

Tr JoelPCM Academic Council*Advanced Secondary Curriculum — ASC*

CHEMISTRY

PAPER 1 — THEORY | SET III

2 Hours 45 Minutes

Candidate Name: _____ Index No: _____

Centre Name: _____ Year: 2026

INSTRUCTIONS TO CANDIDATES

1. Do not open this booklet until you are told to do so.
2. Write your name, index number and centre in the spaces provided above.
3. Answer the compulsory item in Section A.
4. In Section B Part I, answer the compulsory item.
5. In Section B Part II, answer ONE item from the TWO provided.
6. All answers must be written in the spaces provided in this booklet.
7. Where applicable, show ALL working clearly. Give answers to 3 significant figures where appropriate.
8. The use of a silent, non-programmable scientific calculator is permitted.
9. Atomic masses: H = 1; C = 12; N = 14; O = 16; S = 32; P = 31; Cl = 35.5; Br = 80

ASSESSMENT OBJECTIVES AND TOPICS

Section A — Item 1 (AO3): Moles & Equations, Solution Concentration, % Composition

Section B, Part I — Item 2 (AO1): Atomic & Electronic Structure, Ionisation Energy, Electron Affinity, Periodicity I & II

Section B, Part II — Item 3 or 4 (AO2): Organic Chemistry I, Organic Chemistry II, Organic Chemistry III

SECTION A — Answer the compulsory item

Item 1

Assessment Objective 3 (AO3) — Compulsory

Topics Assessed:

Moles & Equations | Solution
Concentration | % Composition

A pharmaceutical quality control laboratory at MedPharma Uganda Ltd in Kampala regularly prepares standard working solutions from concentrated reagent-grade acids and bases. These solutions are used in drug purity testing, volumetric analysis, pH calibration, and industrial cleaning of manufacturing equipment. The laboratory manager has assigned a team of analytical chemists to calculate the exact volumes and compositions needed to prepare a new batch of standard solutions. All concentrated reagents are available in the laboratory stock and their relevant data are summarised in Table 1.1.

Table 1.1 — Data for concentrated reagents available in the MedPharma laboratory

Reagent	% by Mass (Purity)	Density (g cm ⁻³)	Molar Mass (g mol ⁻¹)
Phosphoric acid (H ₃ PO ₄)	85%	1.70	98
Sulfuric acid (H ₂ SO ₄)	98%	1.84	98
Hydrochloric acid (HCl)	37.3%	1.18	36.5
Ammonia solution (NH ₃)	29%	0.880	17

The laboratory also routinely analyses the composition of solutions prepared from solid solutes. A sample calculation involves dissolving 5 g of urea (CO(NH₂)₂) in 95 g of water. A second sample involves a 2% by mass naphthalene (C₁₀H₈) solution in benzene (C₆H₆).

Task

You are the lead analytical chemist at MedPharma Uganda. Write a technical calculations report addressing the following:

- Calculate the volume of the concentrated phosphoric acid (H₃PO₄) from Table 1.1 that is required to prepare 25 cm³ of a 0.1 M phosphoric acid working solution. Show all working clearly.
- Calculate the volume of the concentrated sulfuric acid (H₂SO₄) from Table 1.1 that is required to prepare 1.0 litre of a 2 M sulfuric acid solution for use in the acid-washing unit. Show all steps.
- The laboratory needs 1.0 litre of a 2 M hydrochloric acid solution for pH calibration. Using the data for HCl in Table 1.1, calculate the volume of concentrated hydrochloric acid required.
- Calculate the volume of the 29% concentrated ammonia solution from Table 1.1 required to prepare 1.0 litre of a 2 M ammonia solution for use in the neutralisation unit.

(e) A technician dissolves 5 g of urea ($\text{CO}(\text{NH}_2)_2$) in 95 g of distilled water to prepare a preservation buffer. Calculate the percentage by mass of urea in the resulting solution.

(f) The laboratory receives a sample labelled '2% by mass naphthalene in benzene.' Calculate the percentage by mass of benzene in this solution and determine the mass of benzene present in 500 g of this solution.

SECTION B — PART I (AO1): Answer the compulsory item*Topics: Atomic & Electronic Structure | Ionisation Energy | Electron Affinity | Periodicity I & II***Item 2***Assessment Objective 1 (AO1) — Compulsory***Topics Assessed:**Atomic & Electronic Structure |
Ionisation Energy | Electron Affinity |
Periodicity I & II

A materials science research institute in Nairobi, Kenya, is investigating the electronic properties of Period 3 elements — silicon (Si), phosphorus (P), and sulphur (S) — to evaluate their suitability for use as semiconductor dopants, industrial catalysts, and chemical reagents. The team is analysing successive ionisation energies and first electron affinities to understand the atomic structure and reactivity of these elements. The relevant data have been compiled in Tables 2.1 and 2.2.

Table 2.1 — Successive ionisation energies (kJ mol^{-1}) for selected Period 3 elements

Element	1st IE	2nd IE	3rd IE	4th IE	5th IE
Silicon (Si)	787	1577	3230	4355	16090
Phosphorus (P)	1060	1896	2908	4954	6272
Sulphur (S)	1000	2258	3381	4565	6995

Table 2.2 — First electron affinities (kJ mol^{-1}) for selected Period 3 elements

Element	Al	Si	P	S
First Electron Affinity (kJ mol^{-1})	-44	-134	-71.7	-200

The research institute also requires a detailed analysis of the electrical conductivity of aluminium versus phosphorus, their reactions with sodium hydroxide, and the acid-base behaviour of the oxides of magnesium, aluminium, and silicon.

Task

You are a research scientist at the institute writing a comprehensive report. Your report must address ALL of the following:

(a) Using Table 2.1, state and explain the general trend observed in the successive ionisation energies of each element. In your explanation, identify and account for the large jumps in ionisation energy where they occur for silicon, phosphorus, and sulphur respectively.

(b) Using Table 2.1, explain why:

(i) The first ionisation energy of sulphur (1000 kJ mol^{-1}) is LESS than that of phosphorus (1060 kJ mol^{-1}), even though sulphur has a higher nuclear charge.

(ii) The third ionisation energy of phosphorus (2908 kJ mol^{-1}) is LESS than that of silicon (3230 kJ mol^{-1}).

(c) Using Table 2.2:

- (i) State the trend in first electron affinity from aluminium to sulphur across Period 3.
- (ii) Explain the trend you described in (c)(i), referring to nuclear charge, atomic radius, and electronic configuration.
- (iii) Define the term first electron affinity.
- (iv) State THREE factors that can affect the value of electron affinity of an element.

(d) Both aluminium and phosphorus have compounds in the +3 oxidation state. Using electronic configuration, explain why aluminium conducts electricity but common allotropes of phosphorus (white and red) do not.

(e) Write balanced equations for the reaction of each element — aluminium and phosphorus — with sodium hydroxide solution.

(f) Describe and explain, with equations, how the oxides of magnesium (MgO), aluminium (Al_2O_3), and silicon (SiO_2) react with:

- (i) Sodium hydroxide solution ($\text{NaOH}(\text{aq})$)
- (ii) Hydrochloric acid solution ($\text{HCl}(\text{aq})$)

State clearly the conditions required for each reaction, if any.

SECTION B — PART II (AO2): Answer ONE item only*Topics: Organic Chemistry I | Organic Chemistry II | Organic Chemistry III***Item 3***Assessment Objective 2 (AO2) — Attempt 1 of 2***Topics Assessed:**

Organic Chemistry I | Organic Chemistry II | Organic Chemistry III

An organic chemistry research team at PharmaSynth Tanzania Ltd in Dar es Salaam is investigating two unknown organic compounds — Compound Q and Compound Y — isolated from samples submitted for pharmaceutical analysis. Compound Q has been identified by mass spectrometry as a bromoalkane of the general formula $C_nH_{2n+1}Br$, and elemental analysis has confirmed that it contains 65.04% by mass of bromine. Compound Y is an organic compound of molecular formula $C_nH_{3n}O$, identified through combustion analysis.

The research team has performed a series of experiments to determine the structures of these compounds and investigate their reactions. The experimental data are described below.

Compound Q — Bromoalkane Data:Molecular formula type: $C_nH_{2n+1}Br$

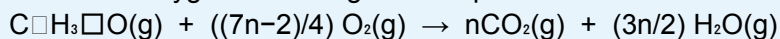
Percentage by mass of bromine: 65.04%

Molar mass of Br = 80 g mol^{-1}

When Q is refluxed with aqueous potassium hydroxide (KOH(aq)), a compound W is formed.

W forms two layers when mixed with concentrated HCl and anhydrous $ZnCl_2$ after five minutes.**Compound Y — Combustion Data:**Molecular formula type: $C_nH_{3n}O$ 30 cm^3 of compound Y was burnt in excess oxygen and cooled to room temperature.240 cm^3 of residual gas remained after combustion.On addition of concentrated KOH solution, the volume reduced by 180 cm^3 .

Y burns in oxygen according to the equation:

**Task**

You are the lead research chemist at PharmaSynth Tanzania. Write a detailed analytical report that addresses ALL of the following:

COMPOUND Q:

(a) Given that Q contains 65.04% by mass of bromine and has the general formula $C_nH_{2n+1}Br$, determine the molecular mass of Q and hence identify the value of n. Show all working.

(b) Write the structural formulae and IUPAC names of ALL possible structural isomers of Q.

(c) When Q is refluxed with aqueous KOH(aq), compound W is formed. W forms two separate layers when mixed with concentrated HCl and anhydrous ZnCl₂ after 5 minutes. Identify:

- (i) Compound Q (name and structural formula)
- (ii) Compound W (name and structural formula) and explain the Lucas test result.

(d) Write equations and suggest a mechanism for the reaction between:

- (i) Q and alcoholic potassium hydroxide solution (KOH in ethanol)
- (ii) Q and an alkaline solution of phenol (PhO⁻Na⁺ in NaOH(aq))

COMPOUND Y:

(e) Using the combustion data provided, determine the molecular formula of Y. Show clearly how you use the gas volume data (residual gas = 240 cm³; volume absorbed by KOH = 180 cm³) to find n.

(f) Write the structural formulae and IUPAC names of all possible structural isomers of Y.

(g) Y reacts with sodium metal producing bubbles of a colourless gas. Identify Y and write an equation for the reaction with sodium.

(h) Discuss the reactions of Y with sulfuric acid (H₂SO₄). Write equations and describe the mechanism(s) involved for each type of reaction that can occur.

Item 4

Assessment Objective 2 (AO2) — Attempt 1 of 2

Topics Assessed:

Organic Chemistry I | Organic Chemistry II | Organic Chemistry III

A second-year chemistry research club at the University of Rwanda in Kigali has been conducting a comparative laboratory investigation into the physical and chemical properties of several organic compounds: phenol (C_6H_5OH), cyclohexanol ($C_6H_{11}OH$), ethanol (C_2H_5OH), ethylamine ($C_2H_5NH_2$), and benzene (C_6H_6). The students have recorded a series of observations and anomalies from their experiments and are required to write a scientific explanation report.

The following observations were recorded during the investigation:

Observation A: Phenol is a stronger acid than cyclohexanol in aqueous solution.

Observation B: The boiling point of ethanol ($78\text{ }^\circ\text{C}$) is higher than that of ethylamine ($17\text{ }^\circ\text{C}$), despite both having similar molecular masses.

Observation C: Phenol is sparingly soluble in water but dissolves very readily in dilute sodium hydroxide solution.

Observation D: Phenol reacts readily with bromine water at room temperature to give a white precipitate, but benzene requires a Lewis acid catalyst (e.g. $FeBr_3$) to react with bromine and does NOT react with bromine water.

Additional experimental data collected by the team:

Compound	Molecular Formula	Molar Mass (g mol^{-1})	Boiling Point ($^\circ\text{C}$)	pKa / pKb	Solubility in Water
Phenol	C_6H_5OH	94	182	9.9 (acid)	Slightly (8.3 g/100 mL)
Cyclohexanol	$C_6H_{11}OH$	100	161	~16 (acid)	Slightly (3.6 g/100 mL)
Ethanol	C_2H_5OH	46	78	~16 (acid)	Fully miscible
Ethylamine	$C_2H_5NH_2$	45	17	3.3 (base)	Fully miscible
Benzene	C_6H_6	78	80	—	Very sparingly soluble

Task

You are a chemistry tutor at the University of Rwanda preparing a detailed explanatory report for the research club. Your report must explain each observation fully using your knowledge of molecular structure, bonding, and organic chemistry. Address ALL of the following:

(a) Observation A — Phenol is a stronger acid than cyclohexanol:

Explain why phenol ($pK_a = 9.9$) is a significantly stronger acid than cyclohexanol ($pK_a \approx 16$), even though both contain an $-OH$ group. In your answer, describe the role of the benzene ring in stabilising the phenoxide ion ($C_6H_5O^-$) formed after deprotonation, using the concept of resonance/delocalisation.

(b) Observation B — Ethanol has a higher boiling point than ethylamine:

Explain why ethanol (B.P. 78 °C) has a higher boiling point than ethylamine (B.P. 17 °C) despite having similar molecular masses (~45–46 g mol⁻¹). Your answer must refer to the type and relative strength of the intermolecular forces present in each compound, and the electronegativity of O versus N.

(c) Observation C — Phenol is sparingly soluble in water but very soluble in NaOH(aq):

(i) Explain why phenol has limited solubility in water despite its –OH group being capable of hydrogen bonding. Refer to the hydrophobic benzene ring.

(ii) Write an equation for the reaction of phenol with NaOH(aq) and explain why the product (sodium phenoxide, C₆H₅O⁻Na⁺) is much more soluble in water than phenol itself.

(d) Observation D — Phenol reacts with Br₂(aq) without a catalyst, but benzene does not:

(i) Explain why benzene does NOT react with bromine water (Br₂(aq)) at room temperature but DOES react with anhydrous Br₂ in the presence of FeBr₃. Describe the role of the FeBr₃ catalyst and name the type of reaction mechanism involved.

(ii) Explain why phenol reacts instantly with bromine water WITHOUT a catalyst. Describe the effect of the –OH group on the electron density of the benzene ring and hence on its reactivity toward electrophiles.

(iii) Write a balanced equation for the reaction of phenol with excess bromine water and state the observation (including the name of the product).

END OF PAPER

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