

## TOPIC 1: Moles and Equation

### Item 1:

Pharmaceutical industries routinely assess the quality of excipients to ensure the safety, stability, and effectiveness of drug formulations. One such excipient is Solid W, a metal carbonate ( $\text{MCO}_3$ ) widely used as an antacid and mineral supplement. According to the United States Pharmacopeia (USP), the acceptable purity range for pharmaceutical-grade metal carbonates lies between **98.0% and 100%** on a dried basis. A certain batch of Solid W is suspected to contain impurities, prompting the quality control laboratory to evaluate its purity through a back-titration procedure.

In the analysis, 0.8 g of Solid W was dissolved in 25  $\text{cm}^3$  measured volume of 2.0  $\text{mol/dm}^3$  hydrochloric acid and solution diluted to 250  $\text{cm}^3$  using distilled water. 25.0  $\text{cm}^3$  of the resultant solution was titrated with 0.20  $\text{mol/dm}^3$  sodium hydroxide solution using phenolphthalein indicator. During the titration, 18.40  $\text{cm}^3$  of the sodium hydroxide solution was required to neutralize the unreacted hydrochloric acid. (M = 40, C = 12, O = 16.)

#### Task:

Using the information provided, determine the percentage purity of Solid W and decide whether the batch meets the USP purity requirement of 98.0–100%.

### Item 2:

A quality control laboratory received a commercial bleach sample (JIK) used in dental clinics for preparing diluted root-canal irrigation solutions. The bleach contains sodium hypochlorite as the active ingredient, and its true concentration must be checked before it can be diluted to the recommended 0.5% solution. A 10.0  $\text{cm}^3$  portion of the JIK sample, with a recorded density of 1.08  $\text{g cm}^{-3}$ , is treated with excess hydrochloric acid to release chlorine gas. The liberated chlorine is immediately passed into a potassium iodide solution, and the iodine formed required 24.60  $\text{cm}^3$  of 0.10  $\text{mol dm}^{-3}$  sodium thiosulphate solution for complete reaction.

#### Task:

Determine the percentage available chlorine in the JIK sample and comment on whether it matches the manufacturer's stated concentration of 3.50% sodium hypochlorite.

**(Read about the equations of reactions involved in this investigation)**

### Item 3:

In a tannin-processing facility, high-quality leather is produced by combining vegetable tannins with mineral mordants. During one production stage, aluminum sulphate is stabilized using organic acid ligands, while oxalic acid iron(III) sulphate act together as mordants to achieve optimal tanning. For effective mineral tanning, the formulation requires a specific ratio of 4:1 by mass of iron(III) sulphate to oxalic acid.

A batch of the mordant mixture is suspected of containing an incorrect ratio. To verify its composition, 1.50 g of the mordant mixture is dissolved in water and the resultant solution diluted to make 250 cm<sup>3</sup> using distilled water. The oxalic acid content was analyzed by titration against 0.020 mol dm<sup>-3</sup> potassium permanganate. 25.0 cm<sup>3</sup> of the solution of the mordant required 8.40 cm<sup>3</sup> of the manganate (VII) to reach the endpoint under acidic conditions.

In another procedure, 50.0 cm<sup>3</sup> of the mordant solution was pipetted into a conical flask and excess zinc powder added followed by filtration. (Zinc powder reduces iron (III) to iron (II)). 25.0 cm<sup>3</sup> of the filtrate required 24.40 cm<sup>3</sup> of the manganate (VII) to reach the endpoint under acidic conditions.

#### Task:

Assess whether the mass ratio of ammonium ferrous sulphate to oxalic acid meets the required ratio.

**(Read about the equations of reactions involved in this investigation)**

## TOPIC 2: Atomic and Electronic Structure

### SUB-TOPIC 2.1: Electron Configurations of Atoms and Ions

#### Item 4:

Six elements labeled A, B, C, D, E, and G have been recommended for use as enzyme activators in biological systems. Elements **A–E** are from period 3, while element **G** is from period 2, but it belongs to the same group as one of the period 3 elements.

An enzyme activator must easily form a **cation** by losing one or more electrons to interact with an enzyme's active site. The first four ionization energies (kJ/mol) of these elements are:

Element	Ionisation energy (Kj/mol <sup>-1</sup> )			
	1	2	3	4
<b>A</b>	496	738	4562	9540
<b>B</b>	1012	1907	2914	16091
<b>C</b>	738	1451	7733	10542.51
<b>D</b>	578	1817	2745	11577
<b>E</b>	1000	2252	3357	4556
<b>G</b>	900	1757	14848	–

**Task:**

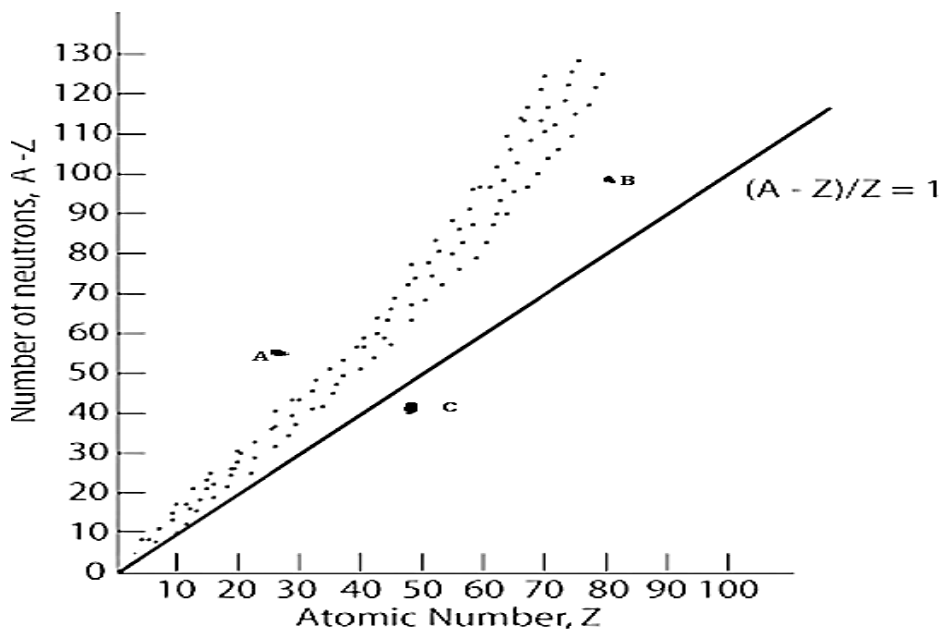
- Using the given information, determine the electronic configurations of the elements and the ions they form, and identify which element would be most suitable as an enzyme activator. **(Include orbital diagrams)**
- Manganese(IV) and iron(II) ions were initially proposed for use; however, they were observed to undergo redox reactions, converting into manganese(II) and iron(III), respectively. Using their electronic configurations, explain why these changes occur and discuss how such redox behavior could influence their suitability for the intended application.

**SUB-TOPIC 2.2: Radioactivity and Its Applications**

**Item 5:**

A learner is evaluating three radioactive-nuclides, A, B, and C, which have been recommended for use in cancer treatment. The nuclide that becomes stable through beta decay is most suitable. The proton (Z) and neutron (N) numbers of each nuclide were measured, and their positions were plotted on the neutron-to-proton (N-Z) graph as shown.

**Support material:**



**Task:**

- Using well balanced nuclear reaction equations, suggest the suitable nuclide to use in the cancer treatment.
- Explain the factors that influence the stability of the nucleus of a given atom.

### Item 6:

A tiny piece of paper (produced from formerly living plant matter) taken from the Dead Sea Scrolls has an activity of 10.8 disintegrations per minute per gram of carbon. If the initial C-14 activity was 13.6 disintegrations/min/g of C.

#### Support material:



#### Task:

- Estimate the age of the Dead Sea Scrolls.
- Suggest a reason how the dead sea scrolls ended up with the radioactive isotope and the type of radioactivity decay involved.

### Item 7:

A learner is studying **Iodine-131**, a radioactive isotope used in the treatment of thyroid disorders and certain cancers. For medical applications, the isotope must have a half-life that is long enough to allow it to be administered and reach the target tissue, but short enough to decay rapidly to avoid prolonged radiation exposure. The isotope has been found to emit a beta particle accompanied with emission of gamma rays that destroy the cancerous cells.

#### Support material:

Elapsed Time (Days)	0	5	10	15	20	25	30
Percentage Remaining (%)	100	68	46	31	21	14	10

#### Task:

As a learner of chemistry;

- Using the beta decay of Iodine-131, suggest the reasons that make it the suitable candidate for the treatment of the cancer.
- Plot the graph for the decay and use it to calculate the amount of the radioactive iodine left in the body on the 32<sup>nd</sup> day.
- Suggest the applications radioactivity in the everyday life.

## TOPIC 3: Bonding and Structure

### Item 8:

A materials research laboratory is investigating why certain Period-3 elements are better suited for high-temperature industrial applications such as furnace linings, electrical heating coils, and aerospace components. The researchers select six elements across the period—**sodium (Na), magnesium (Mg), aluminum (Al), silicon (Si), phosphorus (P), sulphur (S) and chlorine (Cl)**—and compare their melting points to understand trends across the period.

Each element is first purified and then placed in a controlled heating chamber. The team records the temperature at which each element transitions from solid to liquid.

#### Support material:

Element	Na	Mg	Al	Si	P	S	Cl
Melting point/°C	98	639	660	1410	44	113	-101

#### Task:

As a learner of chemistry,

- Plot a graph that can be used to analyse the variation in the melting points of the elements.
- Explain the variation in the trend of the melting points indicating how this influences their industrial applications.

### Item 9:

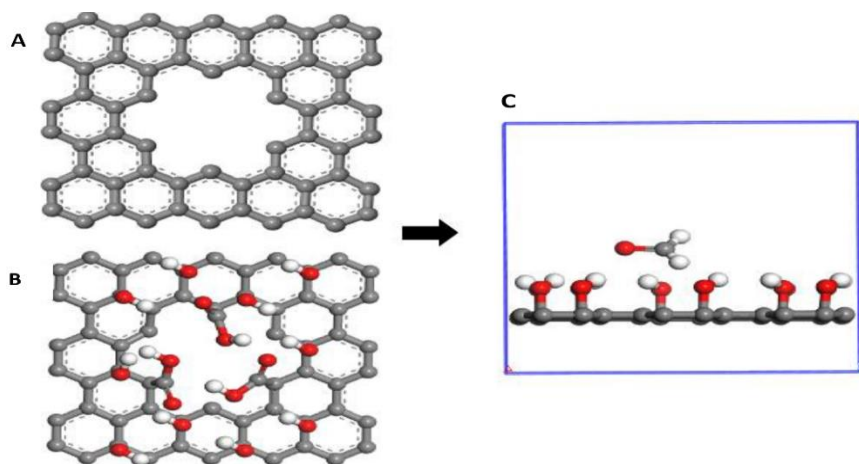
A high-tech electronics company specializing in boron-doped semiconductor chips operates a large processing facility where boron trichloride ( $\text{BCl}_3$ ) and ammonia ( $\text{NH}_3$ ) are frequently used. Boron trichloride is used for boron implantation and plasma etching and Ammonia is used in nitride formation and as a cleaning gas.

Both gases must be precisely controlled because leaks can contaminate products or harm workers. The plant installs a series of conventional gas detectors, but these detectors have difficulty distinguishing between  $\text{BCl}_3$  and  $\text{NH}_3$  molecules. Small ammonia leaks were escaping detection during night shifts, occasionally corroding sensitive deposition equipment.

Graphene, being a single-atom-thick sheet of delocalized electrons, interacts differently with polar vs. non-polar molecules.

- Non-polar molecules like  $\text{BCl}_3$  show minimal adsorption**, causing almost no change in graphene's conductivity.

## Support material



Polar molecules like  $\text{NH}_3$  adsorb strongly on graphene altering its electrical conductivity.

### Task:

- Explain using the knowledge of bonding and structure why the ammonia was able to adsorb strongly on graphene causing a change in the conductivity unlike the boron chloride.
- Suggest how the difference in the two molecules influence their solubility in water.

### Item 10:

An aerospace company is developing a high-temperature protective coating for turbine blades. The process requires immersing metal parts into a molten salt bath that must remain stable, conduct heat efficiently, and interact predictably with metal surfaces. The engineers must choose between two potential salts: sodium chloride ( $\text{NaCl}$ ) and aluminium chloride ( $\text{AlCl}_3$ ).

Tests reveal that **NaCl**, forms a simple, stable interface with the metal. The ions arrange in a typical diffuse double-layer but remain well-separated and do not strongly distort each other. This produces a predictable and stable coating environment. In contrast,  $\text{AlCl}_3$ , the interface becomes reactive and unstable. The ionic charge and size were determined to assist in understanding the difference among the two salts.

### Support material:

Ion	Ionic Charge	Approximate Ionic Radius (pm)	
$\text{Na}^+$	+1	95	
$\text{Al}^{3+}$	+3	50	

**Task:**

- Determine the charge density of the two ions.
- Explain the difference in the behavior of the two salts when used as protective coatings.

## TOPIC 4: Periodicity 1

### Item 11:

A research lab is developing **light-sensitive electronic devices** that rely on the photoelectric effect, in which electrons are emitted from a material when it absorbs light of sufficient energy. The team is investigating elements from **Period 3 (Na to S)** to determine suitable photoemissive surfaces. By comparing photoemission and stability across Period 3, the engineers decide to use Na for high-sensitivity visible-light photocells **and** Al or Si for UV or semiconductor-based devices.

**Support material:**

Element	Na	Mg	Al	Si	P	S
IE <sub>1</sub> (kJ/mol)	496	738	578	789	1012	1000

**Task:**

- Plot a graph of variation of ionisation energy versus elements, analyse and explain the reason why sodium was able to emit electrons easily as compared to other elements.
- Suggest with reasons why chlorine and argon were not included in the study.
- Using the data comment the difference in the reactivity of the metallic elements.

### Item 12:

An environmental lab is tasked with measuring trace levels of fluorinated organic compounds in groundwater. They use electron capture gas chromatography (ECGC), which is highly sensitive to electronegative elements. The **ECD detector** contains a beta-emitting radioactive source, Ni-63, to ionize an inert carrier gas (nitrogen or argon/methane), producing a steady current of free electrons which is captured hence reducing the current and generating a detectable signal.

In this system, other Period 2 elements such as beryllium (Be), lithium (Li), and boron (B) do not significantly affect detection. Fluorine (F), by contrast, produces a strong signal even at very low concentrations, making ECGC ideal for monitoring fluorinated pollutants like PFAS compounds in environmental samples.

**Support material:**

Elements	Li	Be	B	C	N	O	F	Ne
Electron affinity ((kJ/mol <sup>-1</sup> ))	-60	+48	-27	-122	-7	-141	-328	+207

**Task:**

- Using the electron affinity, explain the trend and the reason why fluorine produces the strongest signal.
- Explain how this influences the reactivity of the non-metals.

**Item 13:**

A materials-engineering team designing components for an aircraft engine needs a metal with high melting point, high thermal stability, and resistance to oxidation at elevated temperatures. The team initially considered Group II (alkaline earth) metals because some are lightweight and abundant. A student group picked **barium** because it's available locally. During tests they found that components made from barium alloys/coatings failed (deformed, oxidised or melted) at the required service temperatures.

**Support material:**

Element	Be	Mg	Ca	Sr	Ba	Ra
Melting point (°C)	1287	649	839	769	725	700

**Task:**

- Plot a graph using the data provided and use it to explain the observed trend.
- Describe how each of the elements reacts with water and oxygen, and use your observations to recommend the most suitable element for alloy formation.

**Item 14:**

An environmental monitoring team has detected unusually high concentrations of chlorides and fine particulate matter in soil samples collected near an industrial discharge site. Initial investigations suggest that the contamination may have originated from compounds containing **Period 3 elements** (Na, Mg, Al, Si, P, S, or Cl).

Field chemists suspect that the pollutants include chlorides of these elements, which may react with soil moisture to alter the soil pH. Local researchers further hypothesize that the change in pH caused by hydrolysis of these chlorides is responsible for the decline in microbial growth and shifts in microbial community composition observed in the area.

**Task:**

- Using the reactions of Period 3 element chlorides with water, explain the possible causes of the observed change in soil pH.
- Magnesium and aluminium show a diagonal relationship with other elements. Using chemical reactions, explain the cause and how this affects their distinctions.

**Item 15:**

A pharmaceutical company is developing a new X-ray contrast agent for imaging the digestive system using Group 2 metal compounds. They are considering both **hydroxides (M(OH)<sub>2</sub>)** and **sulphates (MSO<sub>4</sub>)**, where M = Mg, Ca, Sr, Ba, or Ra. The compound must provide sufficient X-ray contrast, which depends on the atomic mass of the metal (preferably a heavy metal), but it must also be safe for ingestion. Insolubility is a key factor: very insoluble compounds remain in the digestive tract, preventing toxic metal ions from being absorbed into the bloodstream while still allowing their dense atoms to produce clear imaging contrast.

**Support material:**

<b>Group 2 Element (X)</b>	<b>Hydroxide X(OH)<sub>2</sub> Solubility (mol/ 100g H<sub>2</sub>O)</b>	<b>Sulphate XSO<sub>4</sub> Solubility (mol/ 100g H<sub>2</sub>O)</b>
<b>Be</b>	$1.0 \times 10^{-6}$	$1.0 \times 10^{-2}$
<b>Mg</b>	$2.0 \times 10^{-5}$	$2.9 \times 10^{-1}$
<b>Ca</b>	$1.5 \times 10^{-3}$	$1.2 \times 10^{-3}$
<b>Sr</b>	$3.4 \times 10^{-3}$	$7.6 \times 10^{-4}$
<b>Ba</b>	$1.5 \times 10^{-2}$	$1.0 \times 10^{-4}$

**Task:**

- With identification of the suitable salt to use in the X-ray, explain the variations in the solubility.

**Item 16:**

A rural community has reported difficulties when using their borehole water for domestic purposes. Soap does not lather properly, large quantities are needed for washing, and a white precipitate often forms in the water. Local health officers suspect contamination with a dissolved salt, possibly group (ii) cation and an anion that may be causing permanent hardness in the water.

Your school's science department has been asked to assist in identifying the ions responsible for the water quality issues and this will assist in developing the best means to soften the water.

**Task:**

You have been provided with a sample of the community's water, labelled **Sample Q**. Your task is to qualitatively identify the cation and anion present in the sample.

- a) Design a scientific investigation that can be used and include; Aim, Hypothesis, Variables, Risks and mitigations:  
 b) Complete the table and assist in the identification of the cation.

TESTS	OBSERVATIONS	DEDUCTIONS
(a) Two spatula endful of Q were heated in a dry test tube strongly until no further change.	A white crystalline solid  A colourless condensate on the cooler parts of the test tube that turns anhydrous copper(II) sulphate from white to blue.  A white residue formed	
(b) To two spatula endful of Q in a test tube was added about 5 cm <sup>3</sup> of distilled water and divided into five parts in using different test- tubes.	A colourless solution	
(iv) To the first part was added 2-3 drops of lead (II) nitrate solution and then warmed.		Cl <sup>-</sup> or SO <sub>4</sub> <sup>2-</sup>
(v) To the second part was added 2-3 drops of silver nitrate solution followed by dilute nitric acid	No observable change	
(vi) To the third part was added 2-3 drops of barium nitrate solution.		SO <sub>4</sub> <sup>2-</sup> confirmed
(ii) To the fourth part was added dilute ammonia solution drop-wise until in excess.	A white precipitate insoluble in excess	
(iii) To the fifth portion was added half a spatula endful of solid ammonium chloride followed by a few drops of disodium hydrogenphosphate solution then ammonia solution drop-wise until in excess.	A white precipitate insoluble in excess ammonia solution	

- c) Analyze the results, and interpret the findings to determine the ions present.

## TOPIC 5: Thermochemistry

### Item 17:

A research team has selected **Metal Y** for a study on clean-energy production using a *Thermal Energy Storage System Based on a Metal Hydride Reactor and a Mechanical Hydrogen Compressor*. In this system, metal Y absorbs hydrogen to form metal Y hydride, releasing heat, and later undergoes endothermic desorption when heated using solar energy, supplying hydrogen to the compressor. Because this reversible cycle allows energy to be stored and delivered without producing emissions, the team will investigate the reaction energy profiles, enthalpy changes, and activation energies to determine whether metal Y is suitable for efficient thermal energy storage and hydrogen-based clean-energy applications.

- **Stage A — Preparation:**  $2\text{Metal (Y)} + \text{H}_2 \rightarrow 2\text{Metal hydride (YH)} \quad \Delta H_r = -112 \text{ KJ}$
- **Stage B — Desorption :**  $\text{Metal hydride (YH)} + \text{H} \rightarrow \text{YH}_2 \quad \Delta H_r = + 92\text{KJ/mol}$

### Task:

- a) With the illustration of energy profile diagrams determine the activation for backward reactions for the two stages involved in the solar energy store. (Stage A transition state energy is 150 KJ/mol and stage B transition state energy is 200KJ/mol)
- b) Suggest applications of enthalpy reaction determinations.

### Item 18:

A research team is studying how the strength of the covalent bond in hydrogen halides affects the energy released when haloalkanes form. They decide to synthesize **2-halo-2-methylpropane** by reacting **2-methylpropene** with two different hydrogen halides: **hydrogen chloride (HCl)** and **hydrogen iodide (HI)**.

The reactions are:

1.  $(\text{CH}_3)_2\text{C}=\text{CH}_2 + \text{HCl} \longrightarrow (\text{CH}_3)_3\text{C}-\text{Cl}$
2.  $(\text{CH}_3)_2\text{C}=\text{CH}_2 + \text{HI} \longrightarrow (\text{CH}_3)_3\text{C}-\text{I}$

The reaction is involving determination of the enthalpy of hydrohalogenation reaction and the path that requires less amount of energy input is preferred.

### Support material:

Students are given the following **average bond energies** (kJ/mol):

Bond	Bond Energy (kJ/mol)
C=C	612
C-C (single)	348
C-H	413
C-Cl	338
C-I	240
H-Cl	432
H-I	299

**Task:**

- Using the bond energies, determine the enthalpy of reaction and explain the factors that are contributing to the differences in the enthalpies of the reactions.
- Suggest suitable mechanism for the reaction

**Item 19:**

At Kampala pharmaceuticals, chemists are evaluating materials that can reduce radioactive iodine exposure to the thyroid gland in nuclear medicine or radiation incidents. One of the most promising compounds is potassium iodide (KI), which is highly soluble in water and can rapidly deliver iodide ions to the thyroid, thereby saturating it and preventing uptake of radioactive isotopes such as iodine-131.

The formation of potassium iodide is represented by the equation:



To assess whether KI is suitable for rapid administration in emergency scenarios, the following thermodynamic data were provided:

- Enthalpy of atomization of K:  $+89 \text{ kJ}\cdot\text{mol}^{-1}$
- Bond dissociation energy of  $\text{I}_2$ :  $+151 \text{ kJ}\cdot\text{mol}^{-1}$
- First ionization energy of K:  $+418 \text{ kJ}\cdot\text{mol}^{-1}$
- Electron affinity of I atom:  $-295 \text{ kJ}\cdot\text{mol}^{-1}$
- Lattice energy of KI:  $-715 \text{ kJ}\cdot\text{mol}^{-1}$
- Enthalpy of formation of KI:  $-329 \text{ kJ}\cdot\text{mol}^{-1}$

**Task:**

As a learner of chemistry;

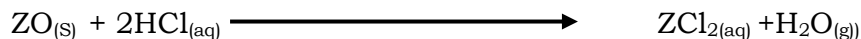
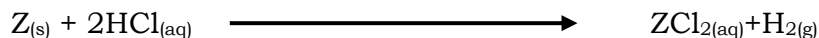
- Using a born-Haber, determine the lattice energy.
- Determine the enthalpy of solution provided that the enthalpy of hydration of KI  $-685 \text{ KJmol}^{-1}$ . Use the value to comment on its possibility to be used given that the salt to be used should have an enthalpy of solution less than  $+30\text{kJ/mol}$ .

## Item 20:

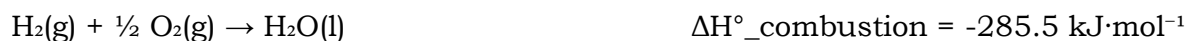
**Aqua Spark Propulsion Ltd.** is currently developing a prototype marine drone powered by metal-oxygen reactions as a clean energy source. The team is investigating the combustion of a diatomic metal element **Z** with oxygen to produce heat energy for propulsion. To evaluate the system's potential, they need to determine the amount of heat released when **1 mole** of metal Z combusts in oxygen to form its corresponding metal oxide:



Since direct laboratory combustion wasn't practical, engineers were are tasked with using Hess's Law and calorimetry to calculate the enthalpy change indirectly. This involved measuring the enthalpies of the following two reactions involving metal Z and its oxide ZO with hydrochloric acid:



Additionally, the standard enthalpy of combustion for hydrogen is provided:



1.5g of metal and 2.0 g of metal oxide Z where separately placed in 50.0 ml of HCl after 1 minute and the variation of temperature with time was recorded. (Z=65, O=16)

### Support material:

Time (seconds)	0.0	30.0	60.0	90.0	120.0	180.0	210.0	240.0	270.0	300.0
Temperature of solution with metal Z	25.0	25.0	25.0	35.0	39.0	42.0	44.0	43.0	43.0	42.0
Temperature of solution with ZO	25.0	25.0	25.0	27.0	30.0	32.0	34.0	35.0	35.0	35.0

### Task:

- Plot a graph of temperature against time and use it to determine the enthalpy of combustion of metal Z.
- Describe a laboratory experiment that can be carried out to determine enthalpy of combustion of a substance.

### Item 21:

A formulation laboratory is testing two possible concentrations of two different **fatty-acid surfactant precursors** to decide which is safe to use during pilot shampoo manufacture. During production the precursor is neutralized with sodium hydroxide, and the heat released can raise the mixture temperature enough to cause discomfort, and burning of the scalp

To model the heat released during neutralisation, learners should use the approximate molar enthalpy of neutralisation for a fatty acid + strong base:  $\Delta H_{\text{neut}} \approx -55.0 \text{ kJmol}^{-1}$

Assume dilute aqueous solutions where the specific heat capacity is  $=4.18 \text{ Jg}^{-1}\text{K}^{-1}$  and solution density  $\approx 1.00 \text{ g}\cdot\text{mL}^{-1}$ .

Two formulation options are tested:

**Formulation A:** Made by reaction of the surfactant precursor with sodium hydroxide of a 1.0 M concentration and this provided a final maximum temperature of 27.39°C and the total volume of solution was 100.0cm<sup>3</sup>(contributed equal volumes).

**Formulation B:** Made by reaction of the 50.0cm<sup>3</sup> surfactant precursor with 50.0cm<sup>3</sup> of a 1.0 M sodium hydroxide solution and hence producing maximum temperature of 29.0°C

During the experiment learners record the **initial temperature as 20.0°C**

#### Task:

- Using the thermometrical data provided, determine the concentration of the fatty acids used and explain the cause of the differences in the heat generated.
- Describe a laboratory experiment to determine the enthalpy of neutralisation of reactions.

## TOPIC 6: Organic Chemistry I

### Item 22:

A pharmaceutical research laboratory working on the development of a novel convulsant agent is studying an organic compound isolated from the Ehrlich pathway, a metabolic route known for producing aromatic amino-acid derivatives. The compound, referred to as Compound Z, must be structurally characterized before it can be modified or incorporated into further drug-development processes.

To determine the elemental composition of Compound Z, the analytical division performs a complete combustion analysis. A precisely weighed sample of Compound A, having a mass of **1.260 g**, is burned in an excess of pure oxygen. The products of combustion are passed through absorbent traps to quantify the carbon and hydrogen content.

After complete combustion, two measurements are recorded:

- The mass of **CO<sub>2</sub> produced is 3.63 g**
- The mass of **H<sub>2</sub>O produced is 0.93 g**

**Task:**

- If the molecular mass of the compound Z was found to be 122g/mol, deduce the molecular formula and the possible isomers.
- Compound Z was found to undergo dehydration in the presence of concentrated sulphuric acid (temperature 180°C). suggest a suitable mechanism and the I.U.P.A.C) name of the product formed.
- The convulsant is found to be belonging to ketone group, describe how it can be synthesized from compound Z.

**Item 23:**

A Compound A is being studied as a substrate for olefin metathesis reactions, which are widely used in industry to rearrange carbon-carbon double bonds and produce valuable chemicals without generating hazardous byproducts. To determine its structure and explore its chemical behavior, a chemist performed several reactions. First, Compound A was halogenated in presence of carbon tetrachloride, absorbing exactly one mole of Br<sub>2</sub> per mole of A to yield compound B. Next, Compound A was subjected to ozonolysis followed by reductive work-up with zinc in water, producing butanal and formaldehyde (CH<sub>2</sub>O).

**Task:**

- With identification of compound A and possible isomers, describe the type of reactions that the homologous series typically undergo.
- Describe the reaction mechanism that resulted into formation of- Compound B, and explain how the reaction might also proceed in the presence of water.

**Item 24:**

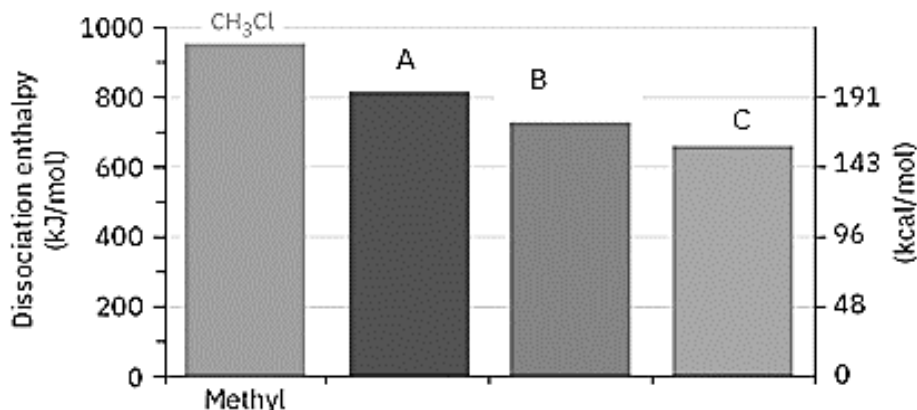
A cosmetics company wants to develop a new fruity top-note for a shower gel. The R&D team decides to make a **fruity ester** as the aroma ingredient. To produce the ester, they require a suitable primary alcohol. The procurement team supplies the synthesis lab with an unknown alkyl bromide (Compound X) and asks the chemists to convert it to the corresponding alcohol, confirm the alcohol's molecular formula, then make and evaluate an ester for fragrance use.

In the lab, Compound X (an alkyl bromide) is heated under reflux with aqueous NaOH to give the corresponding alcohol. To identify the alcohol, the chemists vaporise a measured sample and combust it in the presence of excess oxygen in a closed eudiometric apparatus. The experiment (conducted at STP) gives the following gaseous eudiometry result:

- Volume of alcohol vapour burned: 10.0 cm<sup>3</sup> (measured at STP)
- Volume of CO<sub>2</sub> produced: 40.0 cm<sup>3</sup> (measured at STP)
- (O<sub>2</sub> was supplied in large excess; only CO<sub>2</sub> is collected as gas — water condenses.)

To gain a deeper understanding of the structure of the alkyl bromide, a plot of dissociation enthalpy against substitution pattern for the gas-phase cleavage of alkyl bromides into carbocations was examined. From this analysis, the compound was identified as Compound C.

**Support material:**



**Task:**

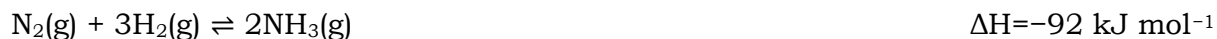
As a learner of chemistry;

- Determine the molecular structure of the alkyl bromide and describe the possible isomers that are exhibited.
- Describe the functional groups of the reactant and products formed in the process and use one of the isomers to suggest a suitable mechanism for the reaction of compound x with sodium hydroxide solution.
- Using the energy profile diagrams for the reaction of sodium hydroxide with possible isomers of compound X, suggest the nature of compound X

## TOPIC 7: Equilibria I

### Item 25:

At Chemhab Fertilizer Plant, ammonia is manufactured on a large scale using the Haber process. The process combines nitrogen (N<sub>2</sub>) obtained from air and hydrogen (H<sub>2</sub>) obtained from natural gas reforming in the presence of an iron catalyst. The overall reaction is:



In the Chemhab plant, the reaction takes place at a pressure of 200 atmospheres and a temperature of 450°C (723 K). At these conditions, the reaction mixture establishes equilibrium, and 15% of the total gaseous mixture is converted into ammonia. After equilibrium is reached, the mixture is cooled to about -20°C, where ammonia liquefies under the high pressure. The liquid ammonia is then separated, while unreacted nitrogen and hydrogen gases are recycled back into the reactor. Through continuous

recycling and liquefaction, the overall yield of ammonia in the entire process reaches about 98%.

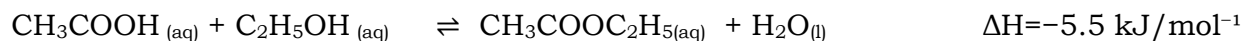
**Task:**

As a learner of chemistry;

- Explain what could have caused the low production of ammonia (15%) per cycle, even though the process operates under high pressure.
- Explain how liquefying ammonia at  $-20^{\circ}\text{C}$  and recycling the unreacted gases helps the plant achieve the 98% overall yield.
- If stoichiometric amounts of nitrogen and hydrogen are introduced into the 20L reactor. Calculate the equilibrium constants ( $K_p$  and  $K_c$ ) for the reaction under the conditions above.
- Suggest any one other benefit of each of the reactants.

**Item 26:**

At ChemEco Industries, engineers are optimizing the production of ethyl acetate ( $\text{CH}_3\text{COOC}_2\text{H}_5$ ) via the reversible esterification reaction: Ethyl acetate is a commonly used solvent in paints, adhesives, coatings, pharmaceuticals, and food flavoring. Because the reaction is slightly exothermic and reversible, the equilibrium limits the per-batch yield.



To improve production efficiency, the plant employs reactive distillation, where water is continuously removed from the reaction mixture: This method combines reaction and separation in a single step, increasing yield and reducing processing time.

**Task:**

- Describe a laboratory procedure that can be carried out to determine the  $K_c$  value for the reaction.
- Explain the effect of increasing pressure on the equilibrium position and rate of attaining equilibrium.
- If the reaction mixture initially contains 1 mol of acetic acid and 1 mol of ethanol, and after reactive distillation 0.6 mol of water is removed, calculate the approximate moles of ethyl acetate formed at equilibrium and hence the value of  $K_c$

**TOPIC 8: Equilibria II**

**Item 27:**

At **EnerChem Fuel Systems**, engineers are testing ways **to** control the vapor pressure of LPG in cylinders. They know that adding a non-volatile solute to the liquid phase lowers the vapor pressure, helping to regulate fuel flow and maintain safety standards.

The initial vapor pressure of the LPG is 2.00 atm at 25°C. For safer operation, the target is to lower the vapor pressure to 1.80 atm.

A researcher dissolves 15.0 g of a non-volatile organic solid (molar mass = 150 g/mol) in 1.0 kg of LPG (assume molar mass of LPG = 44 g/mol).

**Task:**

- Determine whether this amount of solute will achieve the desired vapor pressure lowering.
- Basing on the nature of the organic solid, explain the reason for the result obtained in a).

**Item 28:**

At Arctic Automotive Labs, researchers are designing a winter-ready radiator system. They first dissolve 50.0 g of glucose ( $C_6H_{12}O_6$ ) in 5.0 L of water and observe a certain freezing point depression. To improve efficiency, they now want to use a chloride salt instead. The researchers need to determine how much of the salt must be added to achieve the same freezing point depression as produced by the glucose. The freezing point depression constant for water is  $K_f=1.86\text{ }^\circ\text{C}\cdot\text{kg}/\text{mol}$ . (RMM of the chloride salt is 58.5)

**Task:**

- Describe an experiment using the freezing point depression method on how the Rmm of a given salt can be determined.
- Determine the mass of the salt that will need to be placed in the car radiator and explain why the salt needed less mass than glucose to achieve the same freezing point depression.
- Suggest the limitations for colligative properties.

**Item 29:**

At PharmaTech Labs, engineers are developing a process for manufacturing a heat-sensitive drug. The drug solution contains water as a solvent, and it is essential to maintain a higher boiling point during heating to prevent rapid evaporation and ensure uniform reaction conditions.

To achieve this, a non-volatile solute is added to the water, which elevates the boiling point. This allows the solution to be heated to the required temperature without excessive loss of solvent, maintaining the correct concentration and ensuring consistent product quality.

**Tasks:**

- Explain why adding a non-volatile solute raises the boiling point of a solvent.
- Given 2.0 kg of water and a desired boiling point elevation of 3°C, Determine the mass of a non-electrolyte solute needed. ( $K_b=0.512\text{ }^\circ\text{C}\cdot\text{kg}/\text{mol}$ , RMM of solute 180)

### Item 31:

At **BioLab Research Centre**, scientists are investigating the properties of a freshly extracted enzyme using osmometry. They prepared solutions of the enzyme at different concentrations and the osmotic pressure at different concentrations was determined in a semipermeable osmometer, which is at 25°C.

#### Support material:

<b>Concentration (g/l)</b>	2.0	4.0	6.0	8.0	10.0
<b>Osmotic pressure (Kpa)</b>	0.088	0.180	0.276	0.380	0.490

#### Task:

- Plot a graph of osmotic pressure against concentration and use it to determine the relative molecular mass of the enzyme.
- Explain why the osmotic pressure method is better for determination of the RMM of an enzyme than utilization of freezing point depression or boiling point elevation method.

### Masses of atoms and molecules, accurate relative atomic masses

#### ITEM 32:

At the National Forensic Laboratory, investigators are analyzing soil samples collected from a crime scene where illegal dumping occurred. Soil was also collected from the shoes of **two suspects, David and Roger**, to determine whether either had been present at the site.

The soil contains **element A**, which has two naturally occurring isotopes: **A-69** and **A-70**. The **relative atomic mass (RAM)** of element A in the **crime scene soil** is measured to be **69.8**. Mass spectrometry of the soil samples from the shoes of the two suspects gives the following RAMs:

- David:** RAM = 69.6
- Roger:** RAM = 69.9

#### Task:

- c) Determine the **percentage abundances of the isotopes** in each sample and compare them with the crime scene soil to identify which individual's shoes most likely carried soil from the crime scene.
- d) Suggest possible artefacts in mass spectrometer and how they can be minimized.

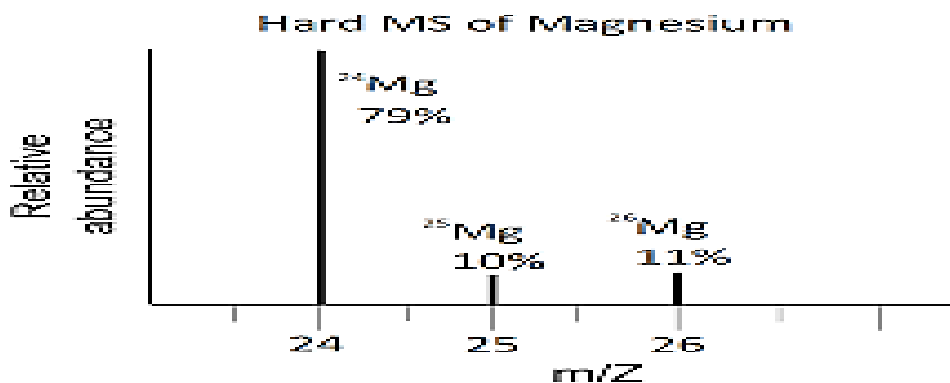
**ITEM 33:**

A pharmaceutical company manager at Aurelia Pharma is finalising the formulation of a new magnesium oxide (MgO) antacid tablet and provides analytical data from the mass spectrometer along with information about stomach acid conditions to determine an appropriate tablet dosage, while also outlining manufacturing limits.

During a typical case of indigestion, the stomach contains 50.0 cm<sup>3</sup> of gastric acid with a concentration of 0.40 mol dm<sup>-3</sup> HCl, and each antacid tablet is to have a maximum total mass of 1.20 g, only part of which can be MgO because the remainder must be reserved for stabilisers, fillers, and binders.

**Support material:**

A magnesium sample is analysed using a mass spectrometer. The spectrum shows three major isotopic peaks:



**Task:**

- c) Explain how the spectral lines of Magnesium were obtained.
- d) Determine the number of tablets that will need to be taken in order to neutralize the acidic stomach. (O= 16, H=1, Cl=35.5)
- e) Suggest three applications of the mass spectrometer.

**END**

**HAPPY HOLIDAYS**