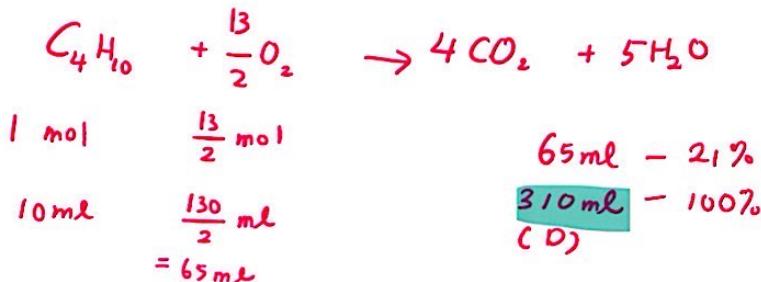


- 1 In this question, you should assume air contains 21% oxygen,

What is the minimum volume of air required to ensure complete combustion of 10 mL of butane gas under room conditions? (Given that, 1 mol of gas occupies 24 L at room conditions)

- A 14 mL B 27 mL C 65 mL D 310 mL



- 2 Laughing gas is a compound formed from nitrogen and oxygen in which there are 1.75 g of nitrogen to 1.00 g of oxygen. Below are given the compositions of several nitrogen-oxygen compounds. Which of these is laughing gas?

- A 6.35 g nitrogen, 7.26 g oxygen B 4.63 g nitrogen, 10.58 g oxygen
 C 8.84 g nitrogen, 5.05 g oxygen D 9.62 g nitrogen, 16.50 g oxygen

$\begin{array}{l} \text{Mass} \\ \text{mole} \\ \text{Ratio} \end{array}$	$\begin{array}{rcl} \text{N} & = & \text{O} \\ 1.75\text{g} & = & 1\text{g} \\ 0.125 & = & 0.0625 \\ 2 & = & 1 \end{array}$	$\begin{array}{rcl} \text{mol} & & \\ 0.631 & : & 0.3156 \\ 2 & = & 1 \end{array}$
---------------------------------------------------------------------------	-----------------------------------------------------------------------------------------------------------------------------	------------------------------------------------------------------------------------

$\therefore \text{N}_2\text{O}$

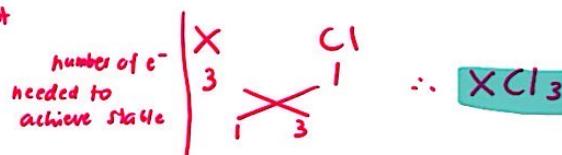
- 3 The table gives the successive ionisation energies of an element X.

	1 st 1.89	2 nd 15	3 rd 1.78	4 th 125	5 th 2	6 th
Ionisation energy/ kJ mol ⁻¹	950	1800	2700	4800	6000	12300

What could be the formula of a chloride of X?

- A XCl B XCl₂ C XCl₃ D XCl₄

X is Group 15 element



- 4 The ion X²⁺ has the same electronic configuration as the atom Kr. (36 electrons)

What is the electronic configuration of an atom of X? X has 38 electrons

- A 1s² 2s² 2p⁶ 3s² 3p⁶ 3d¹⁰ 4s² 4p⁶
 C 1s² 2s² 2p⁶ 3s² 3p⁶ 4s² 4p⁶ 4d¹⁰
 B 1s² 2s² 2p⁶ 3s² 3p⁶ 3d¹⁰ 4s² 4p⁶ 5s² (38 electrons)
 D 1s² 2s² 2p⁶ 3s² 3p⁶ 4s² 4p⁶ 4d¹⁰ 5s² d

- 5 The melting points of the Period 3 elements sodium to aluminium are shown in the table.

Element	Na	Mg	Al
Melting point/ K	371	923	932

Which factor explains the increase in melting points from sodium to aluminium?

- A the changes in first ionisation energy from sodium to aluminium
- B the increase in electronegativity from sodium to aluminium
- C the increase in the A_f of the elements from sodium to aluminium
- D the increase in the number of outer electrons in each atom from sodium to aluminium

→ more valence e^- , stronger metallic bonding,
high melting point.

- 6 These compounds have the physical properties shown in the table.

Compound	P	Q	R
Melting point/ °C	2852	993	-119
Boiling point/ °C	3600	1695	39
Conductivity (solid)	poor	poor	Poor
Conductivity (liquid)	good	good	Poor
Conductivity (aqueous)	insoluble	good	insoluble

What might be the identities of P, Q, and R?

	P	Q	R
A	MgO	KCl	NH ₃
B	MgO	NaF	C ₂ H ₅ Br
C	SiO ₂ X	KCl	C ₂ H ₅ Br
D	SiO ₂	NaF	HCl

(soluble) ↓
Ionic compound
↓ Covalent compound

boiling point lower (-33.3°C), soluble in water

does not conduct electricity

soluble in water

- 7 A 10.0 mL bubble of an ideal gas is formed on the sea bed where it is at a pressure of 2020 kPa. Just below the sea surface, the pressure is 101 kPa and the temperature is the same as the sea bed. P

What is the volume of the bubble when it rises to just below the sea surface?

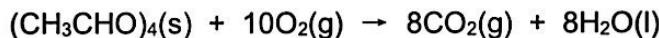
- A 10 mL
- B 20.2 mL
- C 200 mL
- D 2020000 mL

$$P_1 V_1 = P_2 V_2$$

$$2020 \times 10 = 101 \times V_2$$

$$V_2 = 200 \text{ mL}$$

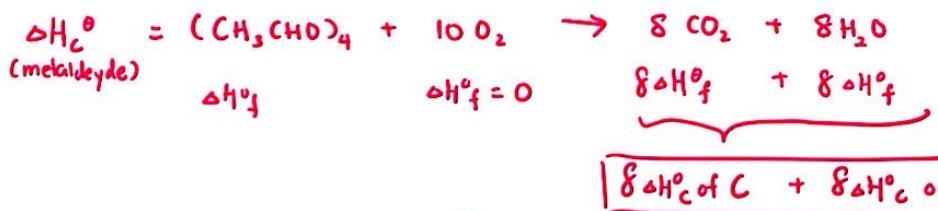
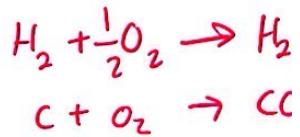
- 8 Metaldehyde, $(\text{CH}_3\text{CHO})_4$, is used as a solid fuel for camping stoves. The equation for the complete combustion of metaldehyde is shown.



ΔH_c^θ = standard enthalpy change of combustion

Which expression will give a correct value for the enthalpy change of formation of metaldehyde?

- A $\Delta H_c^\theta(\text{metaldehyde}) - [8 \times \Delta H_c^\theta(\text{carbon}) + 8 \times \Delta H_c^\theta(\text{hydrogen})]$
- B $\Delta H_c^\theta(\text{metaldehyde}) - [8 \times \Delta H_c^\theta(\text{carbon}) + 16 \times \Delta H_c^\theta(\text{hydrogen})]$
- C $[8 \times \Delta H_c^\theta(\text{carbon}) + 8 \times \Delta H_c^\theta(\text{hydrogen})] - \Delta H_c^\theta(\text{metaldehyde})$
- D $[8 \times \Delta H_c^\theta(\text{carbon}) + 16 \times \Delta H_c^\theta(\text{hydrogen})] - \Delta H_c^\theta(\text{metaldehyde})$



$$\Delta H_f^\theta \text{ of H}_2\text{O} = \boxed{\Delta H_f^\theta}$$

$$\Delta H_f^\theta \text{ of CO}_2 = \boxed{\Delta H_f^\theta}$$

$$\Delta H_c^\theta = [8\Delta H_f^\theta(\text{carbon}) + 8\Delta H_f^\theta(\text{hydrogen})] - \Delta H_f^\theta(\text{metaldehyde})$$

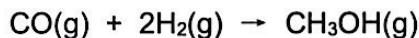
$$\Delta H_f^\theta(\text{metaldehyde}) = [8\Delta H_f^\theta(\text{carbon}) + 8\Delta H_f^\theta(\text{hydrogen})] - \Delta H_c^\theta(\text{metaldehyde})$$

The enthalpy change of a reaction is given by:

$\Delta H^\theta = (\text{Sum of the enthalpies of formation of the products}) - (\text{Sum of the enthalpies of formation of the reactants})$

$$\Delta H^\theta = \sum \Delta H_f^\theta(\text{products}) - \sum \Delta H_f^\theta(\text{reactants})$$

- 9 Methanol may be prepared by the reaction between carbon monoxide and hydrogen.

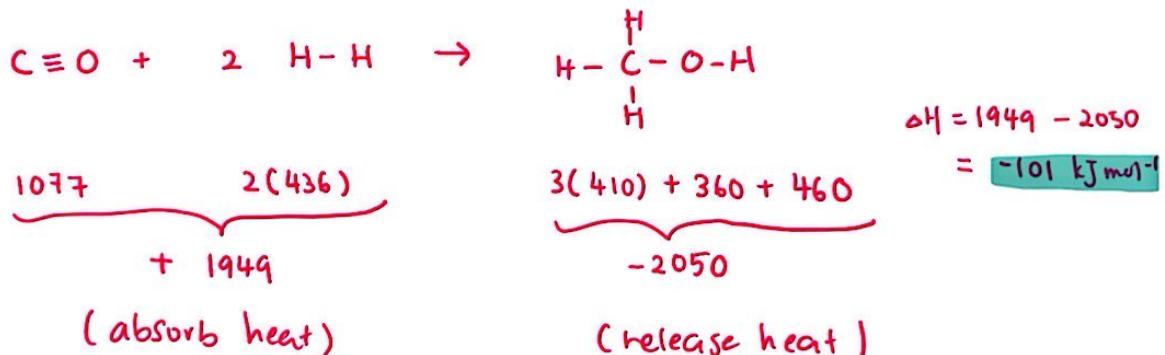


The relevant average bond energies are given below.

$E(\text{C}\equiv\text{O}):$	1077 kJ mol ⁻¹
$E(\text{C}-\text{O}):$	360 kJ mol ⁻¹
$E(\text{C}-\text{H}):$	410 kJ mol ⁻¹
$E(\text{H}-\text{H}):$	436 kJ mol ⁻¹
$E(\text{O}-\text{H}):$	460 kJ mol ⁻¹

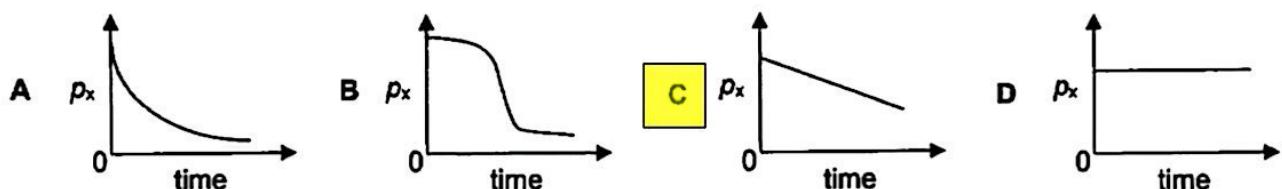
What is the enthalpy change of this reaction?

- A -537 kJ mol⁻¹ B -101 kJ mol⁻¹ C +101 kJ mol⁻¹ D +537 kJ mol⁻¹



- 10 An excess of H₂ gas is reacted with Cl₂ gas in a 1 L vessel at constant temperature. The reaction is catalysed by UV light and is found to be zero order with respect to Cl₂.

Which diagram represents the variation of the partial pressure of Cl₂ gas, p_x, with time?

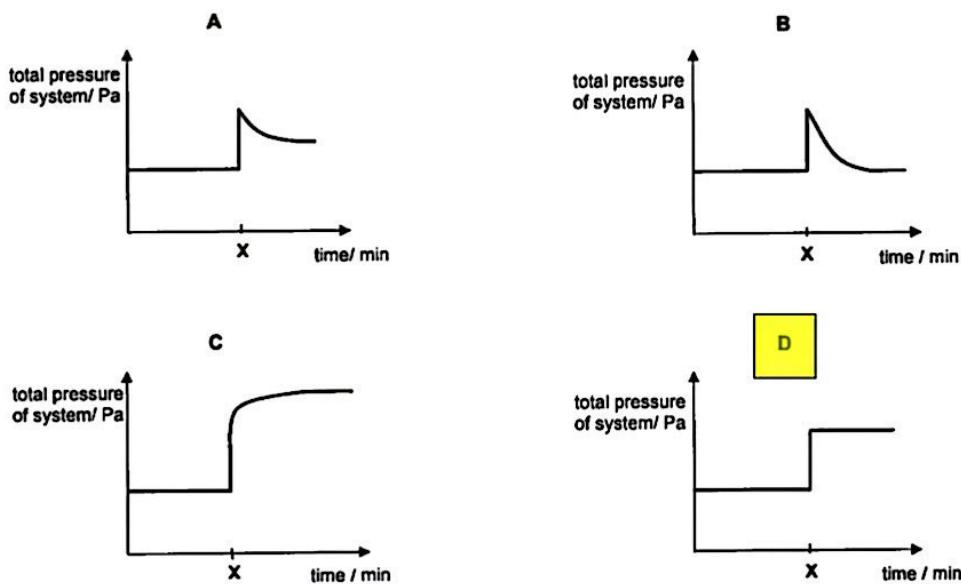


For a zero-order reaction, the rate of reaction is constant and does not depend on the concentration (or partial pressure) of the reactant. This means the partial pressure, decreases linearly with time. Graph C shows a linear decrease in partial pressure over time.

- 11 E and F react in a closed vessel to form G as shown.

At time X min, 1 mol of inert gas P is added at constant volume.

Which of the following graphs represents the variation of total pressure of the system with time?



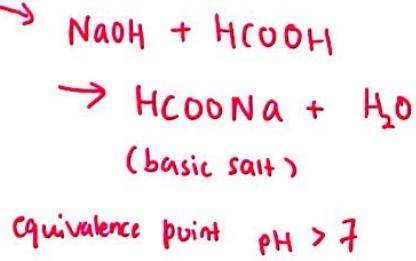
The total pressure of the system increases abruptly at time X due to the addition of inert gas P. Since the volume is constant and the inert gas does not react, the total pressure simply increases and remains at the new, higher level.

- 12 The table below describes some indicators.

Indicator	Colour in acid	Colour in alkali	pK _a	Range of pH for colour change
Methyl orange	Red	Yellow	3.7	3.2 – 4.4
Thymol blue	Yellow	Blue	8.9	yellow → 8.0 – 9.6 blue

For the titration of NaOH(aq) against HCOOH(aq), which row shows the most suitable indicator and the corresponding colour change?

	Indicator	Colour change
A	Methyl orange ↗	Red to orange
B	Methyl orange ↗	Yellow to orange
C	Thymol blue	Yellow to green



D

Thymol blue

Blue to green

During the titration of a strong base (NaOH) with weak acid (HCOOH), the pH at the equivalence point will be slightly basic because the conjugate base (HCOO^-) hydrolyzes:



Thymol blue has a pK_a of 8.9 and a color change range of 8.0-9.6, which is in the slightly basic range.

Therefore, thymol blue is the most suitable indicator, and its color will change from yellow to green (intermediate colour) as the solution goes from alkaline to acidic.

- 13 A solution contains two anions with the following concentrations.

Anion	Concentration/ mol L ⁻¹
CrO_4^{2-}	0.200
Cl^-	0.0100

Aqueous AgNO_3 is slowly added to the solution.

Which is the first compound to precipitate, and what concentration of Ag^+ is necessary to begin its precipitation?

(Given that, $K_{sp}(\text{Ag}_2\text{CrO}_4) = 1.20 \times 10^{-12} \text{ mol}^3 \text{ L}^{-3}$, $K_{sp}(\text{AgCl}) = 1.80 \times 10^{-10} \text{ mol}^2 \text{ L}^{-2}$)

	First precipitate formed	$[\text{Ag}^+]/ \text{mol L}^{-1}$
A	Ag_2CrO_4	6.00×10^{-12}
B	Ag_2CrO_4	2.45×10^{-6}
C	AgCl	1.34×10^{-5}
D	AgCl	1.80×10^{-8}

For Ag_2CrO_4 to form

$$Q = [\text{Ag}^+]^2 [\text{CrO}_4^{2-}]$$

$$[\text{Ag}^+]^2 [\text{CrO}_4^{2-}] = 1.2 \times 10^{-12}$$

$$[\text{Ag}^+] = \sqrt{\frac{1.2 \times 10^{-12}}{0.2}}$$

$$= 2.45 \times 10^{-6} \text{ mol L}^{-1}$$

For AgCl to form

$$Q = [\text{Ag}^+] [\text{Cl}^-]$$

$$[\text{Ag}^+] [\text{Cl}^-] = 1.8 \times 10^{-10}$$

$$[\text{Ag}^+] = \frac{1.8 \times 10^{-10}}{0.01}$$

$$= 1.8 \times 10^{-8} \text{ mol L}^{-1}$$

(lower)

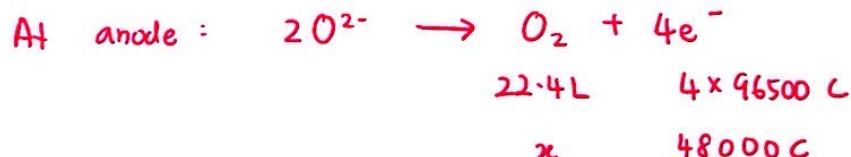
- 14 When 8 A of electricity is passed through molten aluminium oxide using inert electrodes for 100 minutes, what is the closest volume of gas released at STP? (Given that, 1 mol of gas at STP = 22.4 L, Faraday constant = 96500 C mol⁻¹)

A 2.8 L

B 5.6 L

C 8.4 L

D 11.2 L

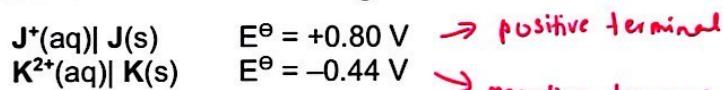


$$Q = It$$

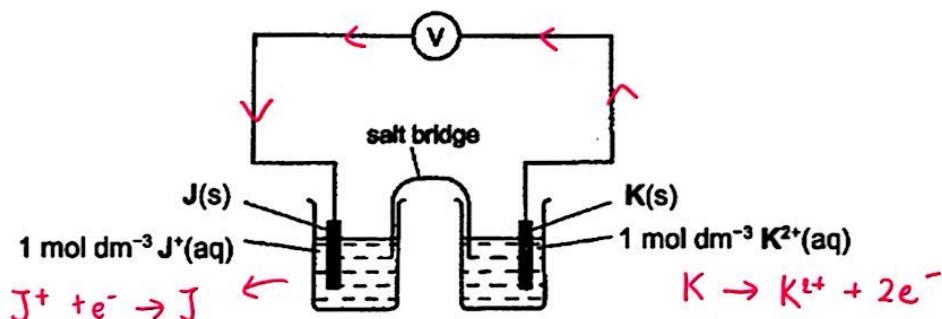
$$= 8 \times (100 \times 60)$$

$$= 48000 \text{ C}$$

- 15 The standard electrode potentials for metals J and K are given below.



The electrochemical cell shown in the diagram below is set up.



Which of the following statements is/are correct description of this cell?

- 1 The e.m.f. of the cell is +1.24 V ✓
- 2 The anions from the salt bridge will enter the $\text{K}^{2+}(\text{aq}) \mid \text{K}(\text{s})$ half-cell. ✓
- 3 The e.m.f of the cell will decrease when the concentration of K^{2+} ions increases.

A 1, 2, and 3 B 1 and 2 only C 1 only D 2 and 3 only

$$\begin{aligned} \textcircled{1} \quad \text{e.m.f.} &= E^\oplus - E^\ominus \\ &= +0.8 - (-0.44) \\ &= +1.24 \text{ V} \end{aligned}$$

2. The anions from the salt bridge will enter the $\text{K}^{2+}(\text{aq}) \mid \text{K}(\text{s})$ half-cell to balance the positive charge of K^{2+} .



3. According to the Nernst equation, the e.m.f. of the cell will decrease when the concentration of K^{2+} ions increases.

- 16 The radioactive isotope iodine-131 has a half-life of 8.0 days. A hospital receives a 100.0 mg sample. How much iodine-131 remains after 26 days?

A 21.0 mg

B 12.5 mg

C 10.5 mg

D 6.25 mg

$$\frac{N}{N_0} = \frac{1}{2}^{\frac{T_{1/2}}{t}}$$

$$\frac{N}{N_0} = \frac{1}{2}^{\frac{26}{8}} = \frac{1}{2}^{3.25}$$

$$\frac{x}{100} = 0.105$$

$$x = 10.5 \text{ g}$$

- 17 SiO_2 , P_4O_{10} , SO_2 and Cl_2O_7 are oxides which are?

A ionic and acidic

B ionic and basic

C covalent and basic

D covalent and acidic

- 18 What can be added to a mixture of MgO and Al_2O_3 to separate them by filtration?

1 water ✓

does not react
with NaOH

2 HCl(aq)

3 NaOH(aq)

A 1, 2 and 3

B 1 and 2 only

C 2 and 3 only

D 3 only



- 19 Which of the following statements is not true for the aluminium metal?

A It dissolves in hot, dilute hydrochloric acid $2\text{Al} + 6\text{HCl} \rightarrow 2\text{AlCl}_3 + 3\text{H}_2$

B Nitric(V) acid does not react with aluminium.

C Aluminium is amphoteric and dissolves in hot sodium hydroxide solution. ✓

D Aluminium reacts with hot, concentrated nitric(V) acid and gives off hydrogen gas.

When aluminium reacts with hot, concentrated nitric acid, the reaction is more like:



So the gas given off is nitrogen dioxide (NO_2), a brown toxic gas, not hydrogen.

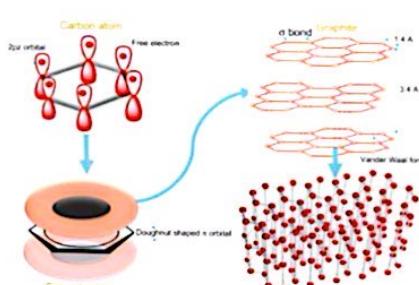
- 20 Why does graphite conduct electricity in the direction parallel to the hexagonal planes but not in the direction perpendicular to these planes?

A The delocalised orbitals in graphite are parallel to the hexagonal planes and are not perpendicular to them.

B sp^2 hybridisation only allows the flow of electrons parallel to the hexagonal planes.

C The valence electrons only move horizontally and not vertically.

D The bond angle of 120° does not allow the conducting of electricity perpendicular to the hexagonal planes.



- 21 Ammonia gas, NH_3 , and hydrogen sulfide gas, H_2S , react together to form the salt ammonium sulfide, $(\text{NH}_4)_2\text{S}$. Ammonium sulfide dissolves in water to produce an orange alkaline solution.



The addition of $\text{NaOH}(\text{aq})$ to this solution produces a gas X.

The addition of $\text{HCl}(\text{aq})$ to a separate portion of this solution produces a gas Y.

What are the identities of X and Y?



	X	Y
A	H_2S	H_2S
B	H_2S	NH_3
C	NH_3	H_2S
D	NH_3	NH_3

- 22 The following table shows the results of two experiments involving Group 17 halides, X^- and Y^- .

Experiment	Deduction
Z more reactive than X Halogen Z_2 added to X^-	X_2 formed
Y more reactive than Z Halogen Z_2 added to Y^-	Y_2 not formed <i>tendency to reduce (gain e^-)</i>

Y_2
 Z_2
 X_2

Which row shows the halogens in decreasing order of oxidising strengths?

- A $\text{Y}_2, \text{Z}_2, \text{X}_2$ B $\text{Y}_2, \text{X}_2, \text{Z}_2$ C $\text{X}_2, \text{Z}_2, \text{Y}_2$ D $\text{X}_2, \text{Y}_2, \text{Z}_2$

- 23 Which statement is true concerning transition metals?

- A Only these metals can form more than one valency (oxidation state). \times
 B Only these metals can form complex ions.
 C Only these metals can produce anhydrous chlorides with covalent bonds.
 D Only these metals can give coloured ions in aqueous solutions.

A. Incorrect. Many non-transition elements can also show multiple oxidation states.

- o Example: Tin (Sn) $\rightarrow +2$ and $+4$
- o Example: Lead (Pb) $\rightarrow +2$ and $+4$

B. Incorrect. While transition metals commonly form complex ions, other elements like Al^{3+} and Mg^{2+} can also form them.

- o Example: $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$

C. Incorrect. Many non-metals and main group elements form covalent chlorides.

- o Example: AlCl_3 (aluminium chloride) is covalent and anhydrous.

- 24 In this question, structural isomerism and stereoisomerism should be considered.

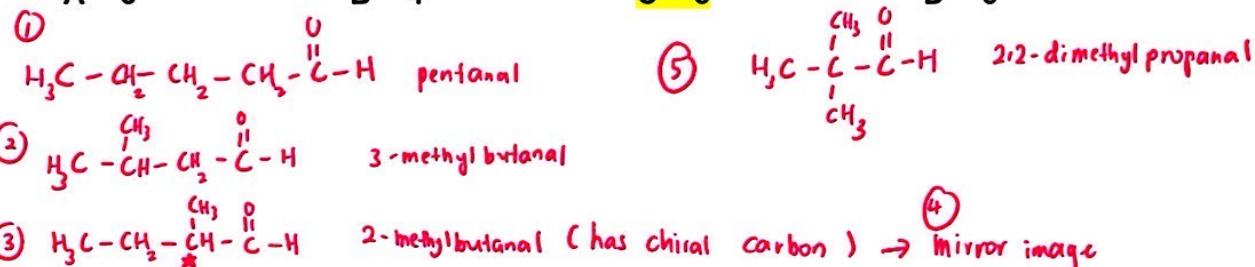
How many isomeric aldehydes have the formula $\text{C}_5\text{H}_{10}\text{O}$? $\text{C}_n\text{H}_{2n}\text{O}$

A 3

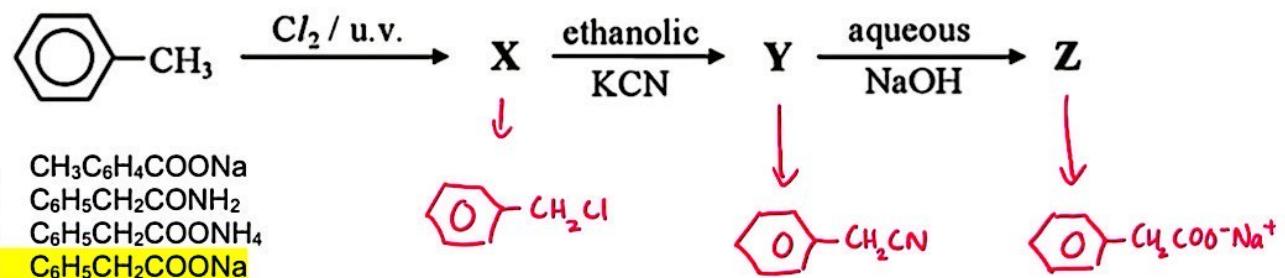
B 4

C 5

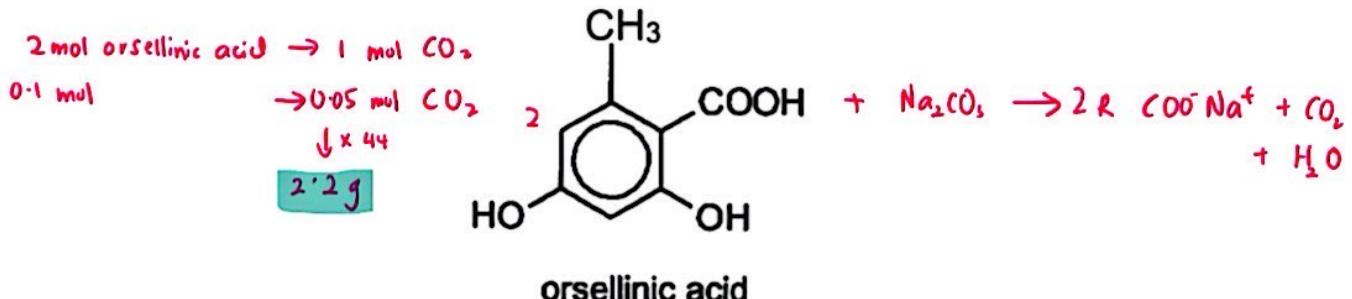
D 6



25 What is the product Z obtained by completely hydrolysing Y in the reaction sequence:



26 Orsellinic acid is found in some species of fungus.



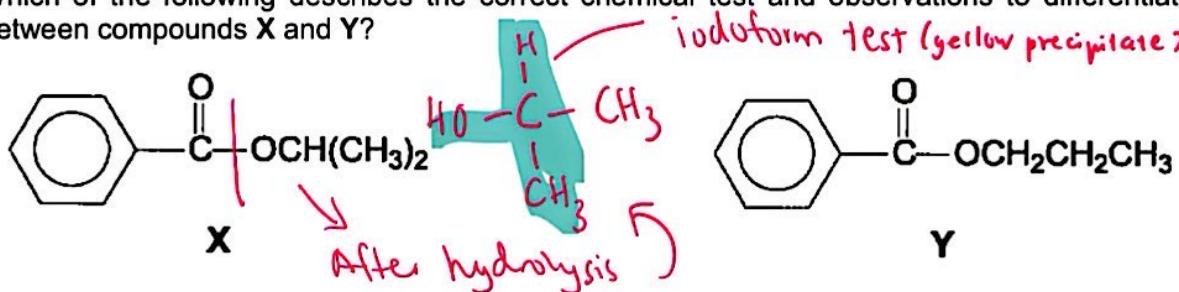
0.1 mol of orsellinic acid is reacted with excess $Na_2CO_3(aq)$, and the gaseous product formed is passed through a bottle of excess concentrated NaOH.

What is the increase in mass in the bottle of concentrated NaOH?

- A 1.1 g B 2.2 g C 4.4 g D 6.6 g
- 27 Which statements regarding ethanoic acid are true?
- A It reacts with hydrogen chloride to form ethanoyl chloride.
 B It can be reduced to ethanol with hydrogen gas in the presence of Pt.
 C It does not form a yellow precipitate when warmed with alkaline aqueous iodine.
 D It reacts with phenol in the presence of concentrated sulfuric acid to form phenyl ethanoate. α

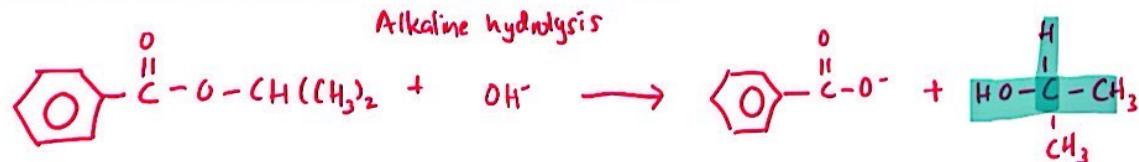
B. To reduce a carboxylic acid to a primary alcohol, a much more powerful reducing agent is required.

- 28 Which of the following describes the correct chemical test and observations to differentiate between compounds X and Y?



	Test	Observations
A	Tollens' reagent, warm	Silver mirror will be observed for Y
B	Fehling's solution, warm	Red-brown precipitate will be observed for X
C	Aqueous alkaline I_2 , warm	Yellow precipitate will be observed for X
D	Acidified $K_2Cr_2O_7$, warm	Orange solution turns green when observed for X

Esters are generally unreactive to the iodoform test under mild conditions. However, the alkaline conditions of the test will hydrolyze the esters first:



- 29 An unknown organic compound has the molecular formula $\text{C}_5\text{H}_{12}\text{O}$. It was subjected to the following chemical tests.



Test	Observations
Alkaline aqueous iodine, warm	Yellow precipitate is seen.
Hot acidified KMnO_4	Purple solution decolourises

Two students saw the tests and each commented.

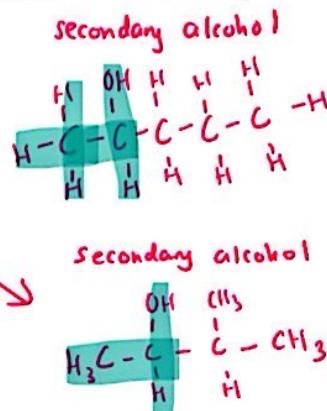
Student A: "The compound is a secondary alcohol." ✓

Student B: "The compound is pentan-2-ol."

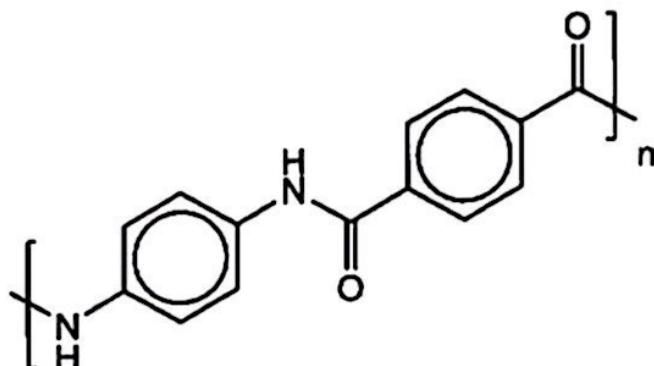
Which students are correct?

can also
be 3-methylbutan-2-ol

	Student A	Student B
A	✓	✓
B	X	✓
C	✓	X
D	X	X

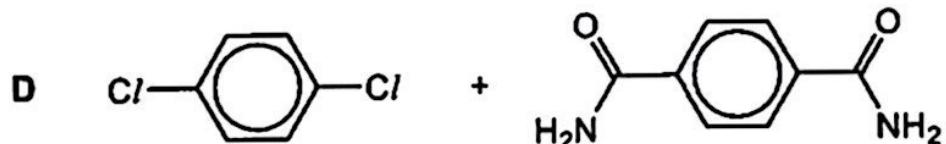
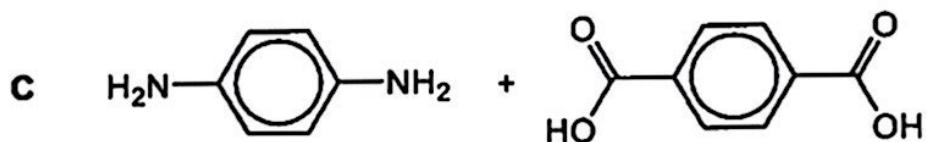
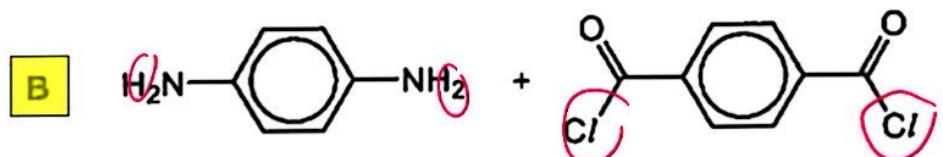
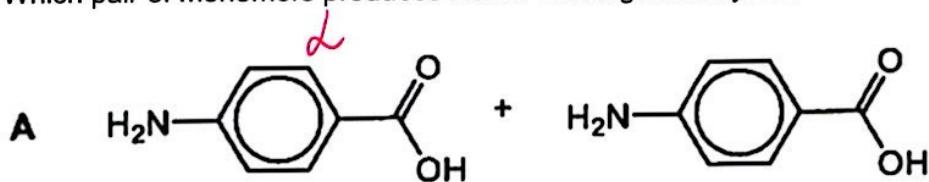


- 30 Kevlar is a lightweight and strong material, used to make tyres and bulletproof vests. Its structure is given below.



Kevlar

Which pair of monomers produces Kevlar in the greatest yield?



An amine and an acyl chloride, will react to form an amide and HCl. Since Cl is a better leaving group than OH, option B will proceed more readily and produce a greater yield of Kevlar.

An amine and a carboxylic acid, can react to form an amide, but this reaction requires specific conditions and often doesn't proceed as efficiently as reactions involving more reactive acyl chlorides.

- END OF QUESTIONS -

Part I Compulsory Questions (34%)**Section A Essay Questions (24%)**

(Attempt all four questions.)

- 1 Germanium, a metalloid once widely used in transistors, can be extracted from the mineral germanite, which also contains sulfur and copper.

A 1.00 g sample of germanite was heated in excess dry hydrogen chloride gas, causing all the germanium present to react and form germanium chloride. This volatile product was collected and weighed. The resulting mass of the chloride was 0.177 g. Further analysis showed that the chloride contained 33.9 % by mass of germanium.

- (a) Using the data provided, determine the empirical formula of the germanium chloride prepared by the method above. (2%)

a	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: center;">Element</th><th style="text-align: center;">Ge</th><th style="text-align: center;">Cl</th></tr> </thead> <tbody> <tr> <td style="text-align: center;">Mass percentage (%)</td><td style="text-align: center;">33.9</td><td style="text-align: center;">66.1</td></tr> <tr> <td style="text-align: center;">Mass per 100 g (g)</td><td style="text-align: center;">33.9</td><td style="text-align: center;">66.1</td></tr> <tr> <td style="text-align: center;">Mole (mol)</td><td style="text-align: center;">$n = \frac{33.9}{73}$ = 0.464</td><td style="text-align: center;">$n = \frac{66.1}{35.5}$ = 1.862</td></tr> <tr> <td style="text-align: center;">Mole ratio</td><td style="text-align: center;">$= \frac{0.464}{0.464}$ = 1</td><td style="text-align: center;">$= \frac{1.862}{0.464}$ = 4</td></tr> <tr> <td style="text-align: center;">Empirical formula</td><td colspan="2" style="text-align: center;">GeCl_4</td></tr> </tbody> </table>	Element	Ge	Cl	Mass percentage (%)	33.9	66.1	Mass per 100 g (g)	33.9	66.1	Mole (mol)	$n = \frac{33.9}{73}$ = 0.464	$n = \frac{66.1}{35.5}$ = 1.862	Mole ratio	$= \frac{0.464}{0.464}$ = 1	$= \frac{1.862}{0.464}$ = 4	Empirical formula	GeCl_4		½ ½ ½ ½
Element	Ge	Cl																		
Mass percentage (%)	33.9	66.1																		
Mass per 100 g (g)	33.9	66.1																		
Mole (mol)	$n = \frac{33.9}{73}$ = 0.464	$n = \frac{66.1}{35.5}$ = 1.862																		
Mole ratio	$= \frac{0.464}{0.464}$ = 1	$= \frac{1.862}{0.464}$ = 4																		
Empirical formula	GeCl_4																			
	Show the working step for all calculations																			
	Or																			
	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: center;">Element</th><th style="text-align: center;">Ge</th><th style="text-align: center;">Cl</th></tr> </thead> <tbody> <tr> <td style="text-align: center;">Mass percentage (%)</td><td style="text-align: center;">0.06</td><td style="text-align: center;">0.117</td></tr> <tr> <td style="text-align: center;">Mass per 100 g (g)</td><td style="text-align: center;">$0.117 \times 0.339 = 0.06$</td><td style="text-align: center;">$0.117 \times 0.661 = 0.117$</td></tr> <tr> <td style="text-align: center;">Mole (mol)</td><td style="text-align: center;">$n = \frac{0.06}{73}$ = 8.22×10^{-4}</td><td style="text-align: center;">$n = \frac{0.117}{35.5}$ = 3.30×10^{-3}</td></tr> <tr> <td style="text-align: center;">Mole ratio</td><td style="text-align: center;">$= \frac{8.22 \times 10^{-4}}{8.22 \times 10^{-4}}$ = 1</td><td style="text-align: center;">$= \frac{3.30 \times 10^{-3}}{8.22 \times 10^{-4}}$ = 4</td></tr> <tr> <td style="text-align: center;">Empirical formula</td><td colspan="2" style="text-align: center;">GeCl_4</td></tr> </tbody> </table>	Element	Ge	Cl	Mass percentage (%)	0.06	0.117	Mass per 100 g (g)	$0.117 \times 0.339 = 0.06$	$0.117 \times 0.661 = 0.117$	Mole (mol)	$n = \frac{0.06}{73}$ = 8.22×10^{-4}	$n = \frac{0.117}{35.5}$ = 3.30×10^{-3}	Mole ratio	$= \frac{8.22 \times 10^{-4}}{8.22 \times 10^{-4}}$ = 1	$= \frac{3.30 \times 10^{-3}}{8.22 \times 10^{-4}}$ = 4	Empirical formula	GeCl_4		
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Mole ratio	$= \frac{8.22 \times 10^{-4}}{8.22 \times 10^{-4}}$ = 1	$= \frac{3.30 \times 10^{-3}}{8.22 \times 10^{-4}}$ = 4																		
Empirical formula	GeCl_4																			
	Show the working step for all calculations																			

- (b) Calculate the percentage of germanium in the original germanite sample, based on the data provided. (2%)

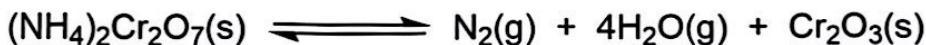
b	Mass of GeCl_4 = 0.177 g $n_{\text{GeCl}_4} = \frac{0.177}{73 + 4(35.5)} = 8.23 \times 10^{-4} \text{ mol}$ $n_{\text{Ge}} = n_{\text{GeCl}_4} = 8.23 \times 10^{-4} \text{ mol}$ $m_{\text{Ge}} = (8.23 \times 10^{-4}) \times 73 = 0.06 \text{ g}$ $\text{Percentage of Ge} = \frac{0.06}{1} \times 100\% = 6\%$ Or $m_{\text{Ge}} = \frac{33.9}{100} \times 0.177 = 0.06 \text{ g}$ $\text{Percentage of Ge} = \frac{0.06}{1} \times 100\% = 6\%$	$\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$
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- (c) Determine the oxidation number of germanium in the chloride identified in (a). Justify your answer using the chemical formula and rules for oxidation numbers. (2%)

[Total: 6%]

c	Let the oxidation number of Ge in GeCl_4 be x. Oxidation number of Cl = -1 $x + 4(-1) = 0$ $x = +4$ Hence, the oxidation number of Ge is +4 .	$\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$
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- 2 A white solid ammonium dichromate, $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$, decomposes when heated in a sealed reaction vessel to produce a mixture of gases and a solid residue. The balanced chemical equation for the decomposition is:



This reaction is allowed to reach dynamic equilibrium at a constant temperature T in a closed system. At equilibrium, the total pressure inside the vessel is measured to be $3.0 \times 10^3 \text{ kPa}$.

- (a) Write an expression for the equilibrium constant, K_p , for the decomposition of ammonium dichromate. Explain clearly why the solid substances are excluded from the K_p expression.

(2%)

a	$K_p = (P_{\text{N}_2}) \times (P_{\text{H}_2\text{O}})^4$ Solid substances are not included because they can be considered to have a constant or zero contribution to the pressure.	$\frac{1}{2}$ $\frac{1}{2}$
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- (b) Calculate the partial pressure of each gas at equilibrium. Then, calculate the value of K_p , including the correct units. (3%)

b	Mole ratio $N_2 : H_2O = 1 : 4$	
	$P_{N_2} = \frac{1}{5} \times (3 \times 10^3) = 0.6 \times 10^3 \text{ kPa}$	1
	$P_{H_2O} = \frac{4}{5} \times (3 \times 10^3) = 2.4 \times 10^3 \text{ kPa}$	1
	$K_p = (0.6 \times 10^3 \text{ kPa}) \times (2.4 \times 10^3 \text{ kPa})^4 = 1.99 \times 10^{16} \text{ kPa}^5 / 1.99 \times 10^{31} \text{ Pa}^5$	1

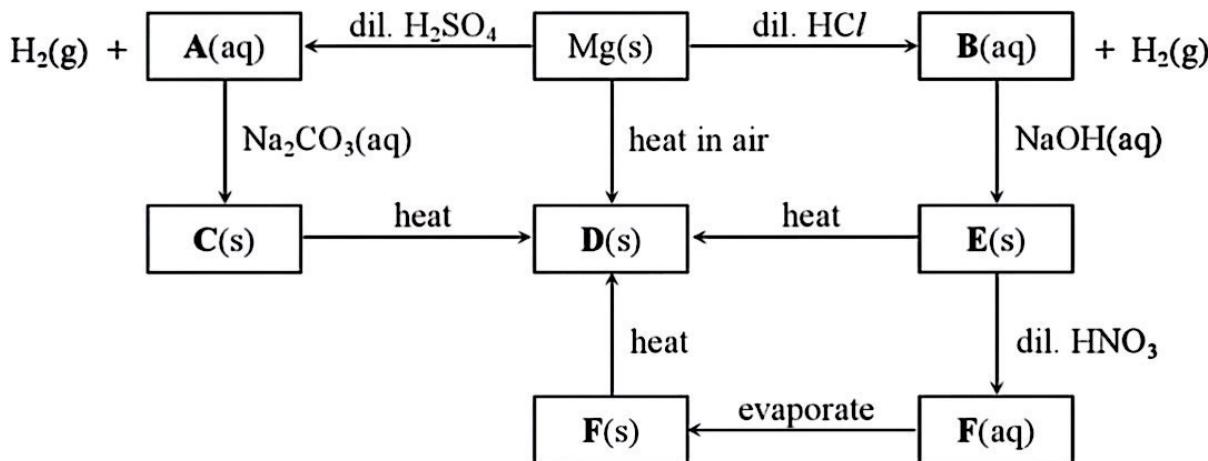
- (c) If the temperature is increased, predict and explain qualitatively how the position of equilibrium and the value of K_p would be affected. (1%)

[Total: 6%]

c	When the temperature increases, the position of equilibrium shifts to the right K_p value will increase.	½ ½
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- 3 Magnesium is a reactive Group 2 metal and readily forms compounds through various types of chemical reactions.

The following reaction scheme illustrates how magnesium undergoes a series of chemical transformations when it reacts with various reagents.



- (a) Write a balanced chemical equation for the following reactions. (5%)

- (i) $A(aq) \rightarrow C(s)$
- (ii) $B(aq) \rightarrow E(s)$
- (iii) $E(s) \rightarrow F(aq)$
- (iv) $F(s) \rightarrow D(s)$
- (v) $C(s) \rightarrow D(s)$

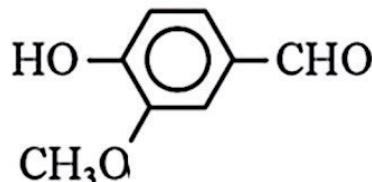
a(i)	$MgSO_4(aq) + Na_2CO_3(aq) \rightarrow MgCO_3(s) + Na_2SO_4(aq)$	1
	Ignore physical state	
a(ii)	$MgCl_2(aq) + 2NaOH(aq) \rightarrow Mg(OH)_2(s) + 2NaCl(aq)$	1
	Ignore physical state	
a(iii)	$Mg(OH)_2(s) + 2HNO_3(aq) \rightarrow Mg(NO_3)_2(aq) + 2H_2O(l)$	1
	Ignore physical state	
a(iv)	$Mg(NO_3)_2(s) \rightarrow MgO(s) + 2NO_2(g) + \frac{1}{2}O_2(g)$ <i>or</i> $2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$	1
	Ignore physical state	
a(v)	$MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$	1
	Ignore physical state	

- (b) Explain why magnesium hydroxide (compound E) decomposes more readily upon heating compared to barium hydroxide. (1%)

[Total: 6%]

b	The Mg^{2+} ion is smaller in size than the Ba^{2+} ion. The Mg^{2+} ion has a larger charge density and greater polarizing power .	$\frac{1}{2}$ $\frac{1}{2}$
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- 4 The perfume vanillin occurs widely in nature and has the structure shown.



State the conditions and observations, and give the balanced chemical equation with structural formula when vanillin reacts with

- (a) aqueous bromine (2%)
 (b) 2,2-dimethylpropanoyl chloride (2%)
 (c) Tollens' reagent (2%)

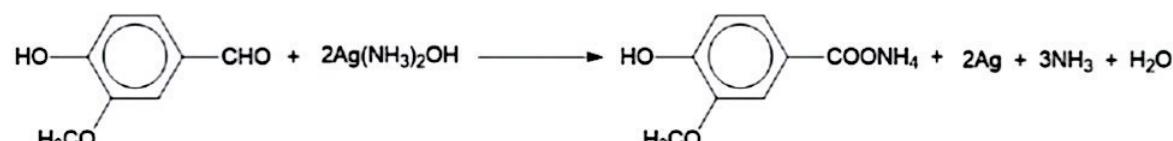
[Total: 6%]

a	Condition: room temperature Observation: (Reddish) brown solution is decolorized/ white precipitate is formed $\text{HO}-\text{C}_6\text{H}_3(\text{CH}_3\text{O})-\text{CHO} + \text{Br}_2 \longrightarrow \text{HO}-\text{C}_6\text{H}_2(\text{Br})(\text{CH}_3\text{O})-\text{CHO} + \text{HBr}$	$\frac{1}{2}$ $\frac{1}{2}$ 1
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b	Condition: room temperature Observation: White fume is observed	$\frac{1}{2}$ $\frac{1}{2}$
	$\begin{array}{ccc} \text{CH}_3 & & \\ & & \\ \text{H}_3\text{C}-\text{C}-\text{COCl} & + & \text{HO}-\text{C}_6\text{H}_3(\text{H}_3\text{CO})-\text{CHO} \\ & & \\ \text{CH}_3 & & \end{array} \longrightarrow \begin{array}{ccc} \text{CH}_3 & & \\ & & \\ \text{H}_3\text{C}-\text{C}-\text{COO}-\text{C}_6\text{H}_3(\text{H}_3\text{CO})-\text{CHO} & + & \text{HCl} \\ & & \\ \text{CH}_3 & & \end{array}$	1
c	Condition: heat Observation: Silver mirror effect is observed	$\frac{1}{2}$ $\frac{1}{2}$



or



Section B Inquiry Questions (10%)

(Attempt the only one question.)

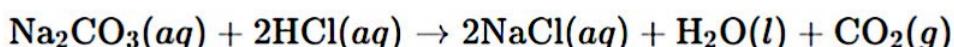
- 5 This question is about calculating the purity of an impure sodium carbonate sample.

A student was given a 2.65 g impure sample of sodium carbonate (Na_2CO_3). The sample may only contain other basic impurities such as sodium hydroxide (NaOH) or sodium hydrogen carbonate (NaHCO_3). The student used two methods to determine the percentage purity of Na_2CO_3 in the sample.

Method 1: Titration with HCl

The entire 2.65 g sample was dissolved in 250.0 mL of distilled water.

- 25.00 mL of the prepared solution was titrated with 0.100 mol L⁻¹ hydrochloric acid using methyl orange as an indicator.
- The neutralization reaction is given as follows:

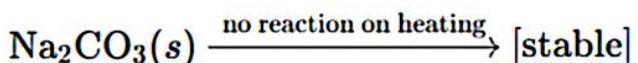


- The following table records the titration result obtained by the student.

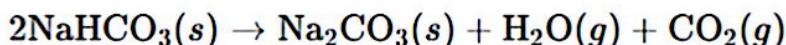
Titration	1	2	3
Final burette reading (mL)	24.20	24.50	24.45
Initial burette reading (mL)	0.50	0.90	0.80
Volume of HCl used	23.70	23.60	23.65

Method 2: Thermal Decomposition

- The same 2.65 g impure sample was placed in a crucible and strongly heated to constant mass.
- The final mass of residue after heating was 2.00 g
- The thermal decomposition reaction is given as follows:



- If NaHCO_3 is present, it decomposes on heating:



- (a) Based on **Method 1**, calculate the percentage purity of sodium carbonate in the sample. (3%)

$$V_{\text{HCl}} = \frac{(23.70 + 23.60 + 23.65)}{3} = 23.65 \text{ mL}$$

$$n_{\text{HCl}} = \frac{0.1 \times 23.65}{1000} = 2.365 \times 10^{-3} \text{ mol}$$

$$n_{\text{Na}_2\text{CO}_3} = \frac{2.365 \times 10^{-3}}{2} = 1.183 \times 10^{-3} \text{ mol}$$

$$n_{\text{Na}_2\text{CO}_3 \text{ in sample}} = 10 \times (1.183 \times 10^{-3}) = 1.183 \times 10^{-2} \text{ mol}$$

$$m_{\text{Na}_2\text{CO}_3 \text{ in sample}} = 1.183 \times 10^{-2} \times 106 = 1.254 \text{ g}$$

$$\% \text{ of purity} = \frac{1.254}{2.65} \times 100\% = 47.3\%$$

- (b) Based on **Method 2**, calculate the percentage purity of the sample, assuming the impurity is entirely the NaHCO_3 , and the residue is pure Na_2CO_3 . (1%)

$$\% \text{ of purity} = \frac{2}{2.65} \times 100\% = 75.5\%$$

- (c) Explain why both Method 1 and Method 2 are likely to overestimate the percentage purity of sodium carbonate. Justify your reasoning based on possible impurities and assumptions in each method. (2%)

c **Method 1 (titration):**

Other basic impurities, such as NaOH and NaHCO_3 , would also neutralize HCl, making it appear as though there is more Na_2CO_3 present than actual.

Method 2 (heating):

NaHCO_3 decomposes to give extra Na_2CO_3 that remains in the residue, so the mass of Na_2CO_3 is overestimated.

- (d) Suppose the impurity was sodium hydroxide (NaOH). Explain how it would affect the result of:
- Method 1 (1%)
 - Method 2 (1%)

d(i)	NaOH would also react with HCl during titration , so more acid is required, and the calculated % purity of Na_2CO_3 is overestimated.	1
d(ii)	NaOH is stable on heating , so it remains in the residue and is counted as Na_2CO_3 , and the calculated % purity is overestimated.	1

- (e) Suggest a chemical test that could help to distinguish between

- NaHCO_3 and Na_2CO_3 . (1%)
- NaOH and Na_2CO_3 . (1%)

e(i)	<p>Test 1: Thermal Decomposition Place the solid Na_2CO_3 and NaHCO_3 in separate boiling tubes and heat. NaHCO_3 is decomposed, and Na_2CO_3 is not decomposed.</p> <p>Or</p> <p>Test 2: Reaction with acid An equal mass of Na_2CO_3 and NaHCO_3 reacts with acid in a separate test tube. Na_2CO_3 gives a more vigorous reaction than NaHCO_3.</p> <p>Or</p> <p>Test 3: pH differences Na_2CO_3 and NaHCO_3 are added to a separate test tube containing distilled water. Na_2CO_3 ($\text{pH} \approx 11 - 12$) gives a more alkaline solution than NaHCO_3 ($\text{pH} \approx 8 - 9$).</p>	1
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e(ii)	<p>Test 1: Reaction with acid Na_2CO_3 and NaOH react with acid in separate test tubes. Na_2CO_3 gives effervescence and no observable changes for NaOH.</p> <p>Or</p> <p>Test 2: Reaction with Ba^{2+} solution An equal mass of Na_2CO_3 and NaHCO_3 is added to separate test tubes with Ba^{2+} solution. Na_2CO_3 gives a white precipitate, and NaHCO_3 is dissolved in Ba^{2+} solution.</p> <p>Or</p> <p>Test 3: pH differences NaOH and Na_2CO_3 are added to separate test tubes containing distilled water. NaOH ($\text{pH} \approx 13$) gives a more alkaline solution than Na_2CO_3 ($\text{pH} \approx 11 - 12$).</p>	1
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[Total: 10%]

Part I Elective Questions (36%)

Section A Organic Chemistry (12%)

(Attempt any one of the two questions.)

- 6 There are several structural isomers of molecular formula $C_nH_nO_2$. One of the isomers, B, is used as a tincture in perfumes and as a food additive.

(a) To find the value of n, a 1.00 g sample of B was burned in an excess of oxygen, and the gases produced were first passed through a U-tube containing P_4O_{10} (to absorb the water vapour) and then bubbled through concentrated $NaOH(aq)$. The P_4O_{10} in the U-tube increased in mass by 0.529 g.

(i) Write the combustion equation of $C_nH_nO_2$ in excess oxygen. (1%)

a(i)	$C_nH_nO_2 + \left(\frac{5n}{4} - 1\right) O_2 \rightarrow nCO_2 + \frac{n}{2}H_2O$ or $C_nH_nO_2 + \left(\frac{5n - 4}{4}\right) O_2 \rightarrow nCO_2 + \frac{n}{2}H_2O$ or $C_nH_nO_2 + \left(\frac{5n}{2} - 2\right) O_2 \rightarrow nCO_2 + \frac{n}{2}H_2O$	1
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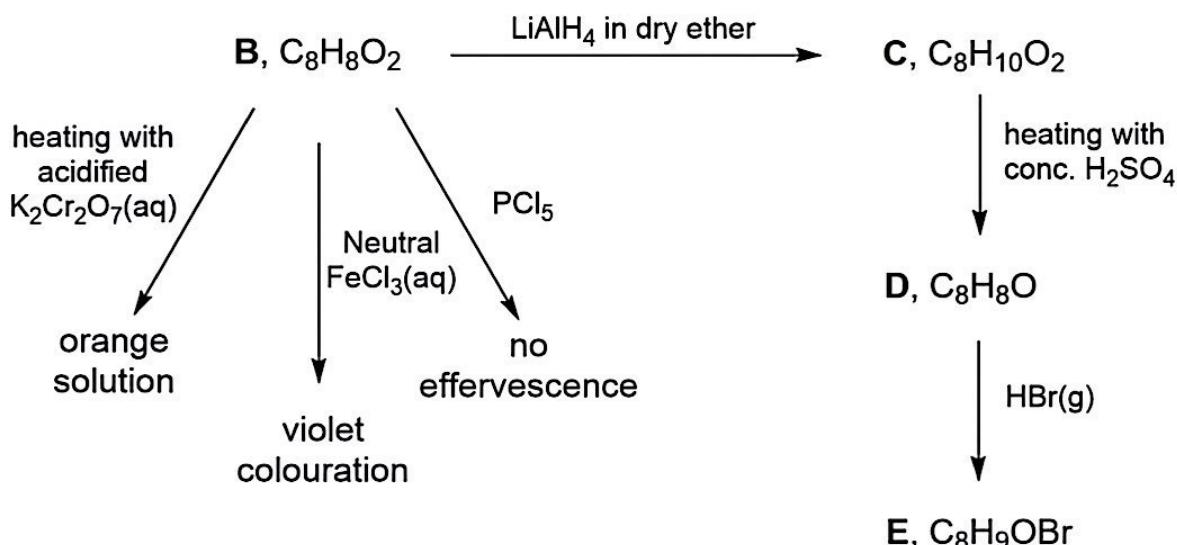
(ii) Calculate the number of moles of water produced. (1%)

a(ii)	$n_{H_2O} = \frac{0.529}{18} = 0.0294 \text{ mol}$	1
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(iii) Use the above data to calculate the value of n. (2%)

a(iii)	$n_B = \frac{1}{12n + n + 32} = \frac{1}{13n + 32}$ $C_nH_nO_2 : H_2O$ $1 : \frac{n}{2}$ $\frac{1}{13n+32} : 0.0294$ $n = 8$	$\frac{1}{2}$
	<i>Based on equation,</i>	
	$1 \text{ mol } C_nH_nO_2 \rightarrow \frac{n}{2} \text{ mol } H_2O$	
	$\frac{1}{13n+32} \text{ mol } C_nH_nO_2 \rightarrow \frac{n}{26n+64} \text{ mol } H_2O$	
	$\frac{n}{26n+64} = 0.0294$	
	$n = 8$	

- (b) A reaction scheme involving compound **B** and its related compounds, **C** to **E**, undergo the following reactions:



- (i) Deduce the possible functional groups present in compound **B** based on the information provided above. You may refer to the following example when answering this question. (3%)

For example:

Compound A gives an orange precipitate with 2,4-dinitrophenylhydrazine shows that it is a carbonyl compound.

primary /secondary		
b(i)	B gives an orange solution with acidified $\text{K}_2\text{Cr}_2\text{O}_7$, showing that it <u>cannot be alcohol or aldehyde</u> .	1
	B gives violet colour with FeCl_3 , showing that <u>it is a phenol</u> . <i>/does not have carbonyl group</i>	1
	B gives no effervescence with PCl_5 , showing that it is <u>not carboxylic acid</u> .	1

- (ii) Given that, 1 mol of compound **B** reacts with excess aqueous bromine to give a white solid, compound **F** with $M_r = 373$. Based on the information given and your deduction on (b)(i), draw the structure of compound **B** and compound **F**. (2%)

b(ii)	<p>Difference in mass = $370 - 136 = 234$</p> <p>$1 \text{ Br} = 80$</p> <p>No. of Br = $234/80 = 2.93 \approx 3$</p> <p>Compound B</p> <p>$M_r = 136$</p>	<p>$\text{C}_8\text{H}_5\text{O}_2\text{Br}_3$</p> <p>Compound F</p> <p>$M_r = 373$</p>	2
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(iii) Draw the structures of compounds C, D, and E. (3%)

<p>b(iii)</p> <p>Compound C</p> <p>Dehydration</p> <p>Compound D</p> <p>Addition +HBr</p> <p>Compound E</p>	<p>1</p> <p>1</p> <p>1</p>
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[Total:12%]

- 7 Compound J is a non-narcotic analgesic commonly sold in pharmacies. Refluxing J in the presence of dilute sulfuric acid produces K and ethanoic acid.

Tables 1 and 2 below show the results of the analysis of compound K.

Table 1

Elemental Analysis (%)			Melting point/ °C
C	H	O	
60.8	4.4	34.8	159

Table 2

Reaction	Reagent	Result
1	Excess aqueous Br ₂	White solid, L formed which has Mr = 296
2	Aqueous Na ₂ CO ₃	Effervescence of gas
3	Excess Na metal	About 174 mL of a colourless gas is evolved when 1 g of K is used at room temperature

- (a) When vapourised in suitable apparatus, 0.12 g of K occupies a volume of 37.5 mL at 250 °C and a pressure of 101 kPa. Calculate the molar mass of K. (1%)

<p>a</p> $PV = nRT$ $PV = \frac{m}{M_r} RT$ $M_r = \frac{mRT}{PV} = \frac{0.12 \times 8.314 \times 523}{(101 \times 10^3) \times (37.5 \times 10^{-6})} = 137.8 \text{ g mol}^{-1} \text{ or } 138 \text{ g mol}^{-1}$	<p>1</p>
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(b) Hence, using your answer in (a) and Table 1, deduce the molecular formula of K. (2%)

b	Element	C	H	O	
	Mass percentage (%)	60.8	4.4	34.8	
	Mass per 100 g (g)	60.8	4.4	34.8	
	Mole (mol)	$n = \frac{60.8}{12}$ = 5.06	$n = \frac{4.4}{1}$ = 4.4	$n = \frac{34.8}{16}$ = 2.18	
	Mole ratio	$= \frac{5.06}{2.18}$ = 2.32	$= \frac{4.4}{2.18}$ = 2	$= \frac{2.18}{2.18}$ = 1	
	Simplest whole ratio	$= 2.32 \times 3$ = 7	$= 2 \times 3$ = 6	$= 1 \times 3$ = 3	
	Empirical formula	$\text{C}_7\text{H}_6\text{O}_3$			

(c) Name the functional group that reaction 1 shows to be present in K and the functional group present in K that is confirmed by reaction 2. (1%)

c	Reaction 1: Phenol Reaction 2: Carboxylic acid/ Carboxyl group	½ ½
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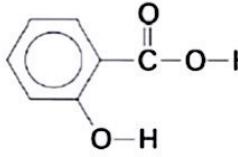
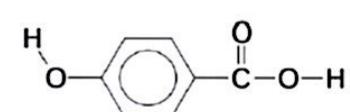
(d) Using your answer in (a) – (c) to account for the result given in reaction 3. (2%)

d	1 mol of K contains 2 mol of –OH group (phenol + carboxylic acid). 2 mol of –OH group produces 1 mol of H ₂ gas $mol\ of\ K = \frac{1}{138} = 7.25 \times 10^{-3}\ mol$ $Volume\ of\ H_2\ expected = 7.25 \times 10^{-3} \times 24 = 0.174\ L$ Or $n_{H_2} = \frac{0.174}{24} = 7.25 \times 10^{-3}\ mol$ $mol\ of\ K = \frac{1}{138} = 7.25 \times 10^{-3}\ mol$ 1 mol of K to produce 1 mol of H ₂ K has 2 -OH group	½ ½ ½ ½ ½ ½ ½ ½ ½ ½
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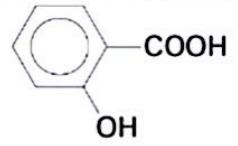
- (e) State the molecular formula of compound L in reaction 1. (1%)

<p>e Difference in mass = $296 - 138 = 158$</p> <p>$1 \text{ Br} = 80$</p> <p>No. of Br = $158/80 = 1.98 \approx 2$</p> <p>$\text{C}_7\text{H}_4\text{O}_3\text{Br}_2$</p>	<p>$\text{C}_7\text{H}_6\text{O}_3 \quad M_r = 138$</p> <p>$\downarrow$</p> <p>$\text{C}_7\text{H}_4\text{O}_3\text{Br}_2 \quad M_r = 296$</p>	<p>1</p>
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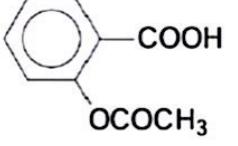
- (f) Hence, suggest and draw the full structural formulae of two possible structural formulae of compound K. (2%)

<p>f Possible K:</p>	 	<p>2</p>
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- (g) Given that one of the compounds in (f) has a melting point of 214°C , state the identity of K and explain your choice. (2%)

<p>g</p>		<p>1</p>
	<p>K can form intramolecular hydrogen bonding, leading to less extensive intermolecular hydrogen bonding, resulting in a lower melting point.</p>	<p>1</p>

- (h) Hence, deduce the structure of compound J. (1%)

<p>h</p>		<p>1</p>
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[Total:12%]

[Turn over

Section B Inorganic Chemistry (12%)
(Attempt any one of the two questions.)

8 The following question is related to halogen.

- (a) The reaction between halogens and hydrogen to produce hydrogen halides is shown in the table below.

Halogen	Reaction with hydrogen
F_2	Explodes in the dark at 200 °C
Cl_2	Explodes in sunlight or slowly in the dark below 200 °C
Br_2	Occurs at 500 °C or lower temperature in the presence of a catalyst
I_2	Occurs at 450 °C in the presence of a catalyst, and the reaction is reversible.

Answer the following questions based on the table above.

- (i) Explain the trend in reactivity of halogens with hydrogen as shown in the table above. In your answer, refer to the bond energy and oxidizing power of the halogens. (3%)

a(i)	Reactivity: $F_2 > Cl_2 > Br_2 > I_2$ (1) The electronegativity of halogens decreases down Group 17, and their tendency to gain electrons also decreases. (1) The oxidizing power of the halogens decreases when going down Group 17. H-X bond energy: $H-F > H-Cl > H-Br > H-I$ (1) Weaker H-X bonds release less energy when formed, the reaction becomes less exothermic and less vigorous down the group.	1 ½ ½ ½ ½
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- (ii) Hydrogen halides dissolve in water to form acidic solutions. Arrange the acids formed (HF , HCl , HBr , HI) in increasing order of acid strength. Explain your answer based on bond strength and ease of ionization in water. (3%)

a(ii)	Acid strength in water: $HF < HCl < HBr < HI$ (1) H-X bond strength decreases down the group. (2) Weaker H-X bonds break more easily to release H^+ . (3) Conjugate base X^- is larger and more polarizable down the group. It becomes more stable and makes H^+ release easier.	1 ½ ½ ½ ½
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- (b) The reaction of halide ions with concentrated sulphuric acid can be used as a chemical test for halide ions. The result of halide ions, X, Y, and Z, reacting with concentrated sulphuric acid is shown in the table below.

Halide ion	Observation
X	White fumes
Y	Purple vapour
Z	Brown vapour

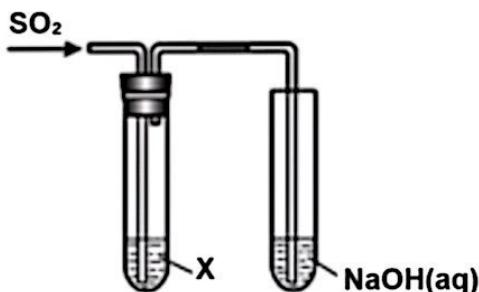
- (i) Identify halide ion X, Y and Z. (1%)
 - (ii) Write the equations involved in the formation of brown vapour. (2%)
 - (iii) Why does X form only white fumes? (1%)
- (c) Explain why chlorine gas is used in water treatment instead of fluorine gas. Refer to chemical reactivity, toxicity, and safety in your answer. (2%)

[Total: 12%]

b(i)	$\text{X} = \text{Cl}^- ; \text{Y} = \text{I}^- ; \text{Z} = \text{Br}^-$ Correct all: 1 mark, correct 2: $\frac{1}{2}$ mark; correct 1 or wrong all: 0 mark.	1
b(ii)	$\text{H}_2\text{SO}_4 + \text{Br}^- \rightarrow \text{HBr(g)} + \text{HSO}_4^-$ $\text{H}_2\text{SO}_4 + 2\text{HBr} \rightarrow \text{Br}_2 + \text{SO}_2 + 2\text{H}_2\text{O}$	1 1
b(iii)	Cl^- is unable to oxidize by concentrated H_2SO_4 .	1
c	Chlorine reacts moderately with water to form hypochlorous acid, an effective disinfectant. Fluorine reacts violently to produce toxic hydrofluoric acid. Fluorine is far more toxic and corrosive than chlorine. It is not safe to handle or control fluorine than chlorine during water treatment.	$\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$

9 The following question is related to sulphur dioxide.

- (a) A group of students used the following apparatus to investigate the properties of SO_2 .



The observations were recorded in the following table.

Experiment	X	Observation
I	Litmus solution	Observation A
II	Fuchsine solution	Solution changes from red to colourless; regains original colour upon heating.
III	Acidified KMnO_4 solution	Solution changes from purple to colourless.

Answer the following question based on the table above.

- (i) In Experiment I, observation A is _____. Justify your answer with the aid of a balanced equation. (2%)
- (ii) Based on Experiment II, deduce the chemical properties shown by SO_2 . (1%)
- (iii) Based on Experiment III, deduce the ions that are present in the colourless solution X. (1%)
- (iv) Write a balanced equation for the reaction that happened in the test tube containing sodium hydroxide solution. (1%)

a(i)	Litmus solution turns red $\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3$ H_2SO_3 dissociates partially in water to give H^+	1 ½ ½
a(ii)	SO_2 has bleaching properties as an agent	1
a(iii)	Mn^{2+} and SO_4^{2-}	1
a(iv)	$\text{SO}_2(\text{g}) + 2\text{NaOH}(\text{aq}) \rightarrow \text{Na}_2\text{SO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$	1

- (b) Predict whether SO_2 will act as a reducing or an oxidizing agent in each of the following reactions. Justify your answer with balanced chemical equations.

- (i) Reaction with acidified potassium dichromate (VI). (1%)
- (ii) Reaction with hydrogen sulphide (H_2S) gas. (1%)
- (iii) Reaction with chlorine gas (Cl_2). (1%)

b(i)	SO ₂ is a reducing agent K ₂ Cr ₂ O ₇ + 3SO ₂ + H ₂ SO ₄ → K ₂ SO ₄ + Cr ₂ (SO ₄) ₃ + H ₂ O	½ ½
b(ii)	SO ₂ is an oxidizing agent SO ₂ + 2H ₂ S → 3S + 2H ₂ O	½ ½
b(iii)	SO ₂ is a reducing agent SO ₂ + Cl ₂ + 2H ₂ O → H ₂ SO ₄ + 2HCl	½ ½

- (c) Explain why SO₂ exhibits both oxidizing and reducing behavior in terms of its oxidation state. (1%)
- (d) Describe a chemical test to confirm the presence of sulphur dioxide gas. (1%)
- (e) Describe a laboratory method to prepare sulphur dioxide gas. Include the chemical equation and precautions needed. (2%)

[Total: 12%]

c	Sulfur in SO ₂ has an intermediate oxidation state +4 It can be either oxidized to +6 or reduced to 0 or -2	½ ½
d	Pass the gas through acidified KMnO ₄ / acidified K ₂ CrO ₇ SO ₂ decolourise the purple solution to a colourless solution/ SO ₂ turns the orange solution green	½ ½
e	<u>1st method</u> heating concentrated sulphuric acid with copper $\text{Cu(s)} + 2\text{H}_2\text{SO}_4(\text{conc}) \rightarrow \text{CuSO}_4(\text{aq}) + \text{SO}_2(\text{g}) + 2\text{H}_2\text{O(l)}$ Prepare in a fume hood. Avoid collecting over water. <u>2nd method</u> Reaction between Na ₂ SO ₃ and dilute hydrochloric acid $\text{Na}_2\text{SO}_3 + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\text{O} + \text{SO}_2$ Prepare in a fume hood. Avoid collecting over water.	½ ½ ½ ½ ½

Section C Physical Chemistry (12%)
 (Attempt any one of the two questions.)

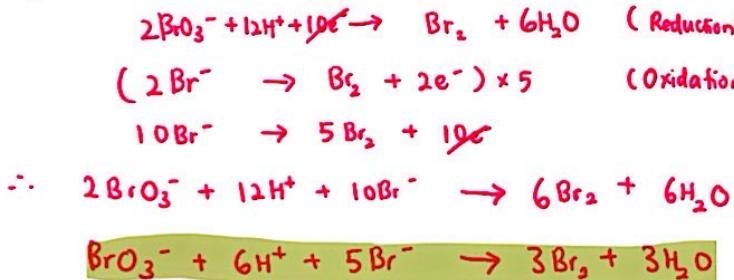
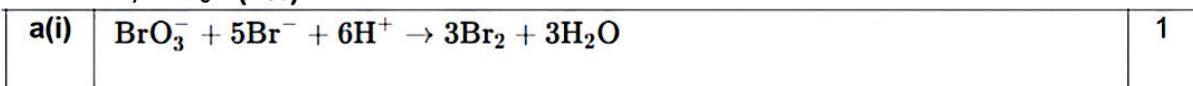
- 10 (a) In acidic solution, bromate(V) ions, BrO_3^- , slowly oxidise bromide ions to bromine. The progress of the reaction may be followed by adding a fixed amount of phenol together with some methyl red indicator.

The bromine produced during the reaction reacts very rapidly with phenol. When all the phenol is consumed, any further bromine bleaches the indicator immediately. The initial rate of formation of Br_2 is indicated by the time for the bromine to bleach the indicator.

The total volume of the reaction mixture is the same in all four experiments, and the following kinetic data are obtained at 25 °C.

Experiment	[BrO_3^-] / mol dm ⁻³	[Br^-] / mol dm ⁻³	pH	Initial rate of formation of Br_2 / mol dm ⁻³ s ⁻¹
1	0.10	0.10	1.00	8×10^{-2}
2	0.10	0.05	1.00	4×10^{-2}
3	0.05	0.05	1.00	2×10^{-2}
4	0.05	0.10	1.30	1×10^{-2}

- (i) Write a balanced equation for the reaction between bromide ion, Br^- , and bromate(V) ion, BrO_3^- . (1%)



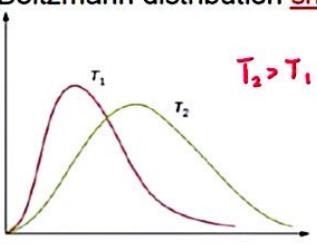
- (ii) Write the rate equation for this reaction and determine the order of the reaction concerning reactants, Br^- , BrO_3^- and H^+ . (3%)

a(ii)	$rate = k[BrO_3^-]^x[Br^-]^y[H^+]^z$ By comparing expt. 1 and expt. 2 $\frac{8 \times 10^{-2}}{4 \times 10^{-2}} = \frac{k[0.1]^x[0.1]^y[0.1]^z}{k[0.1]^x[0.05]^y[0.1]^z}$ $2 = \left(\frac{0.1}{0.05}\right)^y$ $y = 1$ By comparing expt. 2 and expt. 3 $\frac{4 \times 10^{-2}}{2 \times 10^{-2}} = \frac{k[0.1]^x[0.05]^y[0.1]^z}{k[0.05]^x[0.05]^y[0.1]^z}$ $2 = \left(\frac{0.1}{0.05}\right)^x$ $x = 1$ By comparing expt. 3 and expt. 4 $\frac{2 \times 10^{-2}}{1 \times 10^{-2}} = \frac{k[0.05]^x[0.05]^y[0.1]^z}{k[0.05]^x[0.10]^y[0.05]^z}$ $2 = \left(\frac{0.05}{0.1}\right)^y \left(\frac{0.1}{0.05}\right)^z$ $2 = \left(\frac{0.05}{0.1}\right)^1 \left(\frac{0.1}{0.05}\right)^z$ $4 = \left(\frac{0.1}{0.05}\right)^z$ $z = 2$ $rate = k[BrO_3^-][Br^-][H^+]^2$	$\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$
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(iii) Calculate the rate constant of the reaction at this temperature, stating its units. (1%)

a(iii)	$k = \frac{rate}{[BrO_3^-][Br^-][H^+]^2} = \frac{8 \times 10^{-2}}{[0.1][0.1][0.1]^2} = 800$ Unit: $\text{dm}^9 \text{ mol}^{-3} \text{ s}^{-1}$	$\frac{1}{2}$ $\frac{1}{2}$
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(b) Describe and explain in molecular terms how the rate of reaction is affected by an increase in temperature. You should include a reference to the Boltzmann distribution in your answer. (3%)

b	<p>As the temperature increases, the distribution of molecular energies in the Boltzmann distribution <u>shifts to higher values (right)</u> or</p>  <p>A <u>greater proportion of molecules possess energy equal to or exceeding the activation energy (E_a)</u>.</p> <p>This leads to <u>more successful collisions</u>, resulting in a higher reaction rate.</p>	1 1 1
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- (c) The effect of temperature on the rate constant, k , can be expressed by the following equation.

$$\ln k = \ln A - \frac{E_a}{R} \left(\frac{1}{T} \right)$$

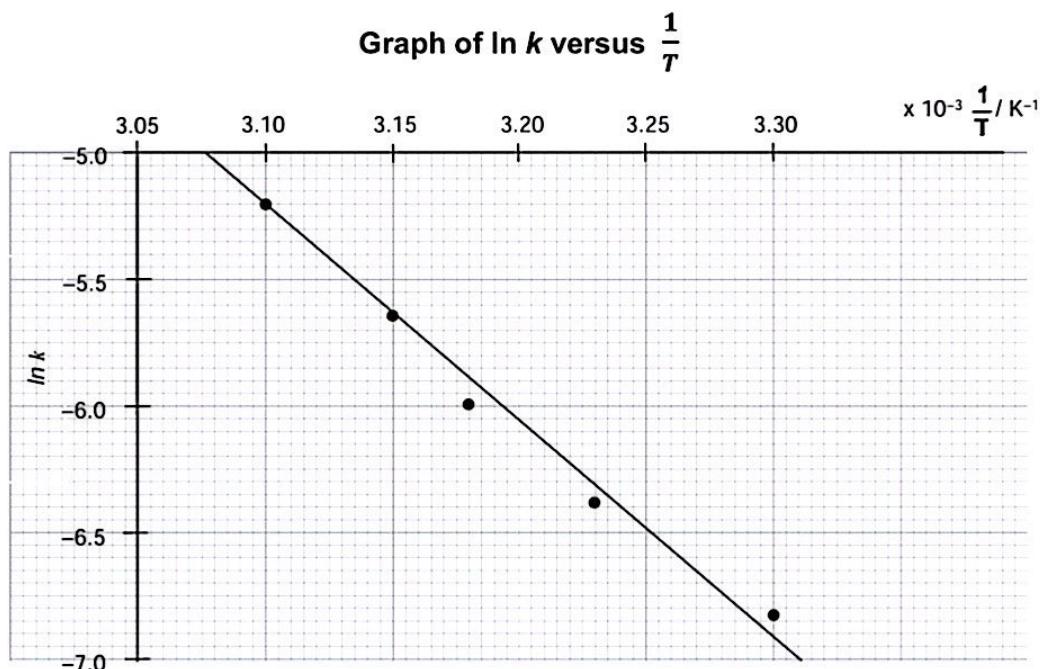
A is constant.

E_a is the activation energy.

R is the molar gas constant ($8.314 \text{ J K}^{-1} \text{ mol}^{-1}$).

T is the absolute temperature.

In a separate experiment to investigate the effect of temperature on the rate constant of the reaction between bromide ion and bromate(V) ion, the graph below was obtained.

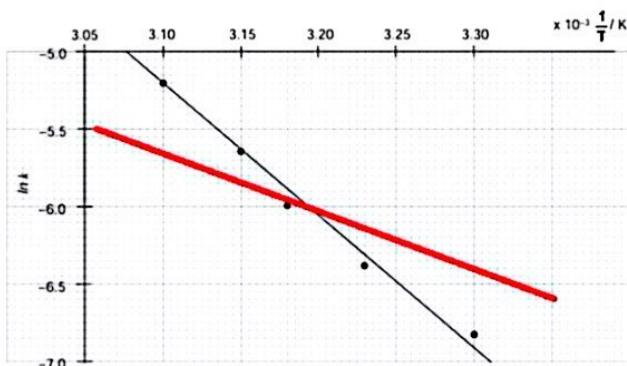


- (i) Calculate the activation energy, E_a , of the reaction. (1%)
- (ii) Suggest why the activation energy of the reaction is high. (1%)
- (iii) Sketch the graph shown above onto your writing paper. On the same axes, sketch the graph of $\ln k$ versus $\frac{1}{T}$ when the reaction proceeds in the presence of a catalyst. Label your graph clearly and explain your answer. (2%)

[Total: 12%]

c(i)	$slope = \frac{(-6.9) - (-5.2)}{(3.3 \times 10^{-3}) - (3.1 \times 10^{-3})} = 8500$ $E_a = slope \times R = 8500 \times 8.314 = 70.67 \text{ kJ mol}^{-1}$ <p style="color: red; font-weight: bold;"><u>Follow student estimation of slope, if no unit or wrong unit 0 mark.</u></p>	1
c(ii)	<p style="color: red; font-weight: bold;"><u>Electrostatic repulsion between the negatively charged ions BrO_3^- and Br^- must approach each other closely in the rate-determining step.</u></p>	1

c(iii)



Draw a line whose slope is less negative than the original.

1

Explain: as the catalyst lowers the E_a , the slope becomes less negative.

1

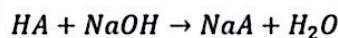
($\frac{E_a}{R}$ Where R is constant)

- 11 Vitamin C is an essential nutrient also known as ascorbic acid. A deficiency of vitamin C leads to a disease known as scurvy. [Given that molar mass of ascorbic acid is 176 gmol^{-1}]

(a) Ascorbic acid is a monobasic acid, HA, with the acid dissociation constant of 7.943×10^{-5} . The amount of ascorbic acid contained in dietary supplement tablets can be verified by titration. A tablet containing 500 mg of ascorbic acid was dissolved in 25.0 mL of deionised water.

- (i) Calculate the volume of 0.100 M sodium hydroxide required for complete neutralisation. (1%)

a(i)	$n_{HA} = \frac{0.5}{176} = 2.84 \times 10^{-3} \text{ mol}$	$\frac{1}{2}$
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$$n_{NaOH} = n_{HA} = 2.84 \times 10^{-3} \text{ mol}$$

$$V_{NaOH} = \frac{2.84 \times 10^{-3}}{0.01} \times 1000 = 28.4 \text{ mL}$$

 $\frac{1}{2}$ $\frac{1}{2}$

- (ii) Calculate the initial pH of the ascorbic acid solution. (2%)

a(ii)	$[HA] = \frac{2.84 \times 10^{-3}}{0.025} = 0.1136 \text{ mol L}^{-1}$	$\frac{1}{2}$
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$$[H^+] = \sqrt{K_a \times [HA]}$$

$$= \sqrt{(7.943 \times 10^{-5}) \times 0.1136}$$

$$= 0.003 \text{ mol L}^{-1}$$

$$pH = -\log_{10}(0.003) = 2.52$$

 $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$

(iii) Suggest a suitable indicator for the titration. Describe the expected colour change at the endpoint. (1%)

a(iii)	Indicator: Phenolphthalein Observation: Colourless to pink	$\frac{1}{2}$ $\frac{1}{2}$
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(iv) With the aid of a suitable equation, explain your choice of indicator in (iii). (3%)

a(iv)	At the equivalence point, the salt NaA hydrolyzes: $A^- + H_2O \rightleftharpoons HA + OH^-$ This produces a basic solution ($pH > 7$). Phenolphthalein is suitable because it changes color in the basic range.	$\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$
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(b) When a vitamin C tablet is swallowed, it dissolves in the stomach. The pH of the stomach is 2.

(i) Determine the percentage of ascorbic acid that is ionised in the stomach. (2%)

c(i)	$[H^+]_{stomach} = 10^{-2} = 0.01 \text{ mol L}^{-1}$ $HA \rightleftharpoons H^+ + A^-$ $K_a = \frac{[H^+][A^-]}{[HA]}$ $[H^+]$ in the stomach is present in large excess, $[H^+] \approx [H^+]_{stomach}$ $K_a = \frac{[H^+]_{stomach}[A^-]}{[HA]}$ $\alpha = \frac{[A^-]}{[HA]} \times 100\%$ $\alpha = \frac{K_a}{[H^+]_{stomach}} \times 100\%$ $\alpha = \frac{7.943 \times 10^{-5}}{0.01} \times 100\% = 0.7943\%$	$\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$
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The pH of blood is maintained at 7.35 by a H_2CO_3/ HCO_3^- buffer.

(ii) Define what is meant by buffer solution. (1%)

(iii) Using appropriate equations, explain how the buffer minimises changes in pH. (2%)

c(ii)	a solution that resists changes in pH when small amounts of acid or base are added.	1
c(iii)	When acid is added, the excess H^+ reacts with bicarbonate $HCO_3^- + H^+ \rightarrow H_2CO_3$ This consumes added H^+ and minimizes the rise in $[H^+]$ When base is added, OH^- reacts with carbonic acid $H_2CO_3 + OH^- \rightarrow HCO_3^- + H_2O$ This consumes OH^- and prevents a large increase in pH.	$\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$

[Total: 12%]