Candidate's Name: _____Trial Questions_____

Signature: _____

Stream.						Personal No.		

Approach to UACE Chemistry Competency Based Exam latest 2026

Introduction

Subject code: 525

Number of papers: Two

Paper 1: Theory (525/1)

Paper 2: Practical (525/2 or 525/3)

Note: Candidates are evaluated using the **KUSVA framework**, which focuses on Knowledge, Understanding, Skills, Values, and Attitudes.

Assessment in the New UACE Curriculum

The end of Cycle assessment for Chemistry will be guided by four assessment objectives focusing on the learner's ability to:

1. *Demonstrate understanding of **atomic and molecular structures, periodic trends and patterns of chemical reactivity** across the Periodic Table.(AO1)*
2. *Analyse the **structure, reactivity, and transformation pathways of organic compounds to predict chemical behaviour, explain natural processes, and propose solutions** in real-world and innovative chemical contexts.(AO2)*
3. *Apply fundamental physical and chemical principles to analyse, model, and predict the behaviour of chemical systems and their transformations under different conditions. (AO3)*
4. *Apply principles of chemical and physical equilibria and electrochemistry to interpret, predict and evaluate the behaviour of chemical systems in industrial and real-world contexts.(AO4)*

Chemistry Paper 1 Structure(Theory P525/1)

All questions are scenario-based.

It is a theory examination lasting **2 hours 45 minutes**.

The paper is divided into **two sections:** A and B.

Section A

Consists of **two compulsory questions**, each with specified tasks.

Items 1 and 2 mainly assess:

- *Application of quantitative chemical principles to analyse, model and predict the amounts of substances, energy changes and reaction rates in chemical systems under varying conditions. (AO3)*

- *Application of the principles of chemical and physical equilibria and electrochemistry to interpret, predict and evaluate the behaviour of chemical systems in industrial and real-world contexts.(AO4)*

Section B

Consists of **four questions** arranged into **Part I** and **Part II**.

Candidates are required to answer **one question from each part**.

Part I (Items 3 & 4) mainly assesses:

- *Understanding of **atomic and molecular structures, periodic trends and patterns of chemical reactivity** across the Periodic Table.(AO1)*

Part II (Items 5 & 6) mainly assesses:

- *Analysis of the **structure, reactivity, and transformation pathways** of organic compounds to **predict chemical behaviour, explain natural processes, and propose solutions** in real-world and innovative chemical contexts.*

Answers are written in the answer booklet(s) provided.

Each assessment item is based on a different competency construct, uses a unique scenario, and is drawn from specific syllabus topics.

Guidelines for Interpreting a Scenario

The provided guidelines offer a structured approach for candidates to effectively interpret and respond to examination scenarios.

To ensure a comprehensive and accurate response, follow these steps:

1. **Read Thoroughly:** Always read the scenario more than once to catch all details.
2. **Identify Context:** Determine the specific topics and concepts being examined.
3. **Highlight Key Information:** Underline keywords that offer hints or specific requirements for your presentation.
4. **Plan Your Response:** Create a logical flow based on the assessment criteria relevant to that specific item.
5. **Execute:** Organise your thoughts and present your final response clearly.

Areas of Assessment

Item 1 : Appreciates stoichiometry, thermochemistry, and reaction kinetics to predict chemical reactions in daily life and industry.

Basis of Assessment

The assessment of Item 1 is based on learners' ability to apply stoichiometry, thermochemistry, and reaction kinetics in predicting and explaining chemical reactions in both daily life and industrial contexts.

Assesable topics include;

1. Moles and equations
2. Thermochemistry
3. Reaction Kinetics

Criteria of Assessment

Basis of Assessment	Criteria of Assessment	Code	Score
A. Understanding of scientific principles	At least two well-explained factors / laws / principles / theories (T + Te)	A1	04
	One well-explained factor / law / principle / theory (T + Te)	A2	03
	No well-explained factor / law / principle / theory	A0	00
B. Analysis, interpretation(Graphical, Calculation or daigram) and conclusion	Complete data analysis, interpretation and conclusion (Ca + Ci + Cc)	B1	03
	Partial analysis and interpretation (Ca + Ci)	B2	02
C. Application and recommendation	Well-explained application and valid recommendation (Ca + Cr)	C1	02
	Either application or recommendation well explained	C2	01
	No valid application or recommendation	C0	00
Note: The scores above are just sample scores.			

ITEM 1

Following heavy rainfall near a former welding and metal recycling site, residents complained of a rotten egg smell and occasional fire out breaks from waste dumps. Environmental inspectors identified two possible sources of contamination: aluminium sulfide (Al_2S_3) formed from corroded aluminium waste and sulphur materials, and calcium carbide (CaC_2) left behind from past welding activities.

Since both substances react with water to produce gases that may affect human health and the environment, the inspection team was provided with thermochemical data to determine which material poses the lower environmental risk and should be prioritized for safe disposal.

Aluminium sulfide (kJ/mol)	Calcium carbide (kJ/mol)
$2Al(s)+3S(s)\rightarrow Al_2S_3(s)= -724.0$	$Ca(s)+2C(s)\rightarrow CaC_2(s)= -60$
$Al(s)\rightarrow Al(g)= +326.4$	$Ca(s)\rightarrow Ca(g)=+178$
$Al(g)\rightarrow Al^+(g)+e^-=+577.4$	$Ca(g)\rightarrow Ca^+ + e^- =+590$
$Al^+(g)\rightarrow Al^{2+}(g)+e^-=+1816.6$	$Ca^+\rightarrow Ca^{2+}+e^-=+1145$
$Al^{2+}(g)\rightarrow Al^{3+}(g)+e^-=+2740$	$2C(s)\rightarrow 2C(g)=+1434$
$S(s)\rightarrow S(g)=+278.8$	$2C(g)\rightarrow C_2(g)=-614$
$S(g)+e^-\rightarrow S^-(g)=-200.4$	$C_2(g)+e^-\rightarrow C_2^-=-315$
$S^-+e^-\rightarrow S^{2-}(g)=+334.1$	$C_2^-(g)+e^-\rightarrow C_2^{2-}(g)=+410$
$Al^{3+}(g)\rightarrow Al^{3+}(aq)=-4690$	$Ca^{2+}(g)\rightarrow Ca^{2+}(aq)=-505$
$S^{2-}(g)\rightarrow S^{2-}(aq)=-1700$	$C_2^{2-}(g)\rightarrow C_2^{2-}(aq)=-2900$

Authorities seek guidance on the issue and therefore, you have been contacted for help.

Task

As a learner of Chemistry:

a. Construct Born–Haber cycle for the formation of:
   i. Aluminium sulfide (Al_2S_3)
   ii. Calcium carbide (CaC_2)

b. Using the cycles, calculate:
   i. The lattice energy hence, enthalpy of solution of each compound.

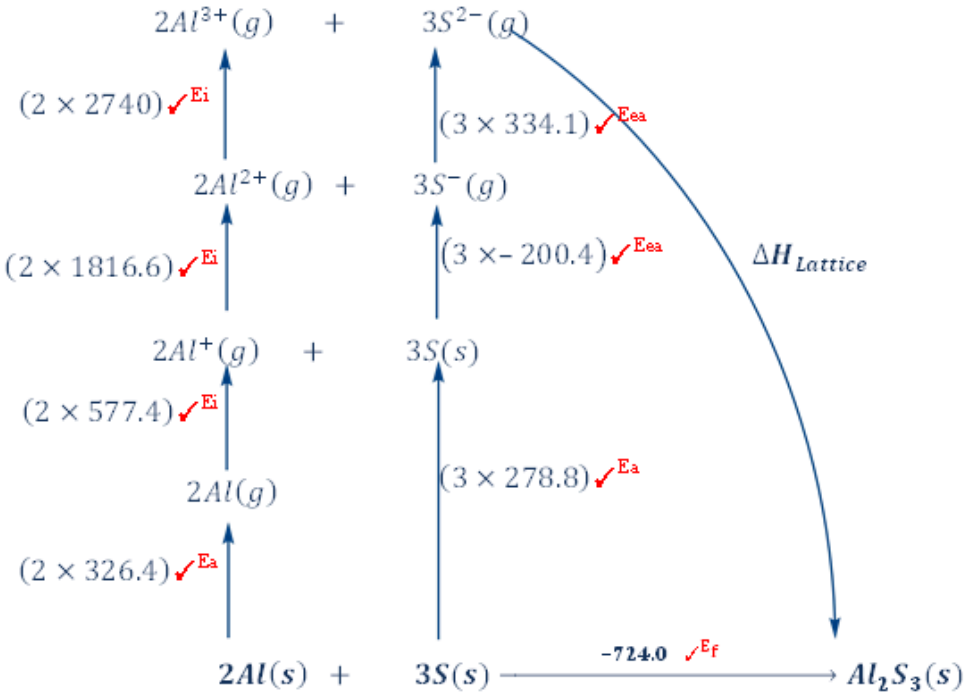
c. i. Advise the environmental team which compound presents less risk to the environment, identifying at least two similarities and two differences.
   ii. State one industrial use of the compound recommended.

d. Explain the environmental effects of the gas produced when the recommended compound reacts with water and suggest suitable mitigation measures.

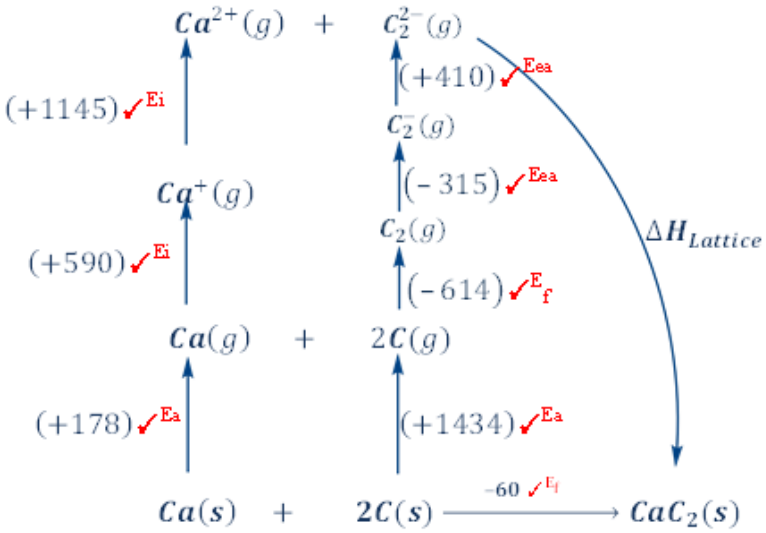
Expected response

ITEM 1

(a) (i) Formation of aluminium sulfide



(ii) Formation of calcium carbide



$$4E_a + 5E_i + 3E_f + 4E_{ea} = E_4 = 06\ scores$$

$$3E_a\ only = E_3 = 05\ scores$$

$$2E_a\ only = E_2 = 03\ scores$$

$$1E_a\ only = E_1 = 01\ score$$

$$0E_a = E_0 = 00\ scores$$

(b) lattice energy and enthalpy of solution of;

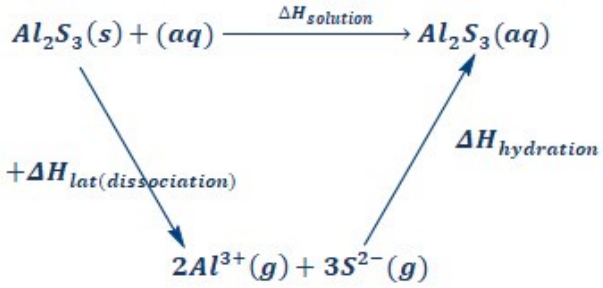
(i) aluminium sulfide.

$$\Delta H_{\text{Lat}} = -724.0 - \Big[2 \times 326.4 + 3 \times 278.8 + 2 \times 577.4 + 2 \times 1816.6 + 3 \times (-200.4) + 2 \times 2740 + 3 \times 334.1\Big]$$ ✓ C_A

$$\Delta H_{\text{Lat}} = -724.0 - 12158.3$$ ✓ C_A

$$\Delta H_{\text{Lat(formation)}} = -12882.3 \text{ kJ mol}^{-1}$$ ✓ C_A

For solution of $Al_2S_3(s)$



$$\Delta H_{\text{solution}} = \Delta H_{\text{lat(dissociation)}} + \Delta H_{\text{hydration}}$$

$$\therefore \ \Delta H_{\text{solution}} = \Delta H_{\text{lattice}} + \left[2\Delta H_{\text{hyd}}\left(\text{Al}^{3+}\right) + 3\Delta H_{\text{hyd}}\left(\text{S}^{2-}\right)\right]$$

$$= 12882.3 + [2(-4690) + 3(-1700)]$$ ✓ C_A

$$= 12882.3 - 14480$$ ✓ C_A

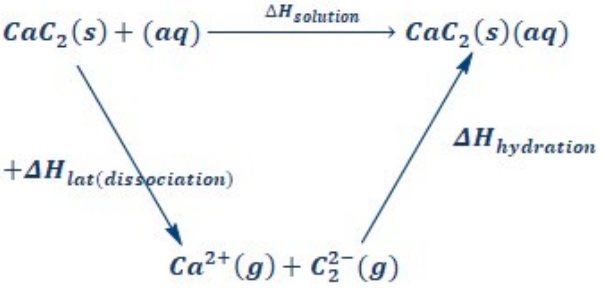
$$\Delta H_{\text{solution}} = -1597.7 \text{ kJ mol}^{-1}$$ ✓ C_A

(ii) calcium carbide.

$$\Delta H_{\text{Lat}} = -60.0 - \Big[178 + 590 + 1434 - 614 - 315410\Big]$$ ✓ C_A

$$\Delta H_{\text{Lat}} = -60.0 - 313822$$ ✓ C_A

$$\Delta H_{\text{Lat(formation)}} = -313882 \text{ kJ mol}^{-1}$$ ✓ C_A



For calcium carbide, CaC_2, the enthalpy of solution is given by:

$$\Delta H_{\text{solution}} = \Delta H_{\text{lat(dissociation)}} + \Delta H_{\text{hydration}}$$

$$\therefore\ \Delta H_{\text{solution}} = \Delta H_{\text{lattice}} + [-505 + (-2900)] \quad \checkmark C_A$$

$$= 313882 + [-3405]$$

$$= 313882 - 3405 \quad \checkmark C_A$$

$$= +310477\ \text{kJ mol}^{-1} \quad \checkmark C_A$$

$$12C_A = C_6 = 06\ scores$$

$$10C_A\ only = C_5 = 05\ scores$$

$$8C_A\ only = C_4 = 04\ scores$$

$$6C_A\ only = C_3 = 03\ scores$$

$$4C_A\ only = C_2 = 02\ scores$$

$$2C_A\ only = C_1 = 01\ score$$

$$1C_A\ or\ 0C_A = C_0 = 00\ scores$$

(c)(i) Evaluation and advice (which substance has less environmental effects)

Similarities

*1. Both are **ionic compounds**✓E_s formed from metal and non-metal elements.*
*2. Both have **strong lattice energies**✓E_s due to ionic bonding.*
*3. Both **react with water**✓E_s to produce gases.*
*4. Both pose **environmental risks when left in abandoned waste sites.**✓E_s*

However

Differences

*1. CaC_2 has **very large positive enthalpy of solution (+310,477 kJ mol⁻¹), showing extreme instability** in water while Al_2S_3 has a **negative enthalpy of solution (−1,597.7 kJ mol⁻¹), indicating more stable** dissolution process.✓E_d*
*2. CaC_2 produces **ethyne (C_2H_2), a highly flammable** but less toxic gas while Al_2S_3 produces **hydrogen sulfide (H_2S), a highly toxic and poisonous gas.**✓E_d*
*3. CaC_2 mainly causes **physical hazards (fire/explosion)** but less long-term chemical poisoning, Al_2S_3 leads to **toxic sulfide pollution in soil and air.**✓E_d*

Conclusion (Advice)

Calcium carbide is preferred for controlled industrial use because its hazards are mainly physical (flammability and explosion risk), while aluminium sulfide produces highly toxic hydrogen sulfide gas that causes severe environmental and health damage. ✓C_a

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(ii) Other industrial uses of calcium carbide (CaC_2)

*1. Used in the **production of acetylene (ethyne)**✓U_i gas for welding and metal cutting.*
*2. Used in manufacture of **organic chemicals such as plastics (PVC production via acetylene route).**✓U_i*
*3. Used in **carbide lamps for lighting**✓U_i in mining and underground operations.*
*4. Used in **fruit ripening processes through controlled release of ethylene.**✓U_i*

5. *Used as a **reducing agent in some metallurgical processes.*** ✓U_i

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$$2E_s + 2E_d + 2U_i \ = E_3 \ = \ 05 \ scores$$

$$2E_s + 2E_d \ only \ = E_2 \ = \ 04 \ scores$$

$$2U_i \ only \ \text{OR} \ 2E_s + 2U_i \ only \ \text{OR} \ 2E_d + 2U_i \ only = \ E_1 \ = \ 02 \ scores$$

$$2E_s \ only \ = E_0 \ = \ 00 \ scores$$

$$2E_d \ only \ = E_0 \ = 00 \ scores$$

(d) Environmental impacts of gas released from CaC_2 + water and mitigation

*Produces ethyne gas (C_2H_2) which is highly flammable and can form **explosive mixtures*** ✓D_i *with air hence can lead to fire outbreaks thus **death and destruction of property.*** ✓D_e. *Mitigated by **storing calcium carbide in dry, sealed containers*** ✓D_m *away from moisture fire sources* ✓D_i

*Burning ethyne produces carbon monoxide and soot if combustion is incomplete. This **reduces air quality*** ✓D_i *and **affects respiratory health*** ✓D_e. *Mititigated by ensuring complete combustion in controlled industrial burners with **proper oxygen supply*** ✓D_m.

*Leakage of ethyne gas in confined spaces can cause **suffocation and dizziness*** ✓D_i *since workers may be exposed to fire risk in **poorly ventilated areas*** ✓D_e. *Mitigated by providing **good ventilation and gas detection systems*** ✓D_m *in industrial areas.*

*Formation of calcium hydroxide increases **soil pH*** ✓D_i. *This can cause **damage to crops and reduce soil fertility*** ✓D_e. *Mitigated by **neutralizing affected soils using controlled acid treatment*** ✓D_m.

$$1D_i + 1D_e + 1d_m \ = D_3 \ = \ 03 \ scores$$

$$1D_i + 1D_e \ only \ \text{OR} \ 1D_i + 1d_m \ only = \ E_1 \ = \ 02 \ scores$$

$$Otherwise \ = E_0 \ = \ 00 \ scores$$

Item 2 : Appreciates equilibria and electrochemical systems to explain reversible and redox processes and their importance in life

Basis of Assessment

The assessment of Item 2 is based on learners' ability to apply principles of chemical equilibrium and electrochemistry in explaining reversible reactions, redox processes, and their applications in real life and industrial systems.

Assesable topics include;

1. Equilibria I
2. Equilibria II
3. Electrochemistry

Criteria of Assessment

Basis of Assessment	Criteria of Assessment	Code	Score
A. Understanding of scientific principles	At least two well-explained equilibrium or electrochemical principles (T + Te)	A1	04
	One well-explained equilibrium or electrochemical principle (T + Te)	A2	03
	No well-explained equilibrium or electrochemical principle	A0	00
B. Analysis, interpretation (Graphical, Calculation or diagram) and conclusion	Complete analysis, interpretation and conclusion of equilibrium or electrochemical data (Ca + Ci + Cc)	B1	03
	Partial analysis and interpretation of equilibrium or electrochemical data (Ca + Ci)	B2	02
C. Application and recommendation	Well-explained application and valid recommendation of equilibrium or electrochemical concepts (Ca + Cr)	C1	02
	Either application or recommendation well explained	C2	01
	No valid application or recommendation	C0	00
Note: The scores above are just sample scores.			

Questions

ITEM 2

Gabeco SA is a leading sulphuric acid producer in Uganda. During a test, 2.00 moles of sulphur dioxide (SO_2) and 1.00 mole of oxygen (O_2) were introduced into a 4.50 dm^3 converter at 450°C and 2.00 atm. The gases reached equilibrium according to the reaction:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g), \quad \Delta H = -196\,\text{kJ mol}^{-1}$$

At equilibrium, 60% of sulphur dioxide was converted to sulphur trioxide.

The sulphur trioxide produced was absorbed to form sulphuric acid. Some effluents containing sulphate ions polluted a nearby water source. To remove the sulphate ions, barium chloride solution was added, forming insoluble barium sulphate ($BaSO_4$).

A saturated solution of barium sulphate at 25°C was found to contain 1.0×10^{-5} mol dm^{-3} of Ba^{2+} ions. The treated water was later mixed with 0.10 mol dm^{-3} sodium sulphate (Na_2SO_4) to

investigate the common ion effect and precipitation.

TASK

As a learner of Chemistry, assist the company to:

a. Determine the equilibrium constant, Kp, for the reaction.
b. Explain how the equilibrium is affected by:
    - increasing SO_2 concentration
    - increasing pressure
    - increasing temperature
    - use of a catalyst
c. Calculate the solubility product, Ksp, of barium sulphate ($BaSO_4$).
d. Calculate the new solubility of barium sulphate when sodium sulphate is added.
e. Explain how addition of sodium sulphate affects removal of sulphate ions from contaminated water.
f. State any other applications of solubility product principles.
g. Explain any environmental impact arising from either the gaseous or aqueous equilibria and suggest methods of reducing the impact.

Expected response

ITEM 2

Determination of Kp and extent of reaction

Equation :	$2SO_2(g) +$	$O_2(g) \rightleftharpoons$	$2SO_3(g)$
Initial moles :	2.00	1.00	0
Moles reacted / formed :	$2x$	x	$2x$
Equilibrium moles :	$2 - 2x$	$1 - x$	$2x$

✓ C_A

60% of SO_2 reacted: $2x = 0.60 \times 2.00 \Rightarrow x = 0.60$ ✓ C_A

Equilibrium moles :

$SO_2 = 2 - 2(0.60) = \mathbf{0.80}$

$O_2 = 1 - (0.60) = \mathbf{0.40}$

$SO_3 = 2(0.60) = \mathbf{1.20}$

✓ C_A

Total moles at equilibrium: $= 0.80 + 0.40 + 1.20 = \mathbf{2.40}$ ✓ M_l

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Since $P_{Total} = 2.00\ atm$, $\quad P_i = \dfrac{n_i}{n_{total}} \times 2.00$

$$P_{SO_2} = \left(\frac{0.80}{2.40} \times 2\right) = \mathbf{0.667\ atm}$$
$$P_{O_2} = \left(\frac{0.40}{2.40} \times 2\right) = \mathbf{0.333\ atm}$$
$$P_{SO_3} = \left(\frac{1.20}{2.40} \times 2\right) = \mathbf{1.00\ atm}$$

✓ P_r

Using expression: $K_p = \frac{(P_{SO_3})^2}{(P_{SO_2})^2(P_{O_2})}$

$$K_p = \frac{(1.00)^2}{(0.667)^2(0.333)}$$

$$\therefore\ K_p \approx \mathbf{6.75\ atm^{-1}}$$

✓ K_p

$3C_A + M_l + P_r + K_p = C_2 = 03$ scores

$2C_A = C_1 = 02$ scores

$2C_A$ (or partial) $= C_0 = 00$ scores

Effect on equilibrium (position, equilibrium constant value and rate of attainment of equilibrium)

Effect of increasing SO_2 concentration

Increasing the concentration of sulphur dioxide introduces more reactant molecules into the reaction mixture. The equilibrium therefore ***shifts from left to right*** ✓ P_i *so as to consume the excess sulphur dioxide and produce more sulphur trioxide, in accordance with Le Chatelier's principle. The* ***value of the equilibrium constant (K_p) remains unchanged*** ✓ K_i *because changing concentration does not affect the equilibrium constant; only temperature does. The* ***rate of attainment of equilibrium increases*** ✓ R_i *because the higher concentration of sulphur dioxide increases the frequency of effective collisions between sulphur dioxide and oxygen molecules.*

Effect of increasing pressure

The reaction involves a ***decrease in the number of gaseous molecules (3 moles → 2 moles)****. Increasing the pressure therefore* ***shifts the equilibrium from left to right*** ✓ P_i*, favouring the formation of sulphur trioxide because the system tends to reduce the applied pressure by forming fewer gaseous molecules. The* ***value of K_p remains unchanged*** ✓ K_i *since pressure changes do not alter the equilibrium constant. The* ***rate of attainment of equilibrium increases*** ✓ R_i *because gas molecules are compressed into a smaller volume, resulting in more frequent effective collisions.*

Effect of increasing temperature

*Since the forward reaction is **exothermic ($\Delta H = -196$ kJ mol^{-1})**, increasing temperature supplies additional heat to the system. Consequently, the equilibrium **shifts from right to left** ✓ P_i to absorb the added heat, favouring the endothermic reverse reaction and reducing the yield of sulphur trioxide. The **value of K_p decreases** ✓ K_i because increasing temperature decreases the equilibrium constant for an exothermic reaction. The **rate of attainment of equilibrium increases** ✓ R_i because molecules possess greater kinetic energy, leading to more frequent and energetic effective collisions.*

Effect of a catalyst

*Introducing a catalyst such as **vanadium(V) oxide (V_2O_5)** provides an alternative reaction pathway with a lower activation energy. The catalyst has **no effect on the position of equilibrium** ✓ P_i because it speeds up both the forward and reverse reactions equally. It also has **no effect on the value of K_p** ✓ K_i since the equilibrium constant depends only on temperature. However, the catalyst **increases the rate of attainment of equilibrium** ✓ R_i by lowering the activation energy, allowing equilibrium to be established more rapidly.*

$$4P_i + 4K_i + 4R_i \ = \ E_3 \ = \ 04 \ scores$$

$$3P_i + 4K_i + 4R_i \ / \ 4P_i + 3K_i + 4R_i \ / \ 4P_i + 4K_i + 3R_i \ = \ E_2 \ = \ 03 \ scores$$

$$4P_i \ OR \ 4K_i \ OR \ 4R_i \ Only \ = E_1 = \ 02 \ scores$$

$$Otherwise = C_0 = 00 \ scores$$

Solubility product (K_{sp}) of barium sulphate

$$BaSO_4(s) \rightleftharpoons Ba^{2+}(aq) + SO_4^{2-}(aq)$$

Since the saturated solution contains 1.0×10^{-5} mol dm^{-3} of Ba^{2+},

$$\therefore \text{Solubility of } BaSO_4 = \mathbf{1.0 \times 10^{-5} \ mol \ dm^{-3}} \quad ✓ \ C_A$$

At equilibrium

$$[Ba^{2+}] = [SO_4^{2-}] = 1.0 \times 10^{-5} \ mol \, dm^{-3}$$

$$K_{sp} = [Ba^{2+}][SO_4^{2-}]$$

$$K_{sp} = (1.0 \times 10^{-5})(1.0 \times 10^{-5})$$

$$\therefore K_{sp} = \mathbf{1.0 \times 10^{-10} \ mol^2 \ dm^{-6}} \quad ✓ \ C_A$$

$$2C_A \ = \ C_2 \ = \ 02 \ scores$$

$$1C_A = C_1 = 01 \; score$$

$$0C_A = C_0 = 00 \; scores$$

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i. **Calculate the new solubility of barium sulphate when 0.10 mol dm⁻³ sodium sulphate is added.**

$$BaSO_4(s) \rightleftharpoons Ba^{2+}(aq) + SO_4^{2-}(aq)$$

$$\text{From (c), } \; K_{sp} = 1.0 \times 10^{-10} \qquad \checkmark C_B$$

Since sodium sulphate is a strong electrolyte, it dissociates completely

$$Na_2SO_4(aq) \rightarrow 2Na^+(aq) + SO_4^{2-}(aq)$$

$$\therefore [SO_4^{2-}] = 0.10 \text{ mol dm}^{-3} \qquad \checkmark C_B$$

Let the new solubility of $BaSO_4 = s$

$$\therefore [Ba^{2+}] = s, \qquad [SO_4^{2-}] = 0.10 + s$$

$$K_{sp} = [Ba^{2+}][SO_4^{2-}]$$

$$1.0 \times 10^{-10} = s(0.10 + s)$$

$$\because s \ll 0.10, \therefore 0.10 + s \approx 0.10 \qquad \checkmark C_B$$

$$1.0 \times 10^{-10} = 0.10s$$

$$s = \frac{1.0 \times 10^{-10}}{0.10} = \mathbf{1.0 \times 10^{-9} \; mol \, dm^{-3}} \qquad \checkmark C_B$$

$$2C_A + 4C_B = C_2 = 04 \text{ scores}$$

$$2C_A + 2C_B \; OR \; 4C_B = C_1 = 02 \text{ scores}$$

$$1C_B \; OR \; 1C_A + 1C_B = C_0 = 00 \text{ scores}$$

Explanation of the common ion effect and precipitation of barium sulphate

Sodium sulphate is a ***strong electrolyte hence fully ionises*** $\checkmark F_i$ *to produce sodium ions and sulphate ions.*

$$Na_2SO_4(aq) \rightarrow 2Na^+(aq) + SO_4^{2-}(aq)$$

The additional sulphate ions ***increase the concentration of SO_4^{2-} ions already present in solution (common ion)*** $\checkmark F_i$.

According to Le Chatelier's principle, the increased sulphate ion concentration ***suppresses the dissociation of barium sulphate and shifts the equilibrium to the left*** ✓ F_i.

$$BaSO_4(s) \rightleftharpoons Ba^{2+}(aq) + SO_4^{2-}(aq)$$

As a result, ***more $BaSO_4$ is formed as a solid precipitate while its solubility decreases*** ✓ F_r.

The increased precipitation ***removes sulphate ions from the contaminated water, making the water less polluted*** ✓F_r.

$$3F_i + 2F_r = F_3 = 03 \text{ scores}$$

$$3F_i + 1F_r = F_2 = 02 \text{ scores}$$

$$2F_i + 1F_r = F_1 = 01 \text{ score}$$

$$Only\ 3F_i\ OR\ Only\ 2F_r\ OR\ 1F_i + 1F_r = F_0 = 00 \text{ scores}$$

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ii. **Applications of solubility product principles**

Qualitative analysis of ions: ✓U_i *Uses differences in* ***solubility products of ionic compounds*** *to* ***selectively precipitate and identify cations or anions in mixtures.*** ✓U_e

Water treatment: ✓U_i *Uses precipitation reactions to* ***remove undesirable ions such as sulphate, fluoride and heavy metal ions from contaminated water.*** ✓U_e

Manufacture of pharmaceuticals: ✓U_i *Uses controlled precipitation based on* ***solubility product principles*** *to* ***prepare highly pure medicinal compounds.*** ✓U_e

Recovery of valuable metals: ✓U_i *Uses selective precipitation to* ***separate and recover metals such as silver, lead and copper from ores or industrial wastes.*** ✓U_e

Prevention of boiler scale: ✓U_i *Applies solubility product principles to* ***control precipitation of sparingly soluble salts that form scales in boilers and pipelines.*** ✓U_e

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$$\text{Only } 2U_i + 2U_e = U_2 = 02 \text{ scores}$$

$$\text{Only } 2U_i \text{ OR Only } 1U_i + 1U_e = U_1 = 01 \text{ score}$$

$$\text{Only } 1U_i \text{ OR Otherwise} = U_0 = 00 \text{ scores}$$

Environmental impacts and mitigation of the Contact Process and sulphate-containing effluents

Emission of ***sulphur dioxide gas (SO_2)*** ✓D_i *causes* ***acid rain, respiratory irritation and damage to vegetation*** ✓D_e. *This can be reduced by* ***absorbing SO_2 in alkaline scrubbers***

before release into the atmosphere ✓D_m.

Emission of ***sulphur trioxide gas (SO_3)*** ✓D_i *reacts with atmospheric moisture to form* ***sulphuric acid mist, leading to acid rain and corrosion of buildings*** ✓D_e. *This is controlled by* ***efficient absorption of SO_3 into concentrated sulphuric acid and proper maintenance of absorption towers*** ✓D_m.

Discharge of ***sulphate-containing industrial effluents*** ✓D_i *causes* ***water pollution and may harm aquatic organisms by altering water quality*** ✓D_e. *This can be minimized by* ***precipitating sulphate ions as insoluble barium sulphate before wastewater is discharged*** ✓D_m.

Release of ***acidic wastewater containing sulphuric acid*** ✓D_i *lowers the* ***pH of rivers and lakes, damaging aquatic ecosystems and increasing corrosion*** ✓D_e. *This is controlled by* ***neutralising the effluent with suitable alkalis such as calcium hydroxide before discharge*** ✓D_m.

Only $2D_i + 2D_e + 2D_m = D_2 = 02$ scores

$1D_i + 1D_e + 1D_m$ OR $2D_i + 2D_e$ OR $2D_i + 2D_m = D_1 = 01$ scores

Only $2D_i + 0D_e + 0D_m = D_0 = 00$ score

Only $1D_i + 0D_e + 0D_m = D_0 = 00$ scores

ITEM 2

An Agro Chemical Industry (U) Ltd produces ammonia used in fertilizers and industrial cleaning products. During production, 2.00 moles of nitrogen gas and 6.00 moles of hydrogen gas were mixed in a 5.00 dm³ reactor at 200 atm and 450°C. The gases were allowed to reach equilibrium according to the reaction:

$$\mathrm{N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)} \qquad \Delta H = -92\ \mathrm{kJ\,mol^{-1}}$$

After equilibrium was reached, analysis showed that the mixture contained 30% ammonia by volume.

The ammonia produced was dissolved in 750 cm³ of water to prepare an aqueous ammonia solution. Equal volumes of 250 cm³ each of this ammonia solution and 2.0 M ammonium chloride solution were mixed to prepare an ammonia–ammonium chloride buffer.

During quality control, two separate 10.0 cm³ portions of the buffer were tested. To one portion, 10.0 cm³ of 2.0 M hydrochloric acid was added. To the other portion, 10.0 cm³ of 2.0 M sodium hydroxide was added. Management would like to assess the pH and buffering action of the solution before it is used in production. You have been contacted for assistance.

Task

As a learner of Chemistry, help the company to;

a. Determine the equilibrium constant, K_p, and predict the extent of the gaseous reaction.
b. Explain how the equilibrium system is affected by:
    i. Passing equilibrium mixture through hydrochloric acid.
    ii. Introducing a catalyst.
    iii. Increasing temperature.
    iv. Increasing pressure.
c. Calculate the pH of the ammonia solution obtained. (Given: $K_b = 1.8 \times 10^{-5}\,\text{mol}\,\text{dm}^{-3}$).
d. Explain how the buffer system works during the cleaning processes.
e. Calculate the change in pH when:
    i. 10.0 cm³ of 2.0 mol dm⁻³ HCl is added. (Given: $K_b = 1.8 \times 10^{-5}$)
    ii. 10.0 cm³ of 2.0 mol dm⁻³ NaOH is added. (Given: $K_b = 1.8 \times 10^{-5}$)
f. Suggest the applications of buffers.
g. Explain the environmental impacts of the gaseous or aqueous equilibria and their mitigations.

Expected Response

Determination of Kp and extent of reaction

Equation :	$N_2(g) +$	$3H_2(g) \rightleftharpoons$	$2NH_3(g)$
Initial moles :	2.00	6.00	0
Moles reacted / formed :	x	$3x$	$2x$
Equilibrium moles :	$2 - x$	$6 - 3x$	$2x$

✓ C_A

$$\text{equ. moles: } = (2 - x) + (6 - 3x) + 2x = \mathbf{(8 - 2x)} \quad \checkmark C_A$$

$$\text{At equ. \% } NH_3 = 30\%: \therefore \frac{2x}{8 - 2x} \times 100 = 30 \Rightarrow x = \mathbf{0.923} \quad \checkmark C_A$$

$$N_2 = (2 - 0.923) = \mathbf{1.077}\,; H_2 = (6 - 3(0.923)) = \mathbf{3.231}$$
$$NH_3 = 2(0.923) = \mathbf{1.846}\,; \text{Total moles} = \mathbf{6.154}$$

✓ M_l

$$\text{Since } P_{Total} = 200\,atm\,; \text{Partial pressure } P_i = \frac{n_i}{n_{total}} \times 200$$

$$P_{N_2} = \left(\tfrac{1.846}{6.154} \times 200\right) = \mathbf{35.0\ atm}$$
$$P_{H_2} = \left(\tfrac{3.231}{6.154} \times 200\right) = \mathbf{105.0\ atm}$$
$$P_{NH_3} = \left(\tfrac{1.846}{6.154} \times 200\right) = \mathbf{60.0\ atm}$$

✓ P_r

Using expression: $K_p = \frac{(P_{NH_3})^2}{P_{N_2}(P_{H_2})^3} \Rightarrow K_p = \frac{60^2}{35(105)^3}$

$\therefore\ K_p = 9.0 \times 10^{-5}\,\text{atm}^{-2}$

} ✓ K_p

$$3C_A + M_l + P_r + K_p = C_2 = 03\ scores$$

$$3C_A\ only = C_1 = 02\ scores$$

$$2C_A = C_0 = 00\ scores$$

Effect on equilibrium(position, constant value and rate of attainment of equilibrium)

Effect of adding HCl

*The concentration of ammonia **decreases** as it reacts with the hydrochloric acid to form ammonium chloride. Therefore, more nitrogen react with hydrogen in order to **replace the ammonia** being removed, so as to **keep the equilibrium constant value the same** ✓ K_i. Equilibrium therefore **shifts from left to right** ✓ P_i and equilibrium constant value remains unchanged. The **rate of attainment of equilibrium decreases** ✓ R_i since there is a decrease in the number of particles in the reaction vessel.*

Effect of catalyst

*Introducing a catalyst(finely divide iron), has **no effect on position** ✓ P_i of equilibrium and **no effect on the value of equilibrium constant** ✓ K_i but only alters the rate of backward and forward reaction equally. A catalyst therefore **increases the rate of attainment of equilibrium** ✓ R_i by decreasing the activation energy needed for hydrogen and nitrogen to combine producing more and more ammonia gas.*

Effect of temperature increase

*Since the reaction is **exothermic (ΔH = −92 kJ/mol)**, increasing temperature adds heat. The equilibrium **shifts from right to the left** ✓ P_i to absorb the added heat. The **value of Kp decreases** ✓ K_i, because for exothermic reactions, increasing temperature reduces the equilibrium constant. The **rate of attainment of equilibrium increases** ✓ R_i, because higher temperature gives molecules more kinetic energy, increasing collision frequency and energy, though less NH3 is produced at equilibrium.*

Effect of pressure increase

*The reaction involves a **decrease in gas molecules (4 → 2)**. Increasing pressure **shifts the equilibrium from left to the right** ✓ P_i, favouring the formation of SO3, to reduce total pressure. The **value of Kp remains constant** ✓ K_i, because pressure changes do not affect Kp (only temperature does). The **rate of attainment of equilibrium increases** ✓ R_i,*

because higher pressure increases the frequency of molecular collisions, speeding up both forward and reverse reactions.

$$4P_i + 4K_i + 4R_i \; = \; E_3 \; = \; 04 \; scores$$

$$3P_i + 4K_i + 4R_i \; OR \; 4P_i + 3K_i + 4R_i \; OR \; 4P_i + 4K_i + 3R_i \; = \; E_2 \; = \; 03 \; scores$$

$$4P_i \; OR \; 4K_i \; OR \; 4R_i \; Only = \; E_0 \; = \; 02 \; scores$$

$$Otherwise = \; C_0 \; = \; 00 \; scores$$

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pH of ammonia solution

$$750 \text{ cm}^3 \text{of solution contains } 1.846 \text{ moles of } NH_3$$

$$\therefore \; 1000 \text{ cm}^3 \text{ of solution contains } \left(\frac{1.846 \times 10^3}{750}\right) = \mathbf{2.46} \text{ M } \mathbf{NH_3} \qquad \checkmark^{C_A}$$

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

$$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$$

$$At \; Equil. \; [OH^-] = [NH_4^+] \; ; \therefore \; K_b = \frac{[OH^-]^2}{[NH_3]} \Rightarrow \frac{[OH^-]^2}{2.46} = 1.8 \times 10^{-5}$$

$$[OH^-]^2 \; = 2.46 \times 1.8 \times 10^{-5}$$

$$[OH^-] = \sqrt{(2.46 \times 1.8 \times 10^{-5})} = \mathbf{6.65 \times 10^{-3} M} \qquad \checkmark^{C_A}$$

$$pOH = -\log(6.65 \times 10^{-3}) = \mathbf{2.18} \qquad \checkmark^{C_A}$$

$$pH = 14 - 2.18 = \mathbf{11.82} \qquad \checkmark^{C_A}$$

$$4C_A \; = \; C_3 \; = \; 02 \; scores$$

$$3C_A \; = \; C_2 \; = \; 01 \; scores$$

$$2C_A \; OR \; 1C_A \; \& \; 0C_A = \; C_0 \; = \; 00 \; scores$$

Buffer action explanation

Ammonium chloride is a ***strong electrolyte hence fully ionises*** $\checkmark^{F_i}$ *to form ammonium ions and chloride ions*

$$NH_4Cl(aq) \rightarrow NH_4^+(aq) + Cl^-(aq)$$

*Ammonia is a **weak base hence only slightly ionises** ✓F_i and its ionisation is suppressed by the high concentration of ammonium ions from the salt*

$$NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

*The solution therefore contains a **high concentration of ammonium ions and a high concentration of unionised ammonia molecules** ✓F_i*
*When a small amount of acid is added, the **hydrogen ions react with ammonia molecules to form ammonium ions, resisting a decrease in pH** ✓F_r*
*When a small amount of base is added, the **hydroxide ions react with ammonium ions to form ammonia molecules and water, resisting an increase in pH** ✓F_r*

$$3F_i + 2F_r \ = \ F_3 \ = \ 03 \ scores$$

$$3F_i + 1F_r \ = \ F_2 \ = \ 02 \ scores$$

$$2F_i + 1F_r \ = \ F_1 \ = \ 01 \ scores$$

$$Only\ 3F_i \ OR \ Only\ 2F_r \ OR \ 1F_i + 1F_r \ = \ F_0 \ = 00 \ scores$$

Change in pH

(i) Calculate the change in pH when 10.0 cm³ of 2.00 mol dm⁻³ HCl is added.

$$\mathrm{p}K_b = -\log(1.8 \times 10^{-5}) = 4.74 \qquad \checkmark\ C_A$$

$$\text{Initial moles of } NH_3 = 2.46 \times \frac{250}{1000} = 0.615 \text{ mol}$$

$$\text{Initial moles of } NH_4^+ = 2.00 \times \frac{250}{1000} = 0.500 \text{ mol} \qquad \checkmark\ C_A$$

$$\text{Moles of HCl added} = 2.00 \times \frac{10.0}{1000} = 0.0200 \text{ mol} \qquad \checkmark\ C_A$$

$$NH_3 + H^+ \rightarrow NH_4^+$$

Species	NH_3	NH_4^+
Initial (mol)	0.615	0.500
Change (mol)	−0.020	+0.020
Final / New (mol)	0.595	0.520

✓ C_A

$$\mathrm{pOH} = \mathrm{p}K_b \ + \log \frac{[SALT]_{New}}{[BASE]_{New}}$$

$$\text{pOH} = 4.74 + \log\left(\frac{0.520}{0.595}\right) = 4.681$$

$$\text{pH} = 14.00 - 4.681 = 9.32 \quad \checkmark\ C_A$$

$$\Delta\text{pH} = 9.35 - 9.32 = 0.03 \quad \checkmark\ C_A$$

(ii) Calculate the change in pH when 10.0 cm³ of 2.00 mol dm⁻³ NaOH is added.

$$\text{Moles of NaOH added} = 2.00 \times \frac{10.0}{1000} = 0.0200 \text{ mol} \quad \checkmark\ C_B$$

$$\text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3 + \text{H}_2\text{O}$$

Species	NH_3	NH_4^+
Initial (mol)	0.615	0.500
Change (mol)	+0.020	−0.020
Final / New (mol)	0.635	0.480

$\checkmark\ C_B$

$$\text{pOH} = 4.74 + \log\left(\frac{0.480}{0.635}\right) = 4.619$$

$$\text{pH} = 14.00 - 4.619 = 9.38 \quad \checkmark\ C_B$$

$$\Delta\text{pH} = 9.38 - 9.35 = 0.03 \quad \checkmark\ C_B$$

$4C_A + 4C_B = C_2 = 04$ scores

$2C_A$ OR $2C_B = C_1 = 02$ scores

$1C_A$ OR $1C_B$ OR $1C_A + 1C_B = C_0 = 00$ scores

Applications of Buffers

- ***Blood pH control (≈ 7.4):*** $\checkmark^{U_i}$ *Uses the* ***carbonic acid–hydrogen carbonate (H₂CO₃/HCO₃⁻)*** *buffer system to* ***maintain a nearly constant blood pH for normal body functions.*** $\checkmark^{U_e}$
- ***Industrial cleaning solutions:*** $\checkmark^{U_i}$ *Commonly use the* ***ammonia–ammonium chloride (NH₃/NH₄Cl)*** *buffer to* ***maintain an alkaline pH for effective cleaning.*** $\checkmark^{U_e}$
- ***Cosmetics and shampoos:*** $\checkmark^{U_i}$ *Often use the* ***citric acid–sodium citrate*** *buffer system to* ***maintain a skin- and hair-friendly pH and reduce irritation.*** $\checkmark^{U_e}$
- ***Food processing :*** $\checkmark^{U_i}$ *Frequently uses the* ***acetic acid–sodium acetate (CH₃COOH/CH₃COONa)*** *buffer to* ***maintain flavour, colour, texture, and product stability.*** $\checkmark^{U_e}$

- ***Pharmaceutical formulations :*** ✓U_i *Commonly use the* ***phosphate buffer (NaH₂PO₄/Na₂HPO₄)*** *to* ***maintain the required pH, ensuring the stability and effectiveness of medicines.*** ✓U_e

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$$\text{Only } 2U_i + 2U_e = U_2 = 02 \text{ scores}$$

$$\text{Only } 2U_i \text{ OR Only } 1U_i + 1U_e = U_1 = 01 \text{ score}$$

$$\text{Only } 1U_i \text{ OR Otherwise} = U_0 = 00 \text{ scores}$$

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iii. **Environmental impacts and mitigation of Buffer solutions**

- *Emission of* ***ammonia gas (NH₃)*** ✓D_i *causes air pollution and contributes to eutrophication in water bodies.* ***ammonia gas (NH₃)*** ✓D_e *This can be controlled using* ***scrubbers in industrial exhaust systems*** ✓D_m.
- *Exposure to* ***ammonia (NH₃)*** ✓D_i *causes* ***respiratory irritation in humans*** ✓D_e. *This is managed through* ***proper ventilation systems and use of personal protective equipment (PPE)*** ✓D_m.
- *Formation of* ***nitrogen oxides (NOₓ)*** ✓D_i *leads to* ***acid rain*** ✓D_e *and environmental degradation. This is reduced by installing* ***catalytic converters in industrial and vehicle exhaust systems*** ✓D_m.
- *Release of* ***ammonium ions (NH₄⁺)*** ✓D_i *into water bodies leads to* ***aquatic pollution and oxygen depletion*** ✓D_m. *This can be mitigated through* ***biological nitrification and wastewater treatment processes*** ✓E_2.

$$\text{Only } 2D_i + 2D_e + 2D_m = D_2 = 02 \text{ scores}$$

$$1D_i + 1D_e + 1D_m \text{ OR } 2D_i + 2D_e \text{ OR } 2D_i + 2D_m = D_1 = 01 \text{ scores}$$

$$\text{Only } 2D_i + 0D_e + 0D_m = D_0 = 00 \text{ score}$$

$$\text{Only } 1D_i + 0D_e + 0D_m = D_0 = 00 \text{ scores}$$

Another Item 2

ITEM 2

Jinja Metal Processing Company Ltd refines copper from its ore and also recovers metals from industrial waste using electrochemical methods. During a study on redox processes, copper(II) ions were observed to be reduced to copper metal while iron metal was oxidised to iron(II) ions in solution. The standard electrode potentials are given as:

$$\text{Cu}^{2+}/\text{Cu} = +0.34 \text{ V}$$

$$\text{Fe}^{2+}/\text{Fe} = -0.44 \text{ V}$$

In another experiment, an electrochemical cell was set up using iron and copper electrodes connected by a salt bridge, and the cell performance was measured.

The company also carried out electrolysis of copper(II) sulphate solution using copper electrodes. A current of 2.00 A was passed for 30.0 minutes to determine the mass of copper deposited.

Management also wants to recover silver metal from a silver nitrate solution using electrolysis, but needs to predict the products and calculate the amount of metal that can be obtained under controlled conditions. You have been contacted for assistance.

Task

As a learner of Chemistry, assist the company to:

a. Write the ionic equation for the redox reaction between iron and copper(II) ions and construct its cell notation.
b. Calculate the e.m.f. of the iron–copper cell and predict with reason whether the reaction is spontaneous.
c. Explain how electrode potentials are measured using a standard hydrogen electrode.
d. Calculate the mass of copper deposited when a current of 2.00 A is passed for 30.0 minutes in $CuSO_4$ solution.
e. State the factors that affect the products formed during electrolysis.
f. Suggest the industrial applications of electrolysis.
g. State environmental effects of electrochemical processes and suggest methods of reducing them.

Response

a. **Redox ionic equation and cell notation**

*Copper(II) ions are **reduced by gaining electrons** ✓R_e while iron metal is **oxidised by losing electrons** ✓O_e.*

$$Cu^{2+}(aq) + Fe(s) \rightarrow Cu(s) + Fe^{2+}(aq)$$

*Iron acts as a **reducing agent** while Cu^{2+} acts as an **oxidising agent** ✓F_i.*

$$Fe(s)\ |Fe^{2+}(aq)\ ||Cu^{2+}(aq)\ |Cu(s)$$

---

b. **Cell e.m.f and spontaneity**

*Standard electrode potential of copper is **more positive** ✓E_i than that of iron, hence Cu^{2+} is reduced.*

$$E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode}$$

$$E^\circ_{cell} = 0.34 - (-0.44) = \mathbf{0.78\ V} \quad \checkmark\ C_A$$

*Since the cell potential is **positive**, the reaction is **spontaneous** ✓C_i.*

---

c. **Standard hydrogen electrode (SHE)**

*Electrode potentials are measured using a **standard hydrogen electrode (SHE) as reference (0.00 V)*** ✓^{R_i}.
*Hydrogen gas is **bubbled at 1 atm over platinum electrode immersed in 1 mol dm⁻³ H⁺ solution*** ✓^{R_e}.
*The metal electrode is then connected to SHE and the **voltage measured is the electrode potential*** ✓^{R_i}.

$$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$$

---

d. **Mass of copper deposited**

$$Q = It = 2.00 \times (30.0 \times 60)$$

$$Q = 3600\ \text{C} \quad \checkmark^{C_A}$$

$$\text{Moles of electrons} = \frac{3600}{96500} = 3.73 \times 10^{-2}$$

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

$$\text{Moles of Cu} = \frac{3.73 \times 10^{-2}}{2} = 1.87 \times 10^{-2}$$

$$\text{Mass of Cu} = 1.87 \times 10^{-2} \times 63.5 = \mathbf{1.19\ g} \quad \checkmark^{C_A}$$

---

e. **Factors affecting electrolysis products**

*The products depend on **position of ions in electrochemical series*** ✓^{F_i}, *and the ion that is **preferentially discharged*** ✓^{F_e}.
*They also depend on **concentration of ions in solution**, and **nature of electrodes (inert or active)*** ✓^{F_i}.

---

f. **Industrial applications of electrolysis**

- ***Electroplating*** ✓^{A_i} *used to coat metals for corrosion resistance and appearance.*
- ***Extraction of reactive metals (Al, Na)*** ✓^{A_i} *from their ores.*
- ***Purification of copper*** ✓^{A_i} *in electrolytic refining.*
- ***Manufacture of chlorine and sodium hydroxide*** ✓^{A_i}.

---

g. **Environmental effects and mitigation**

*Electrolysis may release **toxic gases (e.g. chlorine)*** ✓^{D_i} *which can cause **air pollution and respiratory problems*** ✓^{D_e}.
*This is controlled using **gas scrubbing systems and proper ventilation*** ✓^{D_m}.

*Discharge of **heavy metal ions in effluents** ✓D_i causes **water pollution and bioaccumulation** ✓D_e, and is reduced by **wastewater treatment and recycling of electrolytes** ✓D_m.*

Item 3 & 4 : Appreciates foundations of atomic structure, bonding and periodicity to predict applications of substances due to their properties

Basis of Assessment

The assessment of Items 3 and 4 is based on learners' ability to explain atomic structure, bonding, and periodic trends in order to predict the properties, reactions, and applications of substances in real-life contexts.

Assesable topics include;

1. Atomic and electronic structure
2. Bonding and structure
3. Periodicity I
4. Periodicity II

Criteria of Assessment

Basis of Assessment	Criteria of Assessment	Code	Score
A. Trends, physical properties and factors	Two well-explained trends / physical properties / factors (2Te)	A2	02
	One well-explained trend / physical property / factor (Te)	A1	01
	No explained trend / physical property / factor	A0	00
B. Chemical properties and reactions	Explained reaction with correct chemical equation (Re + Eq)	B2	02
	Explained reaction only (Re)	B1	01
C. Application, dangers and mitigation	Well-explained application, danger and mitigation (Ea + Ed + Em)	C3	03
	Explained application and danger (Ea + Ed)	C2	02
	Either application or danger explained (Ea / Ed)	C1	01
Note: The scores above are just sample scores.			

Sample items

ITEM 3

A technology company is planning to manufacture high temperature semiconductor devices for solar energy control systems. The material selected must withstand temperatures up to 1100 °C, form a stable solid protective oxide layer in air, and resist chemical attack during cleaning with dilute acids and hot concentrated alkalis.

The science club compiled the some data for selected Group IV elements and their oxides.

Element	C	Si	Ge	Sn	Pb
Melting point of element (°C)	3550	1410	937	232	327
Melting point of Dioxide (°C)	−56.5	1700	1116	1827	752

Before decision is made the investigations indicate that:

1. Trends in melting points of the elements and their oxides should be clearly explained.
2. Trends in the chemical behaviour of the oxides in water, dilute acids, and hot concentrated alkalis should be analysed.
3. The relationship between oxide structure and resistance to corrosion should be evaluated.
4. The most suitable Group IV element and oxide for the semiconductor application can be identified
5. The environmental and health impacts of the selected material can be assessed.

You have been appointed as a chemical materials analyst to provide scientific justification for the final selection.

Task

As a learner of Chemistry, write details of a report to assist the company.

Expected Response

Step	Expected Response	Score
Trends, physical properties and factors	***1. Trends in melting point of Group 14 elements and their oxides*** ***Among the Elements*** *Generally melting point of the group IV elements* ***decreases*** ✓T_r *from carbon to lead.* *Carbon has the highest melting point because it has a* ***giant covalent structure*** ✓T_r *with a 3-dimensional network of strong covalent bonds. A very large amount of energy is required to break these bonds.* *Silicon and germanium also have* ***giant covalent structures*** ✓T_r*, however silicon has a higher melting point than germanium because silicon atoms are smaller, resulting in* ***shorter and stronger covalent bonds*** ✓T_e *than those in germanium.* *Tin and lead have* ***metallic structures*** ✓T_r *with delocalised electrons. Their melting points are lower because metallic bonds are weaker than giant covalent bonds.* ***Among the oxides*** *Generally melting point of the group IV oxides* ***increases with some irregularities*** ✓T_r *from carbon diocide to lead (II) oxide.* *Carbon dioxide has a very low melting point because it has a* ***simple molecular structure*** ✓T_r *made up of discrete molecules held by weak Van der Waals forces.* *Silicon(IV) oxide has a very high melting point because it has a* ***giant covalent network structure*** ✓T_r *with strong Si–O bonds throughout the lattice.* *Germanium(IV) oxide has a similar structure but a lower melting point than silicon(IV) oxide because Ge–O bonds are* ***longer and weaker*** ✓T_e *due to larger atomic size.* *Tin(IV) oxide and lead(IV) oxide have* ***ionic structures*** ✓T_r*. However, lead(IV) oxide has a lower melting point than tin(IV) oxide because Pb^{4+} ions are larger than Sn^{4+} ions, leading to* ***weaker ionic attraction*** ✓T_e*.* --- Only $8T_r + 2T_e = T_6 = 06$ scores $7T_r + 2T_e$ OR $8T_r + 1T_e = T_5 = 05$ scores $6T_r + 2T_e$ OR $7T_r + 1T_e$ OR $8T_r = T_4 = 04$ scores $5T_r + 1T_e$ OR $6T_r = T_3 = 03$ scores $4T_r + 1T_e$ OR $5T_r = T_2 = 02$ scores $3T_r$ OR $2T_r + 1T_e = T_1 = 01$ score Otherwise $= T_0 = 00$ scores ---	06
Chemical properties of the substances	**Chemical behaviour of oxides in water, acids, and alkalis** **✓ Water** *Carbon dioxide reacts with water to form* ***carbonic acid*** ✓C_r*.* *Silicon(IV) oxide, germanium(IV) oxide, tin(IV) oxide and lead(IV) oxide do not react with water because they have* ***strong lattice structures*** ✓C_o*.*	04

	✓Dilute acids With dilute acids, most oxides such as SiO_2, GeO_2 and SnO_2 do not react due to their **stable covalent/ionic lattices** ✓ C_r. Lead(IV) oxide may show oxidising behaviour under acidic conditions. **✓hot concentrated alkalis** *With hot concentrated alkalis, carbon dioxide reacts to form a **carbonate** ✓C_r.* *Silicon(IV) oxide reacts with hot concentrated alkalis to form **silicate** ✓ C_r, while germanium(IV) oxide forms **germanate complexes** ✓C_r.* *Tin(IV) oxide and lead(IV) oxide form **stannate and plumbate complexes** ✓ C_r respectively, showing amphoteric behaviour.* --- Only $6C_r + 2C_o = T_4 = 04$ scores $5C_r + 2C_o$ OR $6C_r + C_o = T_3 = 03$ scores $4C_r + 2C_o$ OR $5C_r + C_o$ OR $6C_r = T_2 = 02$ scores $3C_r + 1C_o$ OR $4C_r = T_1 = 01$ score Otherwise $= T_0 = 00$ scores ---	
Application based on the properties	**Trend in resistance to corrosion of Group 14 oxides** *The resistance to corrosion of Group 14 oxides generally **decreases down the group** ✓ T_r because the oxides become less strongly covalent and more reactive towards chemical attack.* **$SiO_2 > GeO_2 > SnO_2 > PbO_2 > CO_2$** ✓ T_r **Silicon(IV) oxide (SiO_2)** is the most resistant to corrosion because of its **giant covalent structure with strong Si–O bonds.** ✓ T_e ***GeO_2, SnO_2 and PbO_2** show progressively lower resistance because their oxide structures become **less strongly covalent** ✓T_e down the group.* *SnO_2 and PbO_2 are **amphoteric and react with strong alkalis,** ✓ T_e while PbO_2 may also react under acidic conditions due to its **oxidising properties.** ✓T_e* ***CO_2** is the least resistant because it is a simple molecular oxide that **reacts readily with water and alkalis.** ✓T_e* --- Only $6T_r + 2T_e = T_4 = 04$ scores $5T_r + 2T_e$ OR $6T_r + 1T_e = T_3 = 03$ scores $4T_r + 2T_e$ OR $5T_r + 1T_e$ OR $6T_r = T_2 = 02$ scores $3T_r + 1T_e$ OR $4T_r = T_1 = 01$ score Otherwise $= T_0 = 00$ scores --- • **Most suitable element and oxide for semiconductor fabrication** *Silicon is the most suitable element because it has a **high melting point (1410°C)** ✓S_s, allowing it to withstand 1100°C operating conditions.*	06

	*Silicon forms silicon dioxide (SiO_2), which has a **giant covalent structure** ✓ S_s that is highly stable and acts as a protective oxide layer.* *This oxide prevents further oxidation and chemical attack, making silicon ideal for semiconductor devices.* *However, SiO_2 can slowly react with **hot concentrated alkalis** ✓ S_l, which is a limitation during harsh cleaning processes.* --- Only $2S_s + 1S_l = T_2 = 02$ scores $1S_s + 1S_l$ OR $2S_s = T_1 = 01$ score Otherwise $= T_0 = 00$ scores ---	
Other industrial applications, environmental/health hazards and mitigation.	**Dangers of Poor Disposal of Silicon, Effects and Mitigation Measures** *Poor disposal of silicon waste may cause **dust pollution in the environment** ✓ D_i. Fine silicon dust can lead to **respiratory irritation and discomfort when inhaled** ✓ D_e. This can be minimized by **using dust-control systems and providing appropriate protective equipment** ✓ D_m.* *Improper disposal of silicon-processing residues may result in **environmental pollution from industrial waste** ✓ D_i. This may contribute to **soil and water contamination around disposal sites** ✓ D_e. The impact can be reduced through **proper waste treatment and disposal in approved facilities** ✓ D_m.* *Discarding silicon-containing electronic materials carelessly may lead to **accumulation of electronic waste in the environment** ✓ D_i. This can cause **long-term environmental degradation and resource wastage** ✓ D_e. The problem can be minimized by **recycling silicon-based electronic components and promoting responsible waste management practices** ✓ D_m.* --- Only $2D_i + 2D_e = T_4 = 04$ scores $1D_i + 2D_e$ OR $2D_i + 1D_e = T_3 = 03$ scores $1D_i + 1D_e$ OR $2D_i$ OR $2D_e = T_2 = 02$ scores Otherwise $= T_0 = 00$ scores ---	04
	TOTAL	=

Item 5 & 6 : Appreciates structure, reactivity and applications of organic molecules in life

Basis of Assessment

The assessment of Items 5 and 6 is based on learners' ability to explain the structure, properties, reactivity, synthesis and applications of organic compounds, and to apply this knowledge in solving problems encountered in everyday life, biological systems and industry.

Assessable topics include;

1. Organic Chemistry I
2. Organic Chemistry II
3. Organic Chemistry III

Criteria of Assessment

Basis of Assessment	Criteria of Assessment	Code	Score
A. Physical properties of the stated compound(s)	Two well-explained physical properties, one for each compound stated (2Ep)	A2	02
	One well-explained physical property of any one of the compounds stated (Ep)	A1	01
	No explained physical property	A0	00
B. Reaction mechanism(s)	All steps correct for Mechanism 1 and Mechanism 2 (All M_1 + All M_2)	B2	08
	At least **2/3** of the required steps correct for Mechanism 1 or Mechanism 2 (2/3 M_1 / 2/3 M_2)	B1	05
	No correct mechanism or less than **2/3** of the required steps completed	B0	00
C. Synthesis of organic compounds	All steps correct for the synthesis of all compounds given (All R_1 + All R_2)	C2	08
	At least **2/3** of the required synthesis steps correct for Synthesis 1 or Synthesis 2 (2/3 R_1 / 2/3 R_2)	C1	05
	No correct synthesis or less than **2/3** of the required synthesis steps completed	C0	00
D. Application, dangers and mitigation	Well-explained application, danger and mitigation (Ea + Ed + Em)	D3	03
	Explained application and danger (Ea + Ed)	D2	02
	Either application or danger explained (Ea / Ed)	D1	01
	No explained application, danger or mitigation	D0	00
Note: The scores above are just sample scores.			

Understanding the Expected Responses

The examples below demonstrate how assessment requirements are interpreted from a competency-based scenario. The scenario provided is illustrative and differs from those that

may appear in an examination. Its purpose is to demonstrate the thought process required when responding to competency-based assessment items.

Basis of Assessment	Illustrative Scenario and Expected Response
A. Well-explained physical property of the stated compound	**Illustrative Scenario** A pharmaceutical company is developing an alcohol-based hand sanitiser that should dry quickly after application without leaving the hands sticky. During product evaluation, the quality-control chemist recommends the use of **ethanol** as the main solvent and asks for the property that makes it suitable. **Expected Response** *Ethanol is suitable because it is **highly volatile** ✓Ep, enabling it to **evaporate rapidly after application** ✓Ep, thereby allowing the sanitiser to **dry quickly without leaving a sticky residue.** ✓Ep* **Key Principle:** *Always relate the physical property directly to the function or suitability described in the scenario.*
B. Reaction mechanism(s)	**Illustrative Scenario** Researchers have successfully converted an alkene into an alcohol in the laboratory. Before approving the procedure, the lead chemist requests a *molecular-level explanation showing exactly how the reaction proceeds from reactants to products.* **Interpretation** The statement above does not directly ask for a reaction mechanism, but it clearly requires one. Similar expressions include: • *"Explain how the reaction occurs."* • *"Illustrate the detailed reaction pathway."* • *"Show the sequence of elementary reaction steps."* • *"Provide a molecular-level explanation."* • *"Illustrate electron movement during the reaction."* **Expected Features of the Mechanism** • *Correct curly arrows showing electron movement.* • *Correct structures of reactants, intermediates and products.* • *Correct formal charges where applicable.* • *Proper bonding throughout the mechanism.* • *No missing intermediate steps.* • *Correct orientation of arrows.* • *Minor products included where appropriate.*
C. Organic synthesis	**Illustrative Scenario** A chemical manufacturing company intends to establish a local production plant for ethyl ethanoate used in perfumes and flavourings. Before production begins, the production manager requests a synthesis route starting from simple laboratory reagents.

	Expected Response Present a logical synthesis pathway beginning with suitable starting materials and proceeding to the required product. The synthesis should include: • *Appropriate starting material(s).* • *Correct reagents.* • *Reaction conditions.* • *Balanced equations or acceptable reaction descriptions.* • *Correct intermediate structures where necessary.* • *The shortest chemically reasonable synthetic route.* Although many synthesis routes are possible, an **efficient route** is generally preferred.
D. Applications, dangers and mitigation	**Illustrative Scenario** Following increased industrial use of methanol as a solvent, environmental officers request a report explaining another important application of the compound, the dangers associated with its use, and appropriate mitigation measures. **Expected Response** • *Explain another practical application of methanol.* • *Explain the associated health or environmental danger.* • *Explain an appropriate mitigation measure.* **Example** *Methanol is used as an **industrial solvent and as a feedstock in chemical manufacture.** ✓Ea However, it is highly **toxic and ingestion may cause blindness or death** ✓Ed. **hSafe storage, proper labelling, use of personal protective equipment and responsible disposal minimise these hazards.** ✓Em* The number of **applications, dangers and mitigation** measures required will always depend on the **instructions** given in the scenario.

All Homologous Series – Applications, Physical Properties, Dangers and Mitigation

*This section links each homologous series to its **physical properties**, **applications**, **dangers** and **mitigation measures**, with clear scientific explanations based on assessment requirements. Learners are expected to explain **why substances behave the way they do** and relate this to real-life use and safety.*

Homologous Series	Uses & Physical Explanation	Environmental & Health Impacts + Mitigation
Alkanes	• ***Solvent for non-polar substances*** *because alkanes are* ***non-polar molecules*** ✓Ep, *therefore they* ***do not interact with water molecules*** ✓Ep, *but dissolve* ***non-polar substances such as oils, fats and waxes*** ✓Ep. • ***Lubricants*** *because higher alkanes have* ***high viscosity and high boiling points*** ✓Ea *due to* ***large molecular size and strong van der Waals forces*** ✓Ea, *allowing them to* ***reduce friction between moving surfaces*** ✓Ea. • ***Fuels (LPG, petrol, paraffin)*** *because alkanes are* ***highly flammable*** ✓Ea *and have* ***high heat of combustion*** ✓Ea, *therefore they* ***release large amounts of energy on combustion*** ✓Ea.	• ***Incomplete combustion*** *produces* ***carbon monoxide*** ✓Ed, *which* ***binds to haemoglobin reducing oxygen transport*** ✓Ed, *leading to* ***suffocation and death*** ✓Ed. ***Mitigation: Ensure sufficient oxygen supply and proper combustion systems*** ✓Em. • ***Complete combustioncarbon dioxide*** ✓Ed, *which* ***enhances the greenhouse effect leading to global warming*** ✓Ed. ***Mitigation: Promote renewable energy sources such as solar, hydro and wind*** ✓Em. • ***Oil spillsform a floating non-polar layer on water*** ✓Ed, *which* ***reduces oxygen and light penetration affecting aquatic life*** ✓Ed. ***Mitigation: Contain and remove spills using absorbents and oil booms*** ✓Em.

Homologous Series	Uses & Physical Explanation	Environmental & Health Impacts + Mitigation
Alkenes	• **Used in making buoyant polymers** because alkenes form **addition polymers with long carbon chains**✓Ea, which produce **lightweight and less dense materials used in life jackets and floating ropes**✓Ea. • **Used as solvents in extraction and purification** because alkenes are **non-polar and immiscible with water**✓Ea, allowing them to **dissolve non-polar substances such as oils and organic impurities**✓Ea. • **Used in fast-drying coatings (inks and paints)** because alkenes are **volatile organic compounds**✓Ea, which **evaporate quickly at room temperature leaving the coating dry**✓Ea. • **Used as aerosol propellants** because they **liquefy easily under pressure**✓Ea, making them **suitable for releasing sprays in perfumes, deodorants and insecticides**✓Ea. • **Used in production of ethane-1,2-diol** because ethene undergoes **controlled oxidation and hydration reactions**✓Ea, forming **glycols used in radiators as antifreeze agents**✓Ea. • **Used in fruit ripening** because ethene acts as a **plant hormone**✓Ea, which **triggers ripening by promoting colour change, softening and aroma development**✓Ea.	• **Incomplete combustion** produces **carbon monoxide**✓Ed, which **binds strongly to haemoglobin and reduces oxygen transport in blood**✓Ed, leading to **respiratory failure and possible death**✓Ed. **Mitigation: Ensure complete combustion and improve ventilation in combustion systems**✓Em. • **Complete combustion** releases **carbon dioxide**✓Ed, which **enhances the greenhouse effect leading to global warming**✓Ed. **Mitigation: Promote renewable energy sources such as solar, hydroelectric and wind energy**✓Em. • **Oil film formation in water** because alkenes form a **thin non-polar layer on water surfaces**✓Ed, which **blocks oxygen and light penetration causing death of aquatic organisms**✓Ed. **Mitigation: Prevent spills and remove oil using absorbent materials or containment booms**✓Em. • **Toxic emissions and air pollution** because volatile alkene vapours **contribute to photochemical smog formation**✓Ed. **Mitigation: Control industrial emissions and avoid release of unburnt hydrocarbons**✓Em.

Homologous Series	Uses & Physical Explanation	Environmental & Health Impacts + Mitigation
Alkynes	• ***Solvent for non-polar substances*** *because alkynes are* ***non-polar hydrocarbons*** ✓Ep*, therefore they* ***do not mix with water but dissolve non-polar substances such as oils and organic compounds*** ✓Ep. • ***Oxy-acetylene welding and cutting*** *because ethyne burns in oxygen to produce a* ***very high-temperature flame*** ✓Ea*, due to* ***high energy stored in the carbon–carbon triple bond*** ✓Ea*, making it suitable for* ***cutting and welding metals in industrial processes*** ✓Ea. • ***Fruit ripening agent*** *because ethyne acts as a* ***plant growth regulator (artificial ripening hormone)*** ✓Ea*, which* ***stimulates enzymatic breakdown leading to softening, colour change and aroma development*** ✓Ea. • ***High energy fuel source*** *because alkynes have* ***high heat of combustion*** ✓Ea*, due to* ***unstable triple bonds that release large energy upon burning*** ✓Ea.	• ***Incomplete combustion*** *produces* ***carbon monoxide (CO)*** ✓Ed*, which* ***binds strongly to haemoglobin reducing oxygen transport in blood*** ✓Ed*, leading to* ***suffocation and possible death*** ✓Ed. ***Mitigation:*** ***Ensure complete combustion by providing sufficient oxygen and proper ventilation*** ✓Em. • ***Complete combustioncarbon dioxide (CO₂)*** ✓Ed*, which* ***enhances the greenhouse effect leading to global warming and climate change*** ✓Ed. ***Mitigation:*** ***Promote renewable energy sources such as solar, wind and hydroelectric power*** ✓Em. • ***Water pollutionnon-polar floating layer on water surfaces*** ✓Ed*, which* ***reduces oxygen diffusion and sunlight penetration, harming aquatic organisms*** ✓Ed. ***Mitigation:*** ***Prevent spills and remove contamination using absorbent materials and containment systems*** ✓Em.

Homologous Series	Uses & Physical Explanation	Environmental & Health Impacts + Mitigation
Alkyl Halides (Halogen Compounds)	• **Fire extinguishing agents** because some halogen compounds such as methyl bromide are **non-flammable and denser than air** ✓Ea, allowing them to **displace oxygen and suppress combustion** ✓Ea. • **Solvents and degreasing agents** because they are **non-polar compounds** ✓Ea, which **dissolve oils, grease and organic stains** ✓Ea, making them useful in **dry cleaning and paint removal** ✓Ea. • **Refrigerants** because compounds such as methyl chloride have **low boiling points** ✓Ea, allowing them to **absorb heat rapidly during vaporisation** ✓Ea, thus **providing cooling in refrigeration systems** ✓Ea. • **Polymer production** because chloroethene undergoes **addition polymerisation** ✓Ea, forming **polyvinyl chloride (PVC) used in pipes, cables and construction materials** ✓Ea. • **Medicinal and industrial intermediates** because alkyl halides are **reactive intermediates in organic synthesis** ✓Ea, used in production of **drugs such as chloramphenicol and local anaesthetics like ethyl chloride** ✓Ea. • **Fumigants** because compounds such as methyl bromide are **toxic to insects and pests** ✓Ea, making them useful in **grain storage and agricultural pest control** ✓Ea.	• **Bioaccumulation** occurs because compounds like DDT are **chemically stable and hydrophobic** ✓Ed, leading to **accumulation in fatty tissues of organisms through the food chain** ✓Ed. **Mitigation: Use of bioremediation techniques such as anaerobic bacteria for degradation** ✓Em. • **Acidic emissions** occur when halogenated compounds are **burned or decomposed at high temperatures** ✓Ed, producing **acidic gases that contribute to acid rain** ✓Ed, which **corrodes limestone buildings and acidifies soils and water bodies** ✓Ed. **Mitigation: Proper waste treatment and controlled incineration with scrubbing systems** ✓Em. • **Air pollution and respiratory effects** because compounds such as chloropicrin are **toxic and irritant gases** ✓Ed, leading to **smog formation and respiratory disorders** ✓Ed. **Mitigation: Limit exposure and ensure proper industrial ventilation and emission control** ✓Em. • **Greenhouse effect contribution** because halogenated gases are **stable atmospheric pollutants** ✓Ed, which **trap heat in the atmosphere contributing to global warming** ✓Ed. **Mitigation: Phase out harmful halogenated compounds and replace with eco-friendly alternatives** ✓Em.

Homologous Series	Uses & Physical Explanation	Environmental & Health Impacts + Mitigation
Benzene & Methylbenzene	• ***Solvent for non-polar substances*** *because benzene and methylbenzene are* ***non-polar aromatic compounds*** ✓Ep*, therefore they* ***do not mix with water but dissolve fats, oils, waxes, inks and resins*** ✓Ep. • ***Volatile organic solvents*** *because they have* ***low boiling points and weak intermolecular forces*** ✓Ea*, allowing them to* ***evaporate quickly and leave solutes behind in fast-drying coatings such as inks, paints and nail polish*** ✓Ea. • ***Industrial applications*** *because methylbenzene is used in* ***cooling and heating systems as a stable liquid over a wide temperature range*** ✓Ea*, while benzene is used as a* ***precursor in the manufacture of plastics such as polystyrene*** ✓Ea. • ***Extraction and industrial processing*** *because their* ***non-polar nature makes them immiscible with water and effective in solvent extraction*** ✓Ea*, allowing separation of* ***organic compounds from aqueous mixtures*** ✓Ea.	• ***Health hazard (carcinogenic effects)*** *because benzene and methylbenzene are* ***highly volatile aromatic hydrocarbons*** ✓Ed*, which* ***are linked to leukemia, respiratory disorders and reproductive system damage*** ✓Ed. ***Mitigation:*** ***Use closed systems, proper ventilation and avoid inhalation exposure*** ✓Em. • ***Direct contact hazards*** *because they are* ***irritating to skin and eyes*** ✓Ed*, leading to* ***chemical burns and tissue damage upon exposure*** ✓Ed. ***Mitigation:*** ***Wear PPE such as gloves, goggles and lab coats during handling*** ✓Em. • ***Environmental pollution*** *because they are* ***volatile organic compounds*** ✓Ed*, which* ***contribute to air pollution, contaminate water bodies and inhibit plant growth in soil*** ✓Ed. ***Mitigation:*** ***Proper waste disposal and controlled industrial emission systems*** ✓Em.

Homologous Series	Uses & Physical Explanation	Environmental & Health Impacts + Mitigation
Alcohols & Phenol	• ***Universal industrial solvent*** *because alcohols possess a* ***polar hydroxyl group and non-polar hydrocarbon chain*** ✓Ea*, allowing them to dissolve* ***both polar and some non-polar substances*** ✓Ea. • ***Beverage alcohol (ethanol)*** *because ethanol is* ***highly soluble in water and volatile*** ✓Ea*, giving it* ***rapid evaporation for aroma release and low melting point*** ✓Ea. • ***Fast-drying inks and aerosol sprays*** *because alcohols are* ***highly volatile liquids*** ✓Ea*, which* ***evaporate quickly at room temperature leaving dry surfaces*** ✓Ea. • ***Fuels (ethanol and methanol)*** *because they have* ***high heat of combustion*** ✓Ea*, releasing* ***large amounts of energy during burning*** ✓Ea. • ***Antiseptics and disinfectants*** *because alcohols* ***denature microbial proteins by disrupting hydrogen bonding*** ✓Ea*, leading to* ***destruction of bacteria and viruses*** ✓Ea. • ***Antifreeze and de-icing fluids*** *because alcohols have* ***very low freezing points*** ✓Ea*, allowing them to* ***prevent freezing in engines and thermometers*** ✓Ea. • ***Phenol resins (Bakelite)*** *because phenol has a* ***highly reactive aromatic structure*** ✓Ea*, forming* ***thermosetting plastics with high thermal and chemical resistance*** ✓Ea. • ***Pharmaceutical production*** *because phenol is used in* ***synthesis of analgesics such as aspirin and paracetamol*** ✓Ea.	• ***Ethanol health effects*** *because it acts as a* ***central nervous system depressant*** ✓Ed*, leading to* ***drowsiness, loss of coordination and impaired judgement*** ✓Ed. ***Mitigation:*** ***Regulated consumption and public awareness on alcohol abuse*** ✓Em. • ***Methanol poisoning*** *because methanol is metabolized into* ***toxic compounds that damage the optic nerve*** ✓Ed*, leading to* ***blindness, organ failure and death*** ✓Ed. ***Mitigation:*** ***Strict labeling, controlled industrial handling and avoidance of ingestion*** ✓Em. • ***Phenol toxicity*** *because phenol is* ***corrosive and highly toxic*** ✓Ed*, causing* ***skin burns, liver damage and chronic poisoning*** ✓Ed. ***Mitigation:*** ***Use protective equipment and proper chemical waste disposal systems*** ✓Em. • ***Aquatic pollution*** *because phenols and alcohol wastes* ***are toxic to aquatic organisms*** ✓Ed*, leading to* ***death of fish and disruption of aquatic ecosystems*** ✓Ed. ***Mitigation:*** ***Treat industrial effluents before discharge into water bodies*** ✓Em.

Homologous Series	Uses & Physical Explanation	Environmental & Health Impacts + Mitigation
Carbonyl Compounds (Aldehydes & Ketones)	• ***Used in fragrances and flavourings (Aldehydes)*** *because they are* ***highly volatile molecules*** ✓Ea, *which* ***evaporate easily to release distinct and pleasant odours*** ✓Ea, *making them suitable for perfumes and food flavouring agents.* • ***Used as preservatives (Aldehydes)*** *because short-chain aldehydes such as formaldehyde are* ***reactive and antimicrobial*** ✓Ea, *allowing them to* ***preserve biological tissues by preventing microbial decay*** ✓Ea. • ***Used in fast-drying sprays (Ketones)*** *because ketones are* ***highly volatile organic liquids*** ✓Ea, *which* ***evaporate rapidly at room temperature leaving surfaces dry*** ✓Ea, *making them suitable for paints, inks and coatings.* • ***Used as solvents (Ketones)*** *because they possess* ***both polar and non-polar characteristics*** ✓Ea, *allowing them to* ***dissolve a wide range of substances including oils, resins and polymers*** ✓Ea, *as used in nail polish removers and paint removers.* • ***Used in industrial synthesis*** *because carbonyl compounds are* ***highly reactive intermediates*** ✓Ea, *making them important in the* ***manufacture of drugs, plastics and resins*** ✓Ea.	• ***Air pollution (smog formation)*** *because carbonyl compounds are* ***volatile organic compounds (VOCs)*** ✓Ed, *which* ***react in sunlight to form photochemical smog*** ✓Ed. ***Mitigation: Control industrial emissions and reduce VOC release through closed systems*** ✓Em. • ***Water pollution (toxicity)*** *because aldehydes such as formaldehyde are* ***toxic and highly reactive in aquatic systems*** ✓Ed, *leading to* ***damage to aquatic organisms and disruption of ecosystems*** ✓Ed. ***Mitigation: Treat industrial effluents before discharge into water bodies*** ✓Em. • ***Health hazards*** *because exposure to aldehydes and ketones may cause* ***eye, skin and respiratory irritation*** ✓Ed, *and long-term exposure to formaldehyde may increase* ***risk of cancer*** ✓Ed. ***Mitigation: Use protective equipment and ensure proper ventilation during use*** ✓Em.

Homologous Series	Uses & Physical Explanation	Environmental & Health Impacts + Mitigation
Carboxylic Acids and Derivatives	• ***Used in food preservation (vinegar / ethanoic acid)*** *because carboxylic acids are* ***weak acids that partially ionise in water*** ✓Ea, *creating a* ***low pH environment that inhibits microbial growth and spoilage*** ✓Ea. • ***Used in ester formation (perfumes and flavourings)*** *because carboxylic acids react with alcohols in* ***esterification reactions under acidic conditions*** ✓Ea, *forming* ***esters with pleasant fruity odours used in perfumes and food flavourings*** ✓Ea. • ***Used in soap and detergent manufacture*** *because long-chain carboxylic acids form* ***salts (soaps) through neutralisation with bases*** ✓Ea, *which* ***reduce surface tension and remove grease and dirt*** ✓Ea. • ***Used in polymer and pharmaceutical synthesis (derivatives)*** *because acid derivatives such as* ***acyl chlorides and esters are highly reactive*** ✓Ea, *allowing them to* ***form amides, esters and other compounds used in drugs and plastics*** ✓Ea.	• ***Acidic nature (corrosive effect)*** *because carboxylic acids are* ***weak acids but still corrosive at high concentration*** ✓Ed, *which can cause* ***skin irritation and damage to tissues*** ✓Ed. ***Mitigation:*** ***Use protective gloves, goggles and handle dilute solutions carefully*** ✓Em. • ***Water pollution*** *because organic acid waste and derivatives are* ***biodegradable but can lower pH of water bodies*** ✓Ed, *which* ***disrupts aquatic life and ecosystem balance*** ✓Ed. ***Mitigation:*** ***Neutralise acidic waste before disposal and treat industrial effluents*** ✓Em. • ***Volatile ester vapoursrespiratory irritation when inhaled in high concentrations*** ✓Ed. ***Mitigation:*** ***Ensure proper ventilation and avoid prolonged inhalation in confined spaces*** ✓Em.

Homologous Series	Uses & Physical Explanation	Environmental & Health Impacts + Mitigation
Amines	• ***Used in pharmaceutical drug synthesis*** *because amines contain a* ***lone pair of electrons on nitrogen*** ✓Ea*, which makes them* ***highly reactive nucleophiles that form bonds with biological molecules*** ✓Ea*, leading to* ***production of drugs such as antihistamines and antibiotics*** ✓Ea*.* • ***Used in dye and textile industry*** *because amines are* ***basic organic compounds*** ✓Ea*, which* ***react with acidic dye molecules to form stable coloured complexes*** ✓Ea*, making them important in* ***fabric coloration and printing processes*** ✓Ea*.* • ***Used in gas treatment (CO_2 removal)*** *because amines are* ***basic and react with acidic gases*** ✓Ea*, allowing them to* ***absorb carbon dioxide and hydrogen sulphide in industrial gas purification*** ✓Ea*.* • ***Used in production of detergents and surfactants*** *because long-chain amines are* ***amphiphilic molecules*** ✓Ea*, having both* ***polar (hydrophilic) and non-polar (hydrophobic) regions*** ✓Ea*, making them useful in* ***cleaning and emulsifying grease*** ✓Ea*.*	• ***Air and water pollution*** *because amines are* ***volatile and reactive organic bases*** ✓Ed*, which can* ***release toxic fumes and contaminate water systems*** ✓Ed*.* ***Mitigation:*** ***Use closed systems and proper waste treatment before discharge*** ✓Em*.* • ***Health hazards (irritation and toxicity)*** *because some amines are* ***corrosive and have strong ammonia-like odour*** ✓Ed*, which may cause* ***respiratory irritation, skin burns and eye damage*** ✓Ed*.* ***Mitigation:*** ***Use protective equipment such as gloves, goggles and work in well-ventilated areas*** ✓Em*.* • ***Environmental toxicity*** *because some amines are* ***bioactive compounds*** ✓Ed*, which can* ***disrupt aquatic ecosystems and affect organism metabolism*** ✓Ed*.* ***Mitigation:*** ***Controlled disposal and neutralisation before release into the environment*** ✓Em*.*

Homologous Series	Uses & Physical Explanation	Environmental & Health Impacts + Mitigation
Polymers & Polymerization	• ***Plastic production (e.g. polythene, PVC)*** *because monomers such as* ***alkenes undergo addition polymerization*** ✓Ea, *where* ***double bonds break and form long-chain macromolecules*** ✓Ea, *resulting in* ***strong, flexible and durable materials used in bags, bottles and pipes*** ✓Ea. • ***Synthetic fibers (e.g. nylon, polyester)*** *because polymerization of* ***di-functional monomers forms long-chain polymers*** ✓Ea, *producing* ***strong and lightweight fibers used in clothing and ropes*** ✓Ea. • ***Rubbers and elastomers*** *because polymer chains can* ***stretch and recoil due to flexible covalent bonds*** ✓Ea, *making them suitable for* ***tyres, gloves and elastic materials*** ✓Ea. • ***Polymerization process (addition type)*** *occurs when* ***unsaturated monomers open double bonds and link repeatedly*** ✓Ea, *forming* ***long chains without loss of small molecules*** ✓Ea. • ***Polymerization process (condensation type)monomers join with elimination of small molecules such as water or HCl*** ✓Ea, *forming* ***polyamides and polyesters used in textiles and packaging materials*** ✓Ea.	• ***Non-biodegradability*** *because most synthetic polymers are* ***chemically inert and resistant to microbial decomposition*** ✓Ed, *leading to* ***accumulation of plastic waste in the environment*** ✓Ed. ***Mitigation: Promote recycling and use of biodegradable polymers*** ✓Em. • ***Air pollution (burning plastics)toxic gases such as CO and dioxins*** ✓Ed, *which* ***cause respiratory diseases and environmental toxicity*** ✓Ed. ***Mitigation: Avoid open burning and use controlled incineration systems*** ✓Em. • ***Water and soil pollutionblock drainage systems and harm aquatic life*** ✓Ed, *leading to* ***death of organisms through ingestion and entanglement*** ✓Ed. ***Mitigation: Proper waste management and plastic collection systems*** ✓Em. • ***Microplastic contamination*** *occurs because large polymers* ***break into small persistent particles*** ✓Ed, *which* ***enter food chains and accumulate in organisms*** ✓Ed. ***Mitigation: Reduce single-use plastics and improve filtration systems*** ✓Em.

In summary, when analysing organic chemistry items in scenarios, learners should systematically focus on:

- **Explained physical properties**✓ of the compounds stated in the scenario, linking structure to observable behaviour and suitability for use.
- **Reaction mechanisms**✓ for the reactions described in the scenario, showing stepwise molecular-level transformations and electron movement.
- **Synthesis pathways**✓ for the compounds mentioned **atleast two**, including reagents, conditions, and logical stepwise formation routes.
- **Applications, dangers and mitigation measures**✓ of the compounds, clearly linking chemical properties to real-life uses, associated risks, and appropriate control strategies.

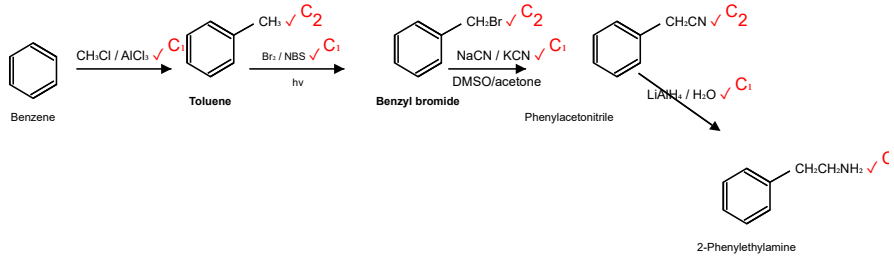
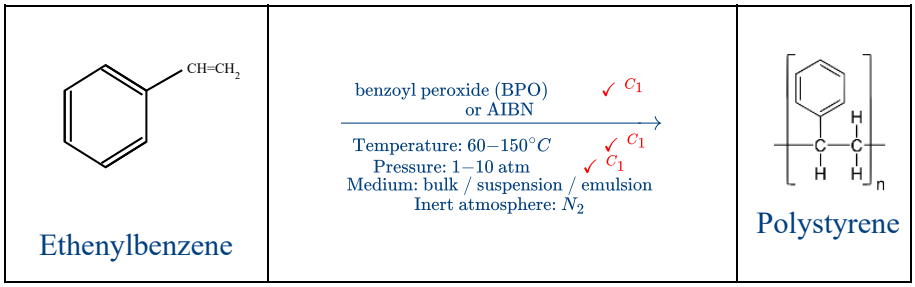
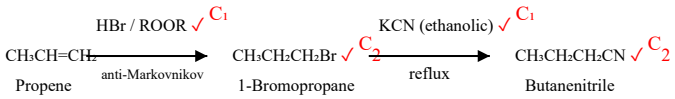
Sample Assessment Item (Organic Chemistry)

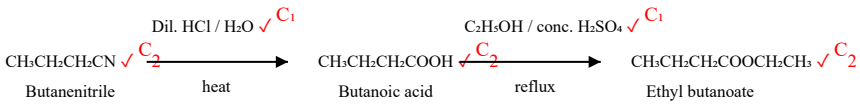
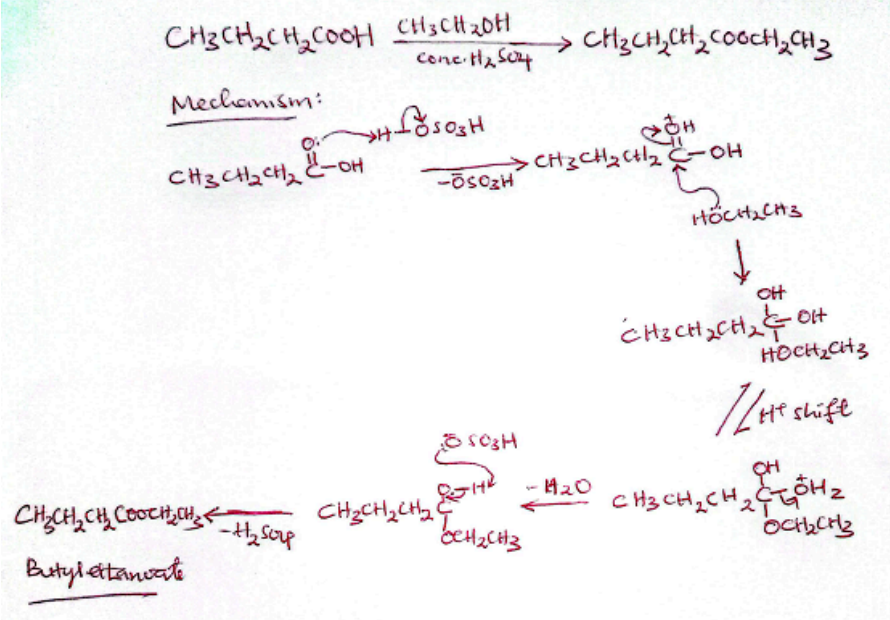
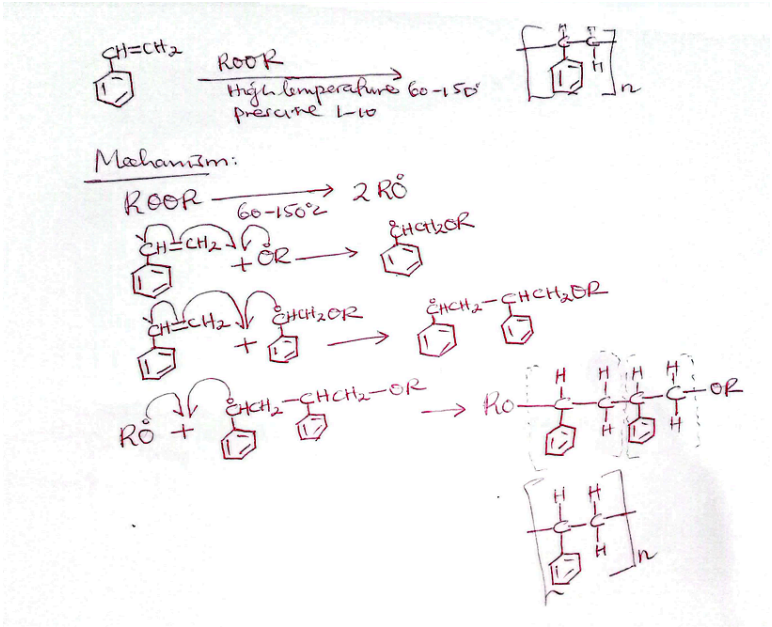
ITEM 5

The Uganda National Oil Company (UNOC) plans to expand the production of organic chemicals. The technical team proposed converting **benzene** into *2-phenylethan-1-amine* for use as a carbon dioxide scrubber, **phenylethene** into *polystyrene* for television packaging, and **propene** into *ethylbutanoate* for use as a fragrance. Before production begins, management seek to know suitability of the target products, explaining the reaction mechanisms and suitable synthesis routes, and evaluating other industrial applications together with possible environmental or health hazards and appropriate mitigation measures. You have been invited to provide technical assistance.

Task

As a learner of Chemistry, prepare a report to guide the technical team.

Step	Expected Response	Score
Physical properties of the compounds to suit thier use	✓ *2-phenylethan-1-amine* *is* ***used in gas treatment (CO_2 removal)*** *because it is* ***basic and react with carbon dioxide since it is an acidic gas*** ✓Ea, *allowing it to* ***absorb carbon dioxide during industrial gas purification*** ✓Ea. ✓ *Polystyrene foam is used for* ***television packaging*** *because it is* ***lightweight and less dense*** ✓Ea, *while its* ***cellular (foam) structure contains numerous trapped air pockets that absorb shocks and vibrations*** ✓Ea, *thereby* ***protecting television sets and other fragile electronic equipment from damage during transportation and storage*** ✓Ea. ✓ *Ethyl butanoate is used for manufacture of* ***fragrances and perfumes*** *because ethyl butanoate is* ***highly volatile*** ✓Ea, *allowing it to* ***evaporate readily and diffuse rapidly through air*** ✓Ea, *thereby* ***releasing a pleasant fruity aroma that makes it suitable for use in perfumes, fragrances and scented products*** ✓Ea.	06
Synthesis of the target products	*Benzene can be converted into* ***2-phenylethan-1-amine*** *through a series of reactions involving alkylation, halogenation and substitution reactions.*  *Styrene undergoes* ***addition polymerisation*** *to form* ***polystyrene***, *a polymer widely used in packaging materials and insulation.*  *Propene can be converted into* ***ethylbutanoate*** *through subsequent industrial processes shown below.*  	09

		
Reaction mechanisms	1. Mechanism for production of a fragrance(ethyl butanoate)  2. Mechanism for production of a television pakaging material (polystyreneren) 	
Other industrial applications, environmental/health hazards and mitigation.	✓ 2-phenylethan-1-amine is used in **pharmaceutical synthesis (drug production)** because it contains **an amine functional group that allows it to form biologically active compounds** ✓ Ea, making it useful in **manufacturing antihistamines and other medicinal drugs** ✓ Ea. ✓ HOWEVER, this compound is **toxic and can irritate the skin, eyes and respiratory system** ✓ Ed, and improper handling may lead to	09

	chemical exposure and poisoning risks in industrial settings✓Ed. ✓ This can be mitigated by **using protective equipment such as gloves, goggles and fume hoods**✓Ea, and by **ensuring proper ventilation and controlled handling in laboratories and industries**✓Ea. --- ✓ Polystyrene foam is used in **thermal insulation of buildings and cold storage systems** because it has **low thermal conductivity due to trapped air in its structure**✓Ea, which reduces **heat transfer between internal and external environments**✓Ea. ✓ HOWEVER, polystyrene foam is **non-biodegradable and produces toxic fumes when burned** ✓Ed, leading to **long-term environmental pollution and release of harmful gases such as styrene compounds**✓Ed. ✓ This can be mitigated by **recycling and reusing polystyrene materials**✓Ea, and by **substituting with biodegradable or eco-friendly insulation and packaging materials**✓Ea. --- ✓ Ethyl butanoate is used in **food flavouring (artificial fruit flavouring)** because it has **a strong fruity aroma similar to pineapple and banana esters** ✓Ea, making it suitable for **enhancing taste and smell in processed foods and beverages**✓Ea. ✓ HOWEVER, ethyl butanoate is **flammable and may form vapours that irritate the respiratory system in poorly ventilated areas** ✓Ed, posing **fire and health risks in industrial environments**✓Ed. ✓ This can be mitigated by **storing it in sealed containers away from ignition sources** ✓Ea, and by **ensuring proper ventilation and safe handling procedures during production and use**✓Ea.	
	TOTAL	=

Assessment of Chemistry Paper2 (P525/2)

The consits of three practical scenario items drawn from three areas Physical, innorganic and oeganic chemistry
Item 1 from physical chemistry is compulsory
Required to choose one between innorganic and organic
The paper is expected to last for 3 hours and 15mins
You are required to read and re-read the scenario more than twice, understand what it is all about before you start to plan

Basis for asses for New UACE practical

Note: The order below can be interchanged depending on the item writer of the day.

No.	Basis of Assessment
1	Aim of the Experiment
2	Variables of the Experiment
3	Hypothesis
4	Procedure (with apparatus + materials)
5	Risks and Mitigations
6	Presentation of data
7	Recording of data
8	Analysis and interpretation of data
9	Conclusion and recommendations/advice

---

1. Aim of the experiment

Aim must be related to the scenario and should have two keywords: independent and dependent variables with a cause and effects. These variables may be quantitative or qualitative.

Quantitative variables include:

- Time measured in seconds using a stop clock/stopwatch/digital watch
- Temperature measured using a thermometer
- Length/height recording in cm
- Volume in cm^3 / concentration

Qualitative variables include:

- Nature/type of substance
- Colour
- Texture of substance/surface area

NOTE: If the aim is not related to the scenario, NO score.

2. Variables of the experiment

These must be identified as independent, dependent and controlled variables.

(a) Independent variable (manipulated variable): The variable which is changed or manipulated by the investigator (experimenter) and this causes a change in dependent variable.

(b) Dependent variable (responding variable): The variable which we measure for every change in the independent variable.

(c) Control variable: The variable(s) which remain constant throughout the experiment.

A hint on these variables will be included in the scenario. (If you follow the procedure well, you can get these variables too from it.)

Sample items

ITEM 1

A company producing industrial sodium carbonate for glass and detergent manufacture suspects that one batch contains impurities. Before supply, its percentage purity must be determined to confirm that it meets the required industrial standard.

The hydrochloric acid available in the laboratory has been stored for a long period and must first be standardized because its concentration may have changed. Borax reacts with hydrochloric acid according to the equation:

$$Na_2B_4O_7 \cdot 10H_2O\,(aq) + 2HCl\,(aq) \rightarrow 2NaCl\,(aq) + 4H_3BO_3\,(aq) + 5H_2O\,(l)$$

The laboratory manager recommends standardizing the acid using a solution prepared from 4.5 g of Solid Q. The standardized acid should then be used to determine the percentage purity of the sodium carbonate solution labelled FA2.

You are provided with:

- FA1: Hydrochloric acid solution.
- FA2: Impure sodium carbonate solution.
- Solid Q: Pure borax.
- Methyl orange indicator.
- Other apparatus and materials.

Carry out the investigation and submit your findings.

Task

As a learner of chemistry;

(a) Plan and design the experiment to help the manager, your design should include *(aim, hypothesis, variables, risks and mitigation, and procedure.*

(b) Carry out the experiment and record at least three titration results.

(c)Analyse and interpret the results.

(d) Draw a conclusion and recommend whether the sodium carbonate is suitable for industrial use.

Marking guide

Aim

To determine the molar concentration of hydrochloric acid solution FA1 using a standard borax solution and then determine the percentage purity of an impure sodium carbonate sample.

Hypothesis

The concentration of hydrochloric acid FA1 is approximately 0.100 mol dm^{-3} and the sodium carbonate sample used to prepare FA2 contains impurities.

Variables

Variable Type	Description
Independent Variable	Volume of standard borax solution and sodium carbonate solution used during titration.
Dependent Variable	Volume of hydrochloric acid required to neutralize the solutions.
Controlled Variables	Indicator used, pipette volume, temperature, concentration of prepared solutions and titration technique.

Risk and Safety Precautions

Hydrochloric acid is corrosive and may cause burns to the skin and eyes. Safety goggles and laboratory coats should be worn throughout the experiment. Acid spills should immediately be washed away with plenty of water. Care should be taken while handling glass apparatus to avoid breakage and injury.

FOR EXAMINERS' USE ONLY

Solution	Preparation	Purpose
FA1	Measure exactly **8.3 cm^3** of concentrated hydrochloric acid (sp. gr. 1.18, approximately 12 M) and carefully dilute to **1000 cm^3** with distilled water.	Hydrochloric acid approximately **0.100 mol dm^{-3}**
Solid Q	Accurately weigh approximately **4.50 g** of pure borax ($Na_2B_4O_7.10H_2O$) for each candidate.	Primary standard for standardizing hydrochloric acid.
FA2	Prepare by dissolving **1.66 g** of impure sodium carbonate (approximately **80% purity**) and make up to **250 cm^3** with distilled water.	Percentage purity determination.

Procedure I

Preparation of Standard Borax Solution (FA3)

Approximately 4.50 g of Solid Q was accurately weighed into a clean dry beaker.

About 100 cm^3 of distilled water was added and the mixture stirred continuously until all the solid dissolved completely.

The solution was transferred quantitatively into a 250 cm^3 volumetric flask. The beaker was rinsed several times with distilled water and the washings transferred into the flask.

Distilled water was added carefully up to the calibration mark. The flask was stoppered and shaken thoroughly to obtain a uniform standard borax solution labelled FA3.

Standardization of Hydrochloric Acid

A burette was rinsed and filled with hydrochloric acid solution FA1.

Using a pipette, exactly 25.0 cm^3 of FA3 was transferred into a clean conical flask.

Two drops of methyl orange indicator were added.

The solution was titrated against hydrochloric acid until the indicator changed from yellow to orange-red.

The titration was repeated until concordant titre values were obtained.

Procedure II

Determination of Percentage Purity

A clean pipette was rinsed with FA2 and exactly 25.0 cm^3 transferred into a clean conical flask.

Two drops of methyl orange indicator were added.

The solution was titrated with the standardized hydrochloric acid until the end point was reached.

The titration was repeated until consistent titre values were obtained.

The results obtained were then used to determine the percentage purity of the sodium carbonate sample.

Results: PART I

Mass of beaker + Solid Q = **7.20 g**

Mass of empty beaker = **2.70 g**

Mass of Solid Q used = **4.50 g**

Volume of pipette used = **25.0 cm^3**

Titration	1	2	3
Final burette reading (cm^3)	23.60	33.55	43.45
Initial burette reading (cm^3)	0.00	9.95	19.85
Titre value (cm^3)	23.60	23.60	23.60

Calculations

$$\text{Average titre} = \frac{23.60 + 23.60}{2}$$

$$= 23.60\, cm^3$$

Relative Formula Mass of Borax

$$Na_2B_4O_7.10H_2O$$

$$= (23 \times 2) + (11 \times 4) + (16 \times 7) + (10 \times 18)$$

$$= 46 + 44 + 112 + 180$$

$$= 382$$

$382\, g$ of borax contain 1 mole

$$4.50\, g \text{ contain } \frac{4.50}{382}$$

$$= 0.0118 \text{ moles}$$

$250\, cm^3$ of FA3 contain 0.0118 moles

$$25.0\, cm^3 \text{ contain } \frac{25.0 \times 0.0118}{250}$$

$$= 0.00118 \text{ moles}$$

Reaction Equation

$$Na_2B_4O_7 + 2HCl + 5H_2O \rightarrow 2NaCl + 4H_3BO_3$$

1 mole of borax

reacts with

2 moles of HCl

0.00118 moles of borax

react with

0.00118×2

$= 0.00236$ moles of HCl

$23.60\, cm^3$ of FA1 contain 0.00236 moles

$$1000\, cm^3 \text{ contain } \frac{1000 \times 0.00236}{23.60}$$

$$= 0.100\, mol\, dm^{-3}$$

Interpretation of Results

$$\therefore$$

$$\boxed{\text{Concentration of FA1} = 0.100\, mol\, dm^{-3}}$$

Interpretation

The concentration of hydrochloric acid solution FA1 was found to be **0.100 mol dm^{-3}**.

Conclusion

Hydrochloric acid FA1 has been successfully standardized and can now be used accurately for quantitative analysis.

PART II : DETERMINATION OF PERCENTAGE PURITY OF SODIUM CARBONATE

Results

Volume of pipette used = **25.0 cm^3**

Titration	1	2	3
Final burette reading (cm^3)	25.05	35.00	44.95
Initial burette reading (cm^3)	0.00	9.95	19.90
Titre value (cm^3)	25.05	25.05	25.05

Calculations

$$\text{Average titre} = \frac{25.05 + 25.05}{2}$$

$$= 25.05\, cm^3$$

Reaction Equation

$$Na_2CO_3 + 2HCl \rightarrow 2NaCl + CO_2 + H_2O$$

$25.05\, cm^3$ of FA1 contain

$$0.100 \times \frac{25.05}{1000}$$

$$= 0.002505 \text{ moles of HCl}$$

1 mole Na_2CO_3

reacts with

2 moles HCl

$$\text{Moles of } Na_2CO_3 = \frac{0.002505}{2}$$

$$= 0.0012525$$

$$25.0\,cm^3 \text{ contain } 0.0012525 \text{ moles}$$

$$250\,cm^3 \text{ contain } 0.012525 \text{ moles}$$

$$\text{Mass of pure } Na_2CO_3 = 0.012525 \times 106$$

$$= 1.328\,g$$

$$\text{Percentage purity} = \frac{1.328}{1.66} \times 100$$

$$= 80.0\%$$

Interpretation of Results

$$\boxed{\text{Percentage purity} = 80.0\%}$$

Interpretation

The impure sodium carbonate sample contained approximately **80.0%** pure sodium carbonate.

Conclusion

The hydrochloric acid solution FA1 was successfully standardized to a concentration of **0.100 mol dm^{-3}**. Using the standardized acid, the sodium carbonate sample was found to have a percentage purity of approximately **80.0%**.

Recommendation

The sodium carbonate should undergo further purification before being supplied for industrial applications where high purity is required.

ITEM 2

A cement factory has acquired a raw material but it's uncertain about its constituent ions. Initial investigations suggest that it's likely to contain two cations and two anions. Suitable material should contain aluminium as one of the cations and sulphate or carbonate as one of the anions. To prevent compromising the quality of their product, the production manager wants to identify the specific ions in the material before using it in the production process. This can be attained by carrying out a qualitative analysis on the sample, using the available laboratory reagents to report observations and hence corresponding deductions. However due to limitations in their laboratory, the manager has sought your chemistry expertise to assist with the analysis whether the company should use the raw material or not. You are provided with; Q which is a sample of the raw material, some standard laboratory test reagents, some apparatus.

Task: As a member in chemistry class

a. **Plan and design an experiment**

Aim

To identify the cations and anions present in sample Q using standard qualitative analysis reagents by observing colour changes, precipitate formation and gas evolution.

Hypothesis

Sample Q contains two cations and two anions. Aluminium ions and at least one of carbonate or sulphate ions are expected to be present and can be confirmed using standard laboratory qualitative tests.

Variables

Independent variable: Nature of reagents added to sample Q (HCl, NaOH, NH_3, Ba^{2+} solution, heat).

Dependent variable: Observations recorded (precipitate formation, colour change, gas evolution, solubility changes).

Controlled variables: Mass of sample Q used, volume/concentration of reagents used, temperature conditions during heating, and time of reaction.

Safety precautions (Risks and Mitigation)

- Acids and alkalis may cause burns → wear gloves, goggles, lab coat and handle with care.
- Heating may cause burns → use test tube holder and heat gently before strong heating.
- Gases such as CO_2 and SO_2 may irritate respiratory system → carry out tests in well-ventilated area.
- Barium salts are toxic → avoid ingestion and skin contact, dispose waste properly.

b. **Carry out the experiment and record observations and deductions**

TEST / PROCEDURE	OBSERVATION	INFERENCE
A spatula end full of Q was placed in a dry test tube and heated gently then strongly.	Green solid changed on heating; colourless liquid droplets formed on cooler parts of test tube; colourless gas evolved; black residue formed.	Hydrated salt present (water of crystallization). Gas turning limewater milky indicates $CO_2 \rightarrow CO_3^{2-}$ likely present. Black residue suggests metal oxide → Cu^{2+} / Ni^{2+} / Fe^{2+} possible.
Q was dissolved in dilute nitric acid until complete dissolution.	Green solution formed.	Transition metal cations such as Cu^{2+}, Fe^{2+} or Ni^{2+} may be present.
NaOH solution added dropwise then in excess.	Green precipitate formed; insoluble in excess; effervescence observed in early stage.	Al^{3+} may be present (white/gelatinous ppt expected); CO_2 indicates CO_3^{2-} present.
Filtration carried out; residue and filtrate separated.	Residue: green solid. Filtrate: colourless solution.	Residue contains transition metal hydroxides/oxides; filtrate contains amphoteric ions such as Al^{3+}, Zn^{2+} or Pb^{2+}.
To filtrate: dilute HNO_3 added until just acidic; solution divided into portions.	White precipitate formed in some conditions; soluble in excess NaOH.	Zn^{2+} / Al^{3+} / Pb^{2+} possible; amphoteric behaviour observed.
(i) To first portion: NaOH added dropwise then excess.	White precipitate soluble in excess forming colourless solution.	Zn^{2+} or Al^{3+} confirmed possible.
(ii) To second portion: NH_3 added dropwise then excess.	White precipitate insoluble in excess.	Pb^{2+} or Al^{3+} may be present.
(iii) To third portion: KI solution added.	No visible change.	Al^{3+} likely present (Pb^{2+} would give yellow ppt).
(iv) Confirmatory test: acid + indicator then NH_3 added.	Characteristic blue-lake / gelatinous precipitate formed.	Al^{3+} confirmed present.
(v) To fifth portion: $Ba(NO_3)_2$ added then acidified.	White precipitate insoluble in dilute acid.	SO_4^{2-} confirmed present.

c. **Data Interpretation**

Cations present: Al^{3+} and Ni^{2+} (or transition metal ions). Anions present: SO_4^{2-} and CO_3^{2-}.

d. **Recommendation**

Since the sample contains aluminium and important anions such as sulphate and carbonate, it is suitable for use in cement production provided impurities are within acceptable industrial limits.

ITEM 3

Categories of organic compounds (Areas of assessment in qualitative organic analysis)

- ***Alcohols (–OH functional group):*** *These are organic compounds containing the* ***hydroxyl group (–OH)*** *as the functional group and may be classified as* ***primary, secondary, or tertiary alcohols****.*
- ***Carbonyl compounds (Aldehydes and Ketones):*** *These are compounds containing the* ***carbonyl group (C=O)*** *as the functional group. Aldehydes have the carbonyl group at the end of the carbon chain while ketones have it within the carbon chain.*
- ***Carboxylic acids and carboxylate salts:*** *These are organic compounds containing the* ***carboxyl group (–COOH)*** *or* ***carboxylate ion ($–COO^-$)*** *respectively and are generally acidic in nature.*
- ***Halocarboxylic acids (e.g. bromopropanoic acid):*** *These are carboxylic acids that contain a* ***halogen atom (C–X bond where X = Cl, Br, I)*** *in their structure, which affects their chemical reactivity.*
- ***Phenols:*** *These are aromatic compounds in which the* ***hydroxyl group is directly attached to a benzene ring****, giving them weak acidic properties.*
- ***Amines:*** *These are organic compounds containing the* ***amino group ($–NH_2$, –NHR, $–NR_2$)*** *and behave as weak bases due to the presence of a lone pair on nitrogen.*

Nature of organic compounds in qualitative analysis

- ***Structure of the compound:*** *Organic compounds may be* ***aliphatic (straight chain or branched)*** *or* ***aromatic (containing a benzene ring)****, which affects their chemical behaviour.*
- ***Functional groups:*** *The chemical properties of organic compounds depend mainly on functional groups such as* ***hydroxyl (–OH), carbonyl (C=O), carboxyl (–COOH), and others****.*
- ***Classification of functional groups:*** *Alcohols may be classified as* ***primary, secondary, or tertiary****, while carbonyl compounds may be classified as* ***aldehydes or ketones****.*
- ***Bond saturation:*** *Organic compounds may be* ***saturated (only single bonds)*** *or* ***unsaturated (double or triple bonds present)****, which influences their reactivity.*

Sample Item

ITEM 3

A petroleum processing plant in the Albertine region has unveiled a new brand of high-quality fuel that reduces emissions during combustion in motor engines. This cleaner-burning fuel is often made by blending gasoline with an alcohol.

A suitable alcohol for the formulation should be a ***methyl primary alcohol****.*

The management has received two alcohol samples, A and B, from the supplier; however, their labels are not clearly identified.

To avoid compromising the quality of the fuel, the production manager wishes to determine the nature of the organic compound in sample Q using qualitative analysis.

You are provided with sample Q, standard laboratory reagents, and apparatus.

(a) Experimental design

Aim

To determine the nature of substance Q using qualitative analysis by carrying out standard organic tests and recording observations.

Hypothesis

Substance Q is an organic compound whose functional group and structural nature can be identified using appropriate qualitative analysis tests.

Variables

- ***Independent variable:*** *Sample Q and reagents used in different chemical tests.*
- ***Dependent variable:*** *Observations made such as colour change, precipitate formation, gas evolution, or solubility changes.*
- ***Controlled variables:*** *Volume of sample, concentration of reagents, temperature, and time of reaction.*

Safety precautions

- *Carry out tests in a well-ventilated area due to flammability and volatility of organic compounds.*

- *Wear lab coat, gloves, goggles, and closed shoes to prevent chemical exposure.*

(e) Experimental procedures, observations and deductions

TEST / PROCEDURE	OBSERVATIONS	DEDUCTIONS
A sample of Q was ignited in a porcelain dish.	Burns with a clean blue, non-sooty flame.	Q is likely an aliphatic organic compound with low carbon content.
Q was mixed with water and tested with litmus paper.	Completely miscible; no change in blue or red litmus.	Q is a neutral, polar organic compound.
Sodium carbonate solution was added to Q.	No effervescence observed.	No carboxylic acid present.
Neutral iron(III) chloride solution was added.	No colour change observed.	No phenolic group present.
2,4-dinitrophenylhydrazine (Brady's reagent) was added.	No precipitate formed.	No carbonyl group present.
Q was heated with ethanoic acid and concentrated H_2SO_4, then poured into cold water.	Fruity smell observed.	Ester formation occurs → alcohol present.
Acidified potassium dichromate(VI) was added.	Orange solution turns green.	Q is a primary or secondary alcohol.
Iodine in alkali (iodoform test) was carried out.	Yellow precipitate formed.	Methyl group adjacent to –OH present.
Lucas reagent was added and left to stand.	No visible change after 10 minutes.	Q is a methyl primary alcohol.

(f) Data interpretation

The results of qualitative tests indicate that substance Q is an aliphatic saturated methyl primary alcohol.

(g) Recommendations

Management should ensure that substance Q is safely stored in tightly closed containers away from heat and ignition sources due to its flammability. Proper labeling and handling procedures should be enforced before use in fuel blending.

oTHE ITEM 3

A dermatologist in a nearby town uses a liquid known as "Liquiderm" to cleanse patients' skin before treatment. This liquid is used to remove residual oils and make-up from the skin surface.
Recently, the dermatologist received a new batch of the liquid from a different supplier and would like to verify its quality before use.
The ideal liquid for this process is expected to contain an ***aliphatic methyl ketone****.*
To confirm the nature of the organic compound present, a qualitative analysis is required to identify the specific functional group in the sample.
One sample, labelled P, has been provided to the school laboratory technician for analysis. However, due to other departmental duties, the technician has requested your assistance.
You are provided with: sample P, common laboratory reagents, a heat source, and standard laboratory apparatus.

TASK

As an advanced level chemistry learner:

1. *Plan and design an experiment to guide the technician.*

2. Carry out the experiment and record observations together with deductions for each test procedure.
3. From the results obtained, state a clear conclusion about the nature of sample P.

ITEM

Experimental design

Aim

To determine the nature of substance P through qualitative analysis using standard laboratory reagents by recording observations obtained from each test carried out.

Hypothesis

Substance P is an organic compound whose functional group can be identified using qualitative chemical tests, and it is expected to be an aliphatic methyl ketone.

Variables

Variable Type	Description
Independent variable	Sample P and the different chemical tests/reagents applied to it.
Dependent variable	Observations made in each test such as colour change, gas evolution, precipitate formation, or solubility changes.
Controlled variables	Volume of sample used, volume and concentration of reagents, temperature, and duration of reaction.

Risks and mitigation measures

- *Sample P is volatile and highly flammable, which may cause fire hazards. This is controlled by working in a well-ventilated area away from open flames.*
- *Glassware may break during heating, causing injuries. This is controlled by using test tube holders and racks during experiments.*
- *Some reagents are corrosive and may cause burns or irritation. This is controlled by wearing lab coats, gloves, goggles, and closed shoes.*

(b) Experimental procedures, observations and deductions

Step	Procedure	Observations	Deductions
1	A spatula-endful of P was burnt on a porcelain dish.	P burns with a blue non-sooty flame.	P is an aliphatic compound with low carbon content.
2	About 1 cm^3 of P was mixed with 1 cm^3 of water and tested with both red and blue litmus papers.	P is miscible with water forming a colourless solution. No change in litmus papers.	P is a neutral, polar compound of low molecular mass.
3	Neutral iron(III) chloride solution was added to the solution.	No observable change.	Phenolic compounds are absent.
4	Brady's reagent (2,4-DNPH) was added.	Yellow precipitate formed.	A carbonyl compound is present.
5	Acidified potassium dichromate(VI) was added and warmed.	Orange solution changes to green.	Oxidation occurs, indicating an aldehyde and not a ketone.
6	Iodoform test using iodine and sodium hydroxide, followed by warming.	Yellow precipitate formed.	Methyl group adjacent to carbonyl is present (methyl aldehyde).
7	Fehling's solution was added and heated.	Brick-red precipitate formed.	Reducing aldehyde is present.

(c) Conclusion and recommendation

The results indicate that substance P is a saturated aliphatic methyl aldehyde rather than an aliphatic methyl ketone.

It is therefore not suitable for use in the dermatological cleaning formulation that requires a methyl ketone.

END