strong electronegative non metals e.g chlorine is more reactive that weak electronegative non-metals like iodine.
Two elements are likely to form a stable compound if they are far apart in the series. Elements that are close will either not combine at all or form unstable compounds. However, non-metals combine very readily with metals but metals do not form stable compounds with one another.

3. **OCCURENCE IN NATURE:** The metal above hydrogen do not occur in the free state in nature but exist as compounds e.g. trioxonitrates (V), trioxocarbonate(IV), Chloride, Sulphides and oxides. These elements are reactive and form compounds with the non-metalic elements in their environment. Metals below hydrogen are inactive and tend to occur in the free state e.g copper, gold, silver.

4. **DISPLACEMENT AND REDOX REACTIONS:** Metals will displace other metals below them in the series e.g. if zinc is placed in copper(II) tetraoxosulphate (VI) solution, zinc atoms will go into solution while copper atoms will come out of the solution.

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

The ease with which one metal can displace another is dependent on the relative positions in the series. The further apart they are, the easier it is for displacement reactions to occur e.g. Zn will displace Cu readily but Pb will not displace Cu readily. A metal cannot displace another that is above it in the series. Copper and metals below it cannot displace hydrogen which is higher than them from acids.
Non metals will displace other non-metals that are above them in the series e.g. chlorine will displace iodine or bromine from solutions of their ions.

$Cl_{2(g)} + MgBr_{2(aq)} \rightarrow MgCl_{2(aq)} + Br_{2(g)}$

Displacement reactions are known as redox reactions and the ECS is also known as redox series. The reducing power of elements decreases progressively down the series while oxidizing power increases down the group.

PREFERENTIAL DISCHARGE OR ION IN ELECTROLYSIS

A metal lower down in the series is usually discharged in preference to the one above it. A non-metal higher up in the series is discharged in preference to the one below it.

LIMITATIONS OF THE ELECTROCHEMICAL SERIES

1. It cannot predict the rate at which a reaction will occur
2. It cannot quantify the amount of materials reacting
3. Values of standard electrode potential are affected by changes in concentration, temperature and pressure

CORROSION

This is the deterioration of metals when they come in contact with the oxygen and moisture in the surrounding air.

This is a great economic importance. The corrosion of iron is known as rusting. Rusting is an electrochemical process since electrochemical cells are set up when iron comes in contact with air and water.
At the anode, ion is oxidized to give iron (II) ions

$Fe_{(s)} \rightarrow Fe^{2+} + 2e^-$

At the cathode, oxygen from air dissolves in water layer and is reduced by the electrons from the anode to give hydroxide ions OH-

$\frac{1}{2} O_{2(aq)} + H_20_{(l)} + 2e^- \rightarrow 2OH^-_{(aq)}H^-_{(aq)}H^-_{(aq)}$

The Fe^{2+} and $2OH^-$ diffuse away from the anode and cathode regions and become deposited as iron (II) hydroxide $Fe(OH)_2$. This is further oxidized by the dissolved oxygen to form brown iron (III) oxide $Fe_2O_3.xH_20$. Rust is soft and breaks easily and the metal below continues to rust.

PREVENTION OF RUSTING BY CATHODIC PROTECTION

Objects made of ions can be protected from rusting by coating it with another metal that does not corrode easily. Zinc and tin can be used to coat iron objects. A tin plated iron container corrodes much faster than a galvanized (zinc plated iron) container when they have been subjected to the same amount of handling. Parts of the zinc or tin coat may be broken. The holes in them become filled with trioxocarbonate (IV) acid, formed by dissolving of carbon (IV) oxide in atmospheric moisture and an electrochemical cell is set up.

	Anode	Electrolyte	Cathode
Tin plated iron	Iron	Dilute acid	Tin
Galvanized iron	Zinc	Dilute acid	Iron

In tin-plated iron, the iron being above tin in the series serve as the anode, when the tin layer is broken, the iron ionizes and goes into solution thereby bringing about its rusting.
In galvanized iron, the zinc being above iron in the series serve as the anode when the zinc layer is broken, the zinc dissolves instead of the iron while the iron (cathode) remains intact. Rusting of iron will only set in when all the zinc has corroded.

ELECTRIC CHARGES

Matter is made up of atoms and atoms are made up of protons, neutrons and electrons. The electrical property is due to the charges on the subatomic particles.
An atom is neutral i.e equal number of protons and electrons. When two materials are rubbed together electrons form atoms of one material can be transferred onto the other material. The material that loses electrons then becomes positively charged while the one that gained electrons will be negatively charged, when objects made of certain materials loose or gain electrons, they become charged. This is known as static electricity (electrons remain in stationary i.e no electron flow) charged objects attract unchanged objects. Objects with like charges repel each other while those with unlike charges attract. Static electricity is exhibited when a plastic ruler is rubbed on the hair or a silk/furry cloth attracts pieces of paper because they have different charges. A glass rod rubbed on silk cloth because they have same charges.
An electric current is a flow of electrons. An electric circuit is the complete continuous path taken by electrons important effects of electric circuit are heating, lighting, magnetic and chemical effects.
A simple electric circuit consist of a source of electric energy (dry cell accumulator) connected by wires to a load (electric bulb) and a switch. A close circuit is a complete conducting path of an electric circuit. An open circuit has gaps along the conducting path of an electric circuit.

In an electric circuit, the cell provides emf which sets up a potential difference across the bulb and drives an electric current through it. Electrons flow from the negative terminal through the connecting wires to the

positive terminal. However, electric current flows from the positive terminal (higher electrode potential value) to the negative terminal (lower electrode potential value) of the cell.
Cells can be arranged in series of parallel.

SOURCE OF ELECTRICITY

1. Simple cells – by chemical action
2. Accumulators – by chemical action
3. Dynamo – by electromagnets

} Little amount of electricity

Large dynamos are called generators which can generate large amount of electricity
In a dynamo, the electric current is always changing its direction. It first passes in one direction and then in the opposite. Such a current is called alternating current (A.C) but cells and accumulators direct current (DC) which does into change its direction.

CONDUCTORS AND INSULATORS

1. Conductors are substances which conduct electricity
   - (a) **Metallic conductors** conduct current by movements of electrons eg. Metal wires, graphite/mercury conductors
   - (b) **Electrolytic conductors** are electrolytes like fused lead (II)bromide, sodium chloride solution and dilute hydrochloride acid

2. **Non conductors** or insulators are substances that do not conduct electricity. They are non electrolytes. They are either pure solid or liquids.

3. **Semi conductors** are poor conductors of electricity e.g. water, earth, moist air and human body. Metalloids like germanium and silicon are semi conductors.

CONDUCTANCE OF SOLUTIONS

1. To determine the relative strength of some acids and bases

Procedure: Place 100cm^3 of IM solutions each of hydrochloric acid, ethanoic acid, potassium hydroxide and aqueous ammonia in a beaker and set up the apparatus as shown in the figure. Switch on the circuit and note the ammeter reading for each solution

Observation: It will be noted that the stronger acid or base will show higher ammeter readings which shows that higher current is flowing in the circuit.
Conclusion: solutions of strong acids, bases or salts show higher conductivity than weak solutions

2. **To investigate the conductance in molten substance.**

Procedure: Place some lead (II) iodide or sodium chloride in a crucible and dip two graphite electrodes rods into it. Connect the two electrodes to a 6-Volt D.C supply, and an ammeter. Note any deflection on the ammeter. Start heating the solid strongly till is melts and observe the needle on the ammeter.

Observation: The ammeter needle deflects when the solid melts.
Conclusion: solid lead (II) iodide or sodium chloride does not conduct electricity but molten lead (II) iodide or sodium chloride does because there are mobile ions present in it
Students exercise: Give the reason why sodium chloride does not conduct electricity in the solid state but conducts electricity in the liquid state?

RADIOACTIVITY

Radioactivity is the spontaneous decay or disintegration of the nucleus of an atom with the emission of radiation and heat by an element. Such elements are called radioactive elements e.g. Uranium, Radon, Carbon-14

Becquerel in 1896 observed that a crystal of Uranium salt spontaneously emitted radiation which could penetrate through opaque material to affect a photographic plate and called it **radioactivity**. Pierre and Marie Curie in 1998 detected radioactivity in thorium and uranium ore (pitch blende). They analyzed pitch blende and isolated polonium and radium. Since then more than 40 naturally occuring radioactive elements have been discovered.

An element may have stable and radioactive isotopes eg ^{12}C and ^{14}C which are stable and radioactive isotopes of carbon respectively.

TYPES OF RADIOACTIVITY

There are two types of radioactivity
<u>Natural radioactivity</u>: This is a nuclear reaction in which an unstable radioactive atom or radioisotope emits radiation spontaneously in order to form a stable nucleus
<u>Artificial radioactivity</u>: This ai a nuclear reaction in which the nucleus of a non-radioactive atom is bombarded with nuclear particles to produce an artificial radioisotope. Another name for artificial radioactivity is nuclear disintegration

CHARACTERISTICS OF RADIOACTIVITY

1. Radioactive substances emit radiation continually and spontaneously
2. Temperature and pressure have no effect on the rate at which radiation is emitted
3. Radiation like visible light affects photographic plates but unlike visible light has high penetrating power.

4. It ionizes the gases through which is passes causing fluorescence in certain substances eg Zinc sulphide

5. Radioactivity is always associated with release of energy. The energy is about one million times that released during a chemical reaction. This energy is known as **Nuclear energy**.

Types of Radiation

There are three types of radioactive radiation

1. **Alpha rays**:
    - **i.** They are fast moving streams of positively charged particle each having a mass number of 4 and atomic
    - **ii.** Each α -particles are actually a helium nucleus $_4$He.
    - **iii.** They are positively charged and fairly heavy, they are deflected to the negative plate in an electrostatic field.
    - **iv.** α – ray have a low penetrating power. They travel a few centimeters in air and can be stopped by a thin sheet of paper or aluminium foil of 0.1mm thick.
    - **iv.** They exert a powerful ionizing effect upon any gas through which they pass. They cause flouresence in some materials eg ZnS.

2. **Beta rays (β-rays)**. They are fast moving streams of electrons
    - i. They are negatively charged and are deflected towards the positive plate in an electrostatic field
    - ii. They are relatively small, each particle has a mass number of zero and a charge of -1 and is representated as $^{0}_{-1}$e
    - iii. They are more penetrating than α -rays. Their range is about 3m in air and can be stopped by **Aluminium** plate of about 4mm in thickness.
    - iv. In air, the ionization power is about 1/1000 that of α particles.
    - v. They cause flouresence in certain substances like anthracene but not zinc sulphide

3. **Gamma rays (□-rays)**: These are not particles but electromagnetic waves similar to visible light and x-rays but with very short wavelengths.
    - i. They travel at the speed of light
    - ii. They are unaffected by an electrostatic field
    - iii. They have neither charge nor mass
    - iv. They are the most penetrating about 100m in air and can penetrate 0.5m of iron or lead
    - v. They have the lowest ionization power
    - vi. They can cause florescence in certain substances like anthracene and zinc sulphide

	Alpha ray **α – ray**	**Beat-ray** **β-ray**	**Gamma ray** **γ - Ray**
Nature	Helium nucl $^{4}_{2}He$ $^{4}_{2}He^{4}_{2}He$	Electron e	Electromagnetic radiation
Electrical charge	+2	-1	No charge
Mass	4 units	1/1840 unit	No mass
Velocity	½ speed of light	3 – 99% of speed of light	Speed of light
Relative penetration	1	100	10,000
Absorber	Thin paper	Metal paper	Large lead block

Radioactive source   *Paper α -absober*   *aluminium plate β-absorber*   *lead block γ -abosrber*

X-rays: these are electromagnetic waves with short wavelength produced by allowing flat moving electrons to bombard metals such as tungsten. The fast moving electrons knock electrons out of the inner shells of the metal atoms. These electrons are replaced by electrons moving in from outer shells. This movement is accompanied y emission of X-rays

1. X-rays can penetrate easily through most solid substances which are opaque to visible light eg metal foil, flesh, wood and paper
2. Hard x-rays have greater, penetrating power than soft x-rays

Uses of X-rays

1. Soft x-rays are used in medicine to photograph body parts
2. The x-rays pass through the flesh but are absorbed by the dense bones and produce a shadow photographs of the bones
3. Hard x-rays are used to destroy cancerous cells
4. In chemistry, they are used to study arrangement of particles in crystal lattices and big molecules like protein

DETECTION OF RADIATON

Different devices have been developed for detecting radiation. The commonly used one s are:

1. Geiger-Muller counter: This device is based on the ionization effect of the radiation on gases. This device consists of an ionization on chamber into which two metal electrodes are sealed and which is filled with a gas usually argon at 100 pressure together with a little bromine vapour. A potential difference of about 45Volts is maintained between the electrodes. When an ionizing particle or radiation enters the chamber, some argon atoms are ionized. The electrons produced drift to the positive terminus while the positive ions migrate to the negative one, a small current (pulse current) is obtained which is amplified and detected by suitable equipment in form of a clicker from a loud speaker or movement of a needle of a ratemeter or reading recorded by a scaler.

Fig: Geiger-muller counter

This is the most widely used detector of radioactivity. It can be used to measure the intensity of radiation since the count rate is proportional to the intensity of the radiation.

2. Scintillation Counter: Certain minerals such as Zinc Sulphide fluoresce or glow when exposed to radiation. The glow is made up of tiny flashes of light scintillations which is transformed into radiant energy of visible wavelength and detected in a scintillation counter.

3. Diffusion Cloud Chamber: This device detects the actual paths followed by an individual α and β -particle. The ionizing particles are allowed to pass through a gas which has been super. Saturated with water vapour. The ions formed in the track of the ionizing particles act like dust serving as centres for condensation of water vapour. As a result, the paths of these particles are revealed as a visible vapour trail which persists long enough to be photographed so that a permanent record of the movement of each particle is obtained.

When a radioactive element is placed on a photographic plate which has been coated with silver halide, the place will become darker due to absorption of radiation. The more intense the radiation, the darker the plate when developed.

α -particles β- particles γ-particles

cloud chamber tracks

Nuclear particles

The following are nuclear particles and their symbols

a. Alpha particle helium nucleus $^{4}_{2}He$
b. Beta particle $^{0}_{-1}e$ or $^{0}_{-1}\beta$
c. Proton / hydrogen nucleus $^{1}_{1}p$ or $^{1}_{1}H$
d. Neutron $^{1}_{0}n$
e. Positron/ positive electron $^{0}_{1}e$

Types of nuclear reactions

1. Radioactive decay
2. Nuclear disintegration
3. Nuclear fission
4. Nuclear fusion

RADIOACTIVE DECAY

Radioactivity is the (natural) spontaneous disintegration of a radioisotope to form an atom with a stable nucleus of an atom with the emission of radiation.

When a certain quantity of a radioactive substance disintegrates spontaneously, the word decay is used during disintegration, a radioactive atom emits either an α - or β-particle, sometimes □-rays accompany the emission of these particles. The parent nucleus (i.e. the disintegrating nucleus) undergoes a change in atomic number and became the nucleus of a different element. This new nucleus is called the daughter nucleus and the process is called **transmutation** of an atom. Radioactive decay is a random process as it is difficult to predict which atom will disintegrate. Rate of decay depends on the radioactive material and varies with material. No physical or chemical process can alter the rate of decay. But in all cases, element disintegrates at a certain definite rate which follows an exponential law whereby a certain definite fraction of the atoms present in the elements disintegrates per second.

ALPHA DECAY

When the nucleus of an atom loose an α-particle (a helium nucleus ${}^{4}_{2}He{}^{4}_{2}He{}^{4}_{2}He$) during disintegration, the atomic number is reduced by two units and the mass number by 4 units. The new element has atomic number and mass number smaller than that of the original atom.

Alpha decay is represented as

${}^{A}_{x}Z \quad {}^{A-4}_{x-2}Y + {}^{4}_{2}He{}^{A}_{x}Z{}^{A}_{x}Z \underline{\qquad\qquad} {}^{A-4}_{x-2}Y + {}^{4}_{2}He{}^{A-4}_{x-2}Y + {}^{4}_{2}He$

If uranium 238 undergoes α-decay

${}^{238}_{92}U{}^{238}_{92}U{}^{238}_{92}U \longrightarrow \quad {}^{234}_{90}Th + {}^{4}_{2}He{}^{234}_{90}Th + {}^{4}_{2}He{}^{234}_{90}Th + {}^{4}_{2}He$

For Radon

${}^{226}_{98}Ra \quad {}^{222}_{86}Rn + {}^{4}_{2}He{}^{226}_{98}Ra{}^{226}_{98}Ra \underline{\qquad\qquad} {}^{222}_{86}Rn + {}^{4}_{2}He{}^{222}_{86}Rn + {}^{4}_{2}He$

BETA – DECAY

When the nucleus of an atom emits a β-particle, it is equivalent to the splitting of a neutron in the nucleus to form an electron (β-particle) and a proton which remains in the nucleus. The atomic number increases by one unit but mass number remains unaltered. The new element formed has similar properties to elements situated one place to the right of the parent nucleus in the periodic table.

It is represented as

${}^{A}_{z}X \longrightarrow {}^{A}_{z+1}Y + {}^{0}_{-1}e{}^{A}_{z}X{}^{A}_{z}X \underline{\qquad\qquad} {}^{A}_{z+1}Y + {}^{0}_{-1}e \; {}^{A}_{z+1}Y + {}^{0}_{-1}e$

For a Thorium nucleus

${}^{234}_{90}Th \longrightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e{}^{234}_{90}Th \; {}^{234}_{90}Th \underline{\qquad\qquad} {}^{234}_{91}Pa + {}^{0}_{-1}e{}^{234}_{91}Pa + {}^{0}_{-1}e$

${}^{210}_{82}Pb \longrightarrow {}^{210}_{83}B1 + {}^{0}_{-1}e{}^{210}_{82}Pb \underline{\qquad\qquad} {}^{210}_{83}B1 + {}^{0}_{-1}e{}^{210}_{82}Pb \underline{\qquad\qquad} {}^{210}_{83}B1 + {}^{0}_{-1}e$

RADIOACTIVE DECAY SERIES

The nucleus of new elements formed by transmutation are unstable and will undergo further disintegration after an interval of time which may vary from a few microseconds to millions of years. These changes occur until a stable nucleus is finally produced. Several such series is named after the longest lives element e.g Uranium series, thorium series, actinium series.

The stability of an atomic nucleus is related to the ratio of neutrons to protons in the nucleus. The neutron: proton ratio for stable atoms varies between 1.5 and 1.0 while values less than 1 or greater than 1.5 tend to be unstable and undergo radioactive decay. Some naturally occurring radioactive isotopes include potassium -40, carbon -14, Uranium -92, Lead – 82.

RATE OF RADIOACTIVE DECAY

Radioactive elements decay at different rates. The half-life (t½) of a radioactive element is the time taken for half of the total number of atom in a given sample of the element to decay. For example the half life of Radium -226 is 1622 years. It means that if there are 100 atoms of Radium – 226 at the beginning, at the end of 1622 years, 50 atoms will remain and at the end of another 1622 years 25 atoms will remain and so on. Polonium -212 is unstable and has a half life of 3.0 x 10^{-7} seconds. Carbon -14 has a half life of 5.76 x 103 years and Uranium – 238 has a half life of 4.51 x 10^9 years

Disintegration Products of Uranium 238

Uranium	${}^{238}_{92}U$ ${}^{238}_{92}U$ ${}^{238}_{92}U$	4.5 x 10^9 years
↓ - α		
Thorium	${}^{234}_{90}Th$ ${}^{234}_{90}Th$ ${}^{234}_{90}Th$	24.1 days
↓ - β		
Protactium	${}^{234}_{91}Pa$ ${}^{234}_{91}Pa$ ${}^{234}_{91}Pa$	1.18 minutes
↓ - β		
Uranium	${}^{234}_{92}U$ ${}^{234}_{92}U$ ${}^{234}_{92}U$	2.5 x 10^5 years
↓ - α		
Thorium	${}^{230}_{90}Th$ ${}^{230}_{90}Th$ ${}^{230}_{90}Th$	8.0 x 10^4 years
↓ - α		
Radium	${}^{226}_{88}Ra$ ${}^{226}_{88}Ra$ ${}^{226}_{88}Ra$	1622 years
↓ - α		
Radon	${}^{222}_{88}Rn$ ${}^{222}_{88}Rn$ ${}^{222}_{88}Rn$	3.8 years
↓ - α		
Polonium	${}^{218}_{84}Th$ ${}^{218}_{84}Th$ ${}^{218}_{84}Th$	2.05 minutes
↓ - α		
Lead	${}^{214}_{82}Pb$ ${}^{214}_{82}Pb$ ${}^{214}_{82}Pb$	26.8 minutes
↓ - β		
Bismuth	${}^{214}_{83}Bi$ ${}^{214}_{83}Bi$ ${}^{214}_{83}Bi$	19.7 minutes
↓ - β		
Polonium	${}^{214}_{82}Po$ ${}^{214}_{82}Po$ ${}^{214}_{82}Po$	1.6 x 10^{-4} seconds
↓ - α		
Lead	${}^{210}_{82}Pb$ ${}^{210}_{82}Pb$ ${}^{210}_{82}Pb$	19.4 years
↓ - β		
Bismuth	${}^{210}_{83}Bi$ ${}^{210}_{83}Bi$ ${}^{210}_{83}Bi$	5 days
↓ - β		
Polonium	${}^{210}_{84}Po$ ${}^{210}_{84}Po$ ${}^{210}_{84}Po$	138 days
↓ - α		
Lead	${}^{206}_{82}Pb$ ${}^{206}_{82}Pb$ ${}^{206}_{82}Pb$	stable

The shorter half life, the faster the isotope decays, the longer half life, the longer and slower the decay process and the more stable the isotope.

EXAMPLE:

The atomic mass of ${}^{16}_{8}O$ ${}^{16}_{8}O$ ${}^{16}_{8}O$ is 15.995amu
If the individual masses of a proton and a neutron are 1.0078amu and 1.0087amu respectively. Calculate the binding energy of the oxygen nucleus in joules (1amu= 1.6X 10^{-27}kg)

Solution

Mass of ${}^{16}_{8}O$ ${}^{16}_{8}O$ ${}^{16}_{8}O$	15.995amu
Total mass	
Mass of 8 patrons 8 X 1.0078	8.0624amu
Mass of neutrons 8 X 1.0087	<u>8.0696amu</u>
	16.132amu
Total mass of oxygen atom	16.132
Actual mass of oxygen atom	<u>15.995</u>
Mass defect	0.137amu

$E= Mc^2$
$= 0.137 \text{ X } 1.6 \text{ X } 10^{-27} (3 \text{ X } 10^8)^2$
$= 1.972 \text{ X } 10^{-11}$ J

16g of 0_2 contains 6.02 X 10^{23}
1g of 0_2 = $\underline{1 \text{ X } 6.02 \text{ X } 10^{23}}$

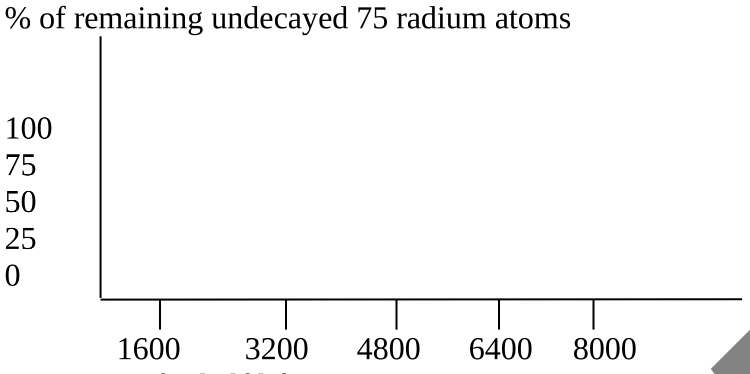
16

$= 3.76 \times 10^{22}$ atoms

Energy released for 1g f oxygen is

$= 3.76 \times 10^{22} \times 1.972 \times 10^{-11}$

$= 7.41 \times 10^{11}$ J



Radioactive decay curve

Expression for half life

$\frac{dN}{dt} = KN$

Integration of the above given the rate equation which is

$\text{Log} \frac{N_o}{N} = \frac{k}{2.303}$

Where N_o=amount of substance at zero time

N=amount left after time t

K=rate constant

Let N_0 =1 and N= ½ when half is decayed

$\text{Log} \frac{N_0}{N} = ½ = \log 2$

Substituting

$\text{Log}2 = \frac{Kt_{1/2}}{2.303} \Rightarrow 0.3010 = \frac{Kt½}{2.303}$

2.304

$t½ = \frac{0.693}{K}$ or $K = \frac{0.693}{t ½}$

Example 1:

1. The common radioactive isotope of radium -226 has a half life of 1620 years. Calculate (a) The first order rate constant first order rate constant for the decay of Ra-226 (b) The fraction of a sample remaining after 100 years.

Solution

(a) $K= \frac{0.693}{t ½} = \frac{0.693}{1620}$ $=4.28 \times 10^{-4}$

$K= 4.28 \times 10^{-4}$

(b) $\text{Log} \frac{No}{N} = \frac{Kt}{2.303}$

$\text{Log} \frac{No}{N} = \frac{4.28 \times 10^{-4} \times 100}{2.303}$ $= 0.0186$

$\text{Log}\ \frac{No}{N} = 0.0186$

$\frac{No}{N} = \text{antilog of } 0.0186 \qquad = 1.044g$

$\text{Fraction left} = \frac{1}{1.44} \times 100\% \qquad = 95.6\%$

Examples 2:

2. The isotope Co has a half life of 5.27 years. What amount of 0.05g sample remain after 1 year

Solution

$K = \frac{0.693}{t\ ½} = \frac{0.693}{5.27}$

$K = 0.131$

$\text{Log}\ \frac{No}{N} = \frac{Kt}{2.303} = \frac{0.131 \text{ X } 1}{2.303} = 0.0573$

$\text{Log}\ \frac{No}{N} = 0.0573$

$\frac{No}{N} = \text{antilog of } 0.0573 = 1.14g$

$\frac{No}{N} = 1.14g$

$\frac{0.05}{N} = 1.14$

$N = \frac{0.05}{1.14} \qquad = 0.043g.$

Examples 3:

3. How much of 5.0g of fb-210 whose half life is 150 days remain after 45days.

Solution

$K = \frac{0.693}{t\ ½} = \frac{0.693}{150} = 0.00462$

$\text{Log}\ \frac{N_o}{N} = \frac{kt}{2.303} = \frac{0.00462 \text{ X } 45}{2.303} \qquad = 0.090$

$\text{Log}\ \frac{N_o}{N} = 0.09$

$\frac{N_o}{N} = \text{antilog of } 0.09$

$\frac{N_o}{N} = 1.23$

$\frac{5}{N} \qquad = 1.23$

$N = \frac{5}{1.23} \qquad = 4.07g.$

QUESTIONS

1. The half life of a radioactive isotope is 5days, if we have 10g of X initially, calculate its mass after 40days.
2. 100g of a radioactive substance has a half life of 15days. Calculate it’s mass after 45days

MASS SPECTROMETER

This is an instrument that measures the masses of the various isotope present in a sample of an element and give the percentage abundance of each isotope. This allows the relative atomic masses to be accurately calculated. The stages of operation of a mass spectrometer include:

1. A test sample is vapourised and injected into the ionization chamber
2. The vapourized sample are bombard by cathode rays which knock out electrons and thus positively charged particles are formed
3. The positive ions are accelerated in an electric field
4. The ions are deflected by a magnetic field according to their mass and charge. Ions of lightest elements are deflected most
5. The ions are then detected by ion detector which is connected to an amplifier and a recorder. The mass spectrum obtained is used to calculate the relative atomic mass of the test element.

NUCLEAR ENERGY

When radioactive elements decay, it is usually accompanied by the evolution of a great quantity of heat known as the nuclear energy which could be harnessed and used.

ARTIFICIAL/ATOMIC TRANSMUTATION

This involves bombarding a stable nucleus of elements with fast-moving atomic particles like neutrons, protons deuterons and α -particles so as to bring about the existence of new elements. Machines used to achieve this include cyclotrons, synchrotrons, batatrons and cosmotrons

In 1919, Lord Rutherford succeeded in transmuting a nitrogen isotope into an oxygen isotope by bombarding the former with α-particles

$$^{14}_{7}N + ^{4}_{2}He \; ^{14}_{7}N + \longrightarrow ^{4}_{2}He \; ^{14}_{7}N + ^{4}_{2}He \quad ^{17}_{8}O + ^{1}_{1}P \; ^{17}_{8}O + ^{1}_{1}P$$

$$^{17}_{8}O + ^{1}_{1}P$$

Nitrogen *helium* *oxygen* *proton*

Bombardment by neutrons is particularly effective since it has no charge

Light elements yield new element s by ejecting charged particles

$$^{14}_{7}N + ^{1}_{0}n \longrightarrow ^{14}_{6}C + ^{1}_{1}P \; ^{14}_{7}N + ^{1}_{0}n \; ^{14}_{7}N + ^{1}_{0}n \rule{2cm}{0.4pt} ^{14}_{6}C + ^{1}_{1}P$$

$$^{14}_{6}C + ^{1}_{1}P$$

Heavy elements captures the neutron to produce an isotope of the original element

$$^{59}_{27}Co + ^{1}_{0}n \longrightarrow ^{60}_{27}Co \; ^{59}_{27}Co + ^{1}_{0}n \; ^{59}_{27}Co + ^{1}_{0}n \rule{2cm}{0.4pt} ^{60}_{27}Co \; ^{60}_{27}Co$$

Suitable transmutations have been used to synthesize artificial elements like neptunium, plutonium, curium, Lawrencium etc

$$^{238}_{92}U + ^{1}_{0}n \; ^{238}_{92}U + ^{1}_{0}n \; ^{238}_{92}U + ^{1}_{0}n \quad ^{239}_{92}U \; ^{239}_{92}U \; ^{239}_{92}U \quad ^{239}_{93}Np + ^{0}_{-1}e$$

$$^{239}_{93}Np + ^{0}_{-1}e \longrightarrow ^{239}_{93}Np + \longrightarrow ^{0}_{-1}e$$

BINDING ENERGY

This is the amount of energy evolved when the particles present in the nucleus are bound to form an atom or when free protons and neutrons form a nucleus.

For example, if the mass of helium atom and the total mass of the protons and neutrons making up the atom are measured, it will be noted that the values differ. This difference in mass is called mass defect which corresponds to a release of energy.

Albert Einstein, in his theory of relativity, states that mass and energy are interconvertible according to the equation.

$E = mc^2$ E = energy in J

M = loss in mass in kg

C = velocity of light in ms^1

For a Helium atom $_4He$

Mass of 2 protons = 2 x 1.0078amu	2.0156amu
Mass of 2 neutrons = 2 x 1.0087amu	2.0174amu
Total mass	4.0330 amu
Actual mass of helium atom	4.0026amu
Mass defect	0.0304 amu

BINDING ENERGY PER NUCLEON

Nucleons are particles present in the nucleus of an atom. If the binding energy is divided by the number of nucleons, we obtain binding energy per nucleon which indicates the stability of elements.

Factors that determine nuclear stability

1. Neutron-proton ratio in the nucleus. Atoms of stable isotopes contain approximately equal number of neutrons and protons. Radioisotopes contain more neutrons than protons. When the neutron: proton ratio is greater than 1.5, the atom is likely to be unstable
2. The half-life of the nucleus
3. The nuclear force and binding energy

Nuclear energy can be obtained from nuclear changes and there are two types of nuclear charges

1. **Nuclear Fission**: This is the process in which the nucleus f a heavy element is split into two nuclei of nearly equal mass with the release of energy and radiation.

In 1939, German scientist brought about nuclear fission by bombarding Uranium -235 atoms with neutrons travelling moderate speed and it split into two fragments of equal sizes accompanied by a release of a tremendous amount of energy and neutrons.

$^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$ $^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$ $^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$ + energy

$^{235}_{92}U + ^{1}_{0}n$ $^{235}_{92}U + ^{1}_{0}n$ $^{235}_{92}U + ^{1}_{0}n$ $\nearrow$ $\searrow$

$^{144}_{54}Xe + ^{90}_{38}Sr + 2\,^{1}_{0}n$ $^{144}_{54}Xe + ^{90}_{38}Sr + 2\,^{1}_{0}n$ $^{144}_{54}Xe + ^{90}_{38}Sr + 2\,^{1}_{0}n$ + energy

These two fragments are unstable isotopes of heavy elements. In nuclear fission, the total mass of all the fragments and the neutrons released differ from the mass of the original atom and the bombarding neutron. This difference is due to conversion of mass to energy during fission.

Calculations

Mass of $^{235}_{92}U$ $^{235}_{92}U$ $^{235}_{92}U$		*235.404amu*
Mass of 1 $^{1}_{0}n$ $^{1}_{0}n$ $^{1}_{0}n$		*1.009 amu*
Total mass	*236.049amu*	
Mass of $^{14}_{56}Ba$ $^{14}_{56}Ba$ $^{14}_{56}Ba$		*140.910amu*
Mass of $^{92}_{36}Kr$ $^{92}_{36}Kr$ $^{92}_{36}Kr$		*91.910amu*
Mass of 3 $^{1}_{0}n$ $^{1}_{0}n$ $^{1}_{0}n$		*3.027amu*
Total Mass	*235.847amu*	

Mass defect = 236.049 – 235.847 = 0.202 amu

Using $E=Mc^2$

$= 0.202 \times 1.6\times10^{-27}kg \times (3 \times 108\ mls)2$

$= 2.9 \times 10^{-11}J$

For every atom of U -235 that undergoes fission,
1.9×10^{-11}J of energy is released
for 1g of U-235
235 of uranium contain 6.02×10^{23} atms
1g of Uranium will contain $\frac{6.02 \times 10^{23}}{235} \times 1$
$= 2.563 \times 10^{21}$ atoms
Energy released for 1g of Uranium -235

$= 2.563 \times 10^{21} \times 2.9 \times 10^{-11}$ J
$= 7.433 \times 10^{10}$J

This amount of energy can be obtained when 3×10^{6}kg of coal is burnt as compared to 1g of Uranium.

NUCLEAR REACTOR/ PLANT

If the neutrons produced during fission of Uranium -235 atom could bombard the parent atom to produce more energy and more neutrons and the process is repeated over and over again, then a self-maintaining or chain reaction could be obtained. This is the principle of the atomic/fission bomb and the atomic pile/nuclear reactor (atomic power plants where nuclear energy is used to produce electrical energy).
An atomic explosion results when the right amount (critical mass) of fissionable materials is split by neutrons in a chain reaction. The explosion of atomic bomb is instantaneous and uncontrolled chain reaction but in atomic pile, the rate of nuclear fission is controlled so that the heat evolved can be dissipated.

A nuclear reactor is a device in which the large quantity of heat produced during nuclear fission is controlled to generate electrical energy

Atomic pile made of rods of Uranium-235 serves as the nuclear fuel and the main source of energy
Moderators are added in the atomic pile to sustain the chain reaction and slow down the fast moving neutrons without absorbing them so that the reaction does not get out of control. Examples are graphite and heavy water (deuterium)
Neutron absorbers Movable rods of Cadmium and Boron steel are inserted between the Uranium-235 rods in order to absorb the neutrons and control the chain reaction in order to obtain a steady and continuous production of heat
The **thick concrete structure** acts as a shield and provides protection against radioactive radiation fallouts
The **critical mass** is the quantity of radioactive substance required to sustain a chain reaction. Above the critical size, explosion is possible
The rate of nuclear fission is controlled by adding Uranium-238 with the fissionable Uranium-235. Atoms of U-238 capture the fast moving neutrons while the atoms of U-235 capture the slow moving neutrons.
The presence of U-238 slows down the rate of absorption of neutrons by U-235 and so helps to control the fission rate.
A **chain reaction** is a self-sustaining sequence of reactions in which a reactive product or by-product causes additional reactions to take place

NUCLEAR FUSION

This is a process in which two or more light nuclei fuse or combine to form a heaver nucleus with a release of energy and radiation.
When nuclei of light atoms combine to form a heavy nucleus, energy is released due to a slight loss I mass during the fusion. The amount of energy per unit mass of nuclear fuel liberated by nuclear fusion is greater than that liberated by nuclear fission. In practice, nuclear fusion occurs only at extremely high temperatures (1.5×10^{7}°C) and are referred to as **Thermonuclear reactions**. This is because large energies have to be given to the positively charged nuclei to overcome repulsion between them.

SOLAR ENERGY

Thermonuclear reactions are believed to be the sources of energy of the sum and the stars. This usually involves the nuclear fusion of hydrogen nuclei to form helium nuclei with the liberation of a great amount of energy.

USES OF RADIOACTIVE ISOTOPES

1. In **medicine**, intense γ radiation can be used to destroy cancerous growths. Care should be taken to ensure that only cancerous cells are irradiated

- a. Cobalt -60 is used to destroy cancerous growths
- b. Iodine-131 is used to treat cancer of the thyroid gland
- c. Phosphorus–32 is used to treat leukemia
- d. Heart pacemakers used to maintain heartbeat of patients with heart disease can now be powered by nuclear batteries which can last for about 10 years.

2. Sterilization: when an object is exposed to gamma radiation, germs are killed, leaving it perfectly sterile with no trace of radioactivity. It is used to sterilize surgical equipments which can be irradiated after it is sealed without fear of contamination

3. Industrial uses:

(a) α, β and Ɣ radiations are used to control and monitor the thickness of sheet material such as plastic, paper, metal during production to detect variations in the intensity of the radiation passing through the material.

(b) The β and Ɣ radiations are used to measure the wall thickness of pipes to check for internal corrosion. Pipelines can be checked for leaks by adding a radio isotope to the following liquid and testing for activity along the length of the pipe

(c) β and Ɣ radiations are used to control the filling of packets, tins, tanks etc by machines. When the material reaches a pre-determined height in the container, the radiation supply is cut off and the filling stopped

(d) Cobalt-60 is used in industrial radiography for the rapid checking of faults in welds and castings.

4. Agricultural Uses: Radioactive radiation is employed in agricultural research to induce mutations (genetic modification) in plants and animals in order to obtain new and improved varieties with desired characteristics such as early maturation, better nutritional value, high yield or greater resistance to diseases. Radiation can be used to sterilize male pupae of an undesirable insect such that they are sterile and cannot produce virile male eggs to fertilise the female eggs. Fertilizers containing radioactive Phosphorus-32 are used to study the uptake of tetraoxophosphate(V) ions from the soil by plants.

5. Radioactive tracers: The movement or behaviour of a radioactive atom can be traced because it emits radiation. Therefore, a radioactive isotope of an element can be used as a marker or tracer to trace what happens to the element during a chemical reaction. Tracers have been used to study the mechanisms and kinetics of chemical reactions and metabolic reactions e.g Iodine -131 have been used to study iodine uptake by thyroid gland and Carbon-14 have been used to study the course of photosynthesis.

6. Dating techniques: Long-lived isotopes e.g Uranium-238 present in the earth crust is utilized by geologists to estimates the age of rocks and archeological objects. This is done by comparing the radioactivity of rocks and that which were presumed to have had when they are first formed. Radiocarbon dating is used to determine the age of the more recent organic remains found in archeological excavations. Carbon-14 are radioisotope of Carbon -12 is produced by bombardment of carbon (IV) oxide by cosmic rays and is distributed in the atmosphere, water bodies and all living things. When plants and animals die, the Carbon-14 present in their body decays at a known rate. Thus by measuring the radioactivity of the remaining carbon -14, the age of the specimen can be determined.

7. In Atomic or Hydrogen bomb: When a mixture of deuterium and tritium (heavy isotopes of hydrogen) is exposed the heat from a fission bomb explosion, nuclear fusion occurs resulting in the hydrogen or fusion bomb. The lethal power of this bomb is due to (loss in mass) energy released and the large quantity of Ɣ -radiation produced

$$ {}_{1}^{2}D + {}_{1}^{3}Th\ {}_{1}^{2}D + {}_{1}^{3}Th\ {}_{1}^{2}D + {}_{1}^{3}Th \qquad {}_{2}^{4}He + {}_{0}^{1}n\ {}_{2}^{4}He + {}_{0}^{1}n\ {}_{2}^{4}He + {}_{0}^{1}n \ + \text{energy} $$

8. NUCLEAR ENERGY FOR POWER: The heat developed in a nuclear reactor is used to produce power. A heat-transfer liquid or gas (heavy water or carbon(IV)oxide) is circulated through a reactor where it becomes heated and is then pumped into a heat interchanger where it converts waters to steam. The steam produced is used to drive turbines which turn electrical generators to produce electricity. Thermonuclear reaction under controlled conditions provide a source of cheap power. In nuclear submarines, such energy is used to power the ship. A nuclear reactor can work day and night with the same uranium fuel for a few years.

BIOLOGICAL EFFECTS (HEALTH HAZARDS) OF RADIATION

- Exposure to radioactive radiations have harmful physiological effects since some of the effects are cumulative.

- Mild doses of radiation can cause change in cell structure and body chemistry leading to anaemia, cancer, (especially leukemia) and genetic mutations.
- Heavier doses result in death. Workers in radiological laboratories should be checked to see if they have not been exposed to dangerous doses of radiation. The natural radiation to which we are exposed from the radioactive material in the earth's crust and from cosmic rays from outer space is called background radiation. The amount is so small that is has no harmful effects. The amount of radiation is measured in rad or rem.

- Solid radioactive waste should not be disposed by burying because it may decay and contaminate the soil or release harmful radiations

DIFFERENCES BETWEEN FISSION AND FUSION

NUCLEAR FISSION	NUCLEAR FUSION
1. It involves splitting the nucleus of a heavy isotope into two light nuclei of equal mass	It involves combining two or more nuclei of light element to form a heavy nucleus
2. Produce neutrons to sustain chain reaction	Occurs only at extremely high temperature
3. Amount of energy per unit mass of nuclear fuel is large	Amount of energy per unit mass of nuclear fuel is larger than that of nuclear fission

DIFFRENCES BETWEEN CHEMICAL AND NUCLEAR REACTION

Chemical reaction	Nuclear reactions
1. Involve electrons in the outer most shell of atoms	Involve the particles in the nucleus of an atom
2. Energy released during reactions is little	Energy released during reactions is greater
3. Some chemical reactions require catalyst to proceed	They are spontaneous reactions
4. The atom retains its integrity	A new atom of another element is formed