H

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME	

CLASS		TUTOR'S NAME	

CHEMISTRY **9729/03**

Paper 3 Free Response **14 September 2021**

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and class on all the work you hand in. Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions in the spaces provided on the Question Paper. If additional space is required, you should use the pages at the end of this booklet. The question number must be clearly shown.

Section A
Answer all questions.

Section B
Answer **one** question.

A Data Booklet is provided.
The use of an approved scientific calculator is expected, where appropriate.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	**/22**
2	**/18**
3	**/20**
4	**/20**
5	**/20**
Total	**/80**

This document consists of **31** printed pages..

[Turn Over

Section A

Answer **all** the questions in this section.

1 Phosgene, $COCl_2$, is a colourless gas that has the odour of freshly cut hay. It is a major industrial chemical used to make plastics and pesticides. It is highly toxic and was used extensively during World War I as a choking agent.

(a) **(i)** Draw a dot-and-cross diagram of the phosgene molecule. [1]

(ii) The actual value of the *Cl*-C-*Cl* bond angle is 117 °. Using the principles of the VSEPR theory,

- deduce the expected *Cl*-C-*Cl* bond angle.
- compare the two values and suggest a reason for the discrepancy. [2]

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(b) As phosgene is highly toxic and its odour may not be noticeable at low concentration, reactions involving phosgene must be carried out in a fume hood equipped with a method of monitoring phosgene concentration.

A simple method is to tape phosgene indicator papers, which changes colour upon exposure to gaseous phosgene, to the fume hood sill. The detection limit of one such indicator paper is 1.87 ppm (by volume). One part per million (ppm) denotes one part per 10^6 parts.

Calculate the concentration of phosgene, in mg dm^{-3}, that can be detected in the air by the phosgene indicator paper at room temperature and pressure. [2]

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(c) Phosgene can be converted into urea, $CO(NH_2)_2$, which can be used to remove oxides of nitrogen from the flue gases of power stations where hydrocarbon fuels are burnt.

(i) After conversion, urea only acts as a base when reacted with strong acids. Suggest an explanation. [1]

(ii) Explain why it is important to remove oxides of nitrogen from the flue gases. [1]

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(d) Phosgene was first prepared in 1811 by the photochemical reaction of carbon monoxide and chlorine in the presence of a catalyst at 150 °C.

$$CO(g) + Cl_2(g) \longrightarrow COCl_2(g) \qquad \Delta H_{reaction}$$

(i) Calculate a theoretical value for $\Delta H_{reaction}$ using *bond energies* from the *Data Booklet.* [2]

(ii) The actual value of $\Delta H_{reaction}$ is -107.6 kJ mol^{-1}. The two values are different as bond energies used in calculation of the theoretical value in **(d)(i)** are average values.

Identify which bond accounts for why the actual value is more exothermic. Explain your reasoning. [1]

(iii) By considering the entropy change during the preparation of phosgene, suggest how the Gibbs free energy change of the reaction varies with temperature. Hence, justify **fully** the conditions used for the reaction. [3]

(iv) The mechanism for the formation of phosgene is thought to involve three steps:

$$Cl_2 \overset{\text{Fast}}{\rightleftharpoons} 2\,Cl$$

$$Cl + CO \overset{\text{Fast}}{\rightleftharpoons} COCl$$

$$COCl + Cl_2 \overset{\text{Slow}}{\rightleftharpoons} COCl_2 + Cl$$

Suggest the rate equation for the formation of phosgene that would result from the given mechanism. [1]

(v) Define, with the aid of an equation, the term *standard enthalpy change of formation* of **liquid** phosgene. [2]

(vi) Use the following data, together with actual value of $\Delta H_{reaction}$ given in **(d)(ii)**, to calculate the standard enthalpy change of formation of **liquid** phosgene.

	value / kJ mol^{-1}
Standard enthalpy change of formation of CO(g)	−110.5
Standard enthalpy change of vaporisation of $COCl_2$(l)	+33.3

[2]

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(e) Describe the behaviour of the following oxides with the following bases and write equations for the reactions that occur. Explain **fully** whether the behaviour of the oxides is what you would expect from the position of the element in the Periodic Table.

- Al_2O_3 and NaOH
- P_4O_{10} and $Ba(OH)_2$

[4]

[Total: 22]

2 **(a)** **(i)** Use relevant $E^\ominus$ values from the *Data Booklet* to describe the relative reactivity of the halogens as oxidising agents. [2]

(ii) Describe a reaction that illustrates the relative oxidising abilities of two halogens of your choice. [1]

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(b) The volume of 0.40 mol of hydrogen chloride gas was measured at a temperature of 25 °C when various pressures were applied. The following results were obtained.

Table 2.1

pressure, p / atm	V / dm^3	pressure x volume, pV / atm dm^3
5	1.924	9.62
10	0.926	
15	0.592	

(i) Calculate the volume of 0.40 mol of an ideal gas at a temperature of 25 °C and at a pressure of 12 atm. [1]

(ii) Complete the third column in Table 2.1.

- Use your values of pV to estimate the value of pV when p = 12 atm.
- Use your estimated value of pV to calculate the value of V when p = 12 atm. [2]

(iii) Suggest an explanation for the difference in the values of pV you have obtained in **(b)(i)** and **(b)(ii)** in terms of the properties of HC*l* molecules. [1]

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(c) Hydrogen halides usually react with alkenes via an electrophilic addition mechanism. However, in the presence of organic peroxides, R-O-O-R, hydrogen bromide reacts with alkenes via a different mechanism, free radical addition.

The reaction is initiated by R – O • free radicals produced by the breaking of an oxygen – oxygen bond in the peroxide. These free radicals then extract a hydrogen atom from a hydrogen bromide molecule to produce bromine radicals. The two initiation steps are shown below.

Initiation steps:

$$R-O-O-R \longrightarrow 2R-O\bullet$$

$$R-O\bullet + HBr \longrightarrow R-O-H + Br\bullet$$

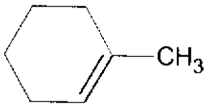
The bromine radical formed in the initiation step goes on to react with propene, forming $\bullet CH(CH_3)CH_2Br$ radicals first before forming 1-bromopropane as one of the final products.

(i) Outline the subsequent steps of the free radical addition mechanism, using curly arrows to indicate the movement of electrons. [3]

(ii) The reaction starts when the reactants are exposed to bright light. Suggest why the reaction continues with increasing rate after the brief exposure to the bright light has stopped. [2]

(iii) Unlike HBr, HC*l* does not react with alkenes via free radical addition under the same conditions. Suggest a reason why. [1]

(iv) Give the structural formula of all the organic products formed when 1-methylcyclohexene undergoes free radical addition with HBr in the presence of peroxide radicals.



1-methylcyclohexene

[2]

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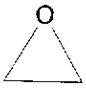
(d) In another addition reaction, ethene reacts with oxygen atoms to form epoxyethane.

$CH_2{=}CH_2$ (g) + O (g) $\longrightarrow$  (g) ΔH_1 = −354 kJ

epoxyethane

Draw an energy level diagram to determine the enthalpy change of formation of epoxyethane, given that the standard enthalpy change of formation of ethene is +52 kJ mol^{-1}.

Your energy level diagram should include relevant data from the *Data Booklet*.

[3]

[Total: 18]

3 In recent years, research in the field of organic electrosynthesis has received considerable attention. Organic electrosynthesis involves the synthesis of organic compounds in an electrolytic cell via anodic oxidation and cathodic reduction. An example of such organic electrosynthesis reaction is shown below.

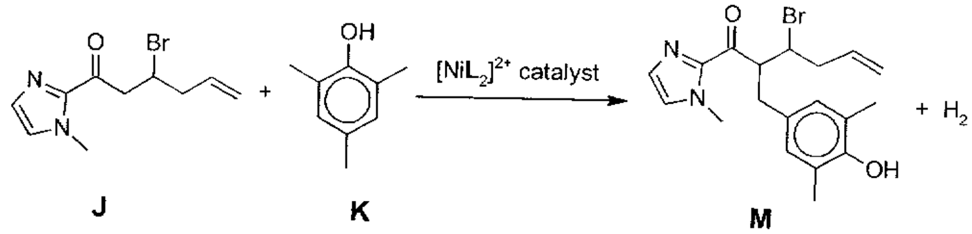


Fig. 3.1 shows three metals **F**, **G** and **H** connected in pairs in two electrochemical cells under standard conditions.

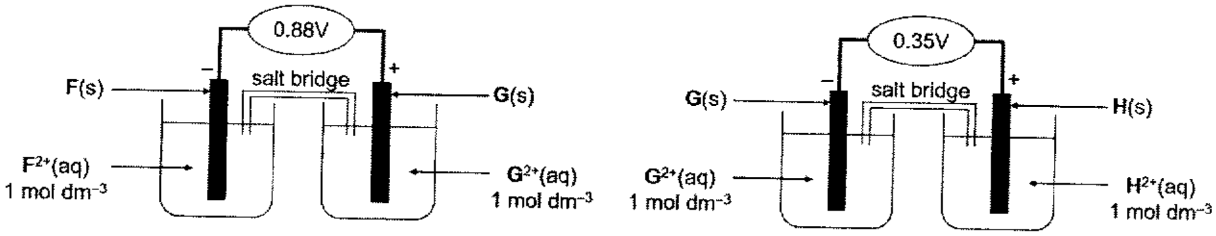


Fig. 3.1

Metals **F** and **H** were subsequently connected in an electrochemical cell. It is used to generate electrical voltage for an electrolytic cell used for organic electrosynthesis as shown in Fig. 3.2.

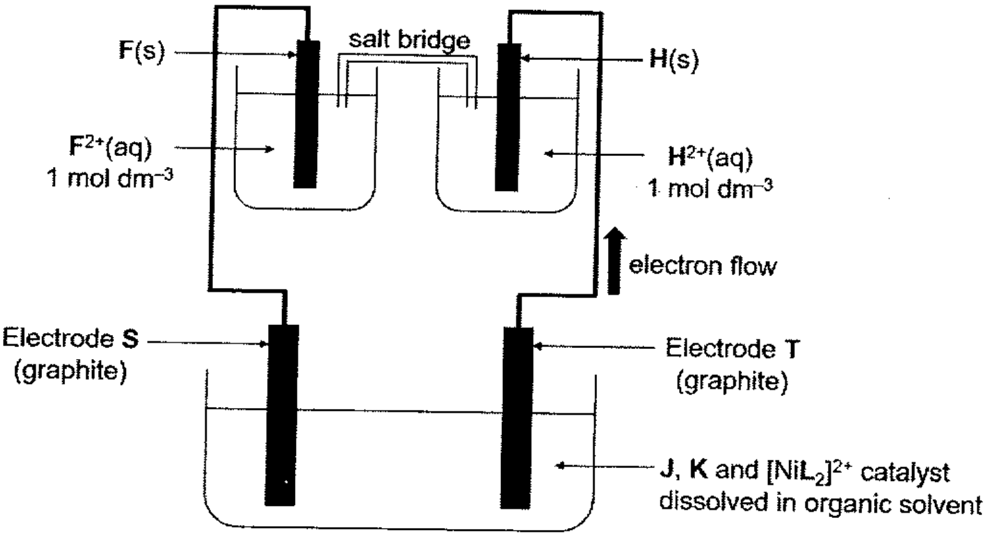


Fig. 3.2

(a) **(i)** With reference to Fig. 3.1, arrange $E^\ominus$($\mathbf{F}^{2+}$/**F**), $E^\ominus$($\mathbf{G}^{2+}$/**G**) and $E^\ominus$($\mathbf{H}^{2+}$/**H**) from the least positive to the most positive. [1]

(ii) Calculate the standard cell potential between metals **F** and **H** in the electrochemical cell used in Fig. 3.2. Write the overall equation, including state symbols. [2]

(iii) Calculate the standard Gibbs free energy change, ΔG , per mole of metal **H**. [1]

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(b) Fig. 3.3 shows a series of steps for the organic electrosynthesis occurring at electrode **T** in Fig. 3.2.

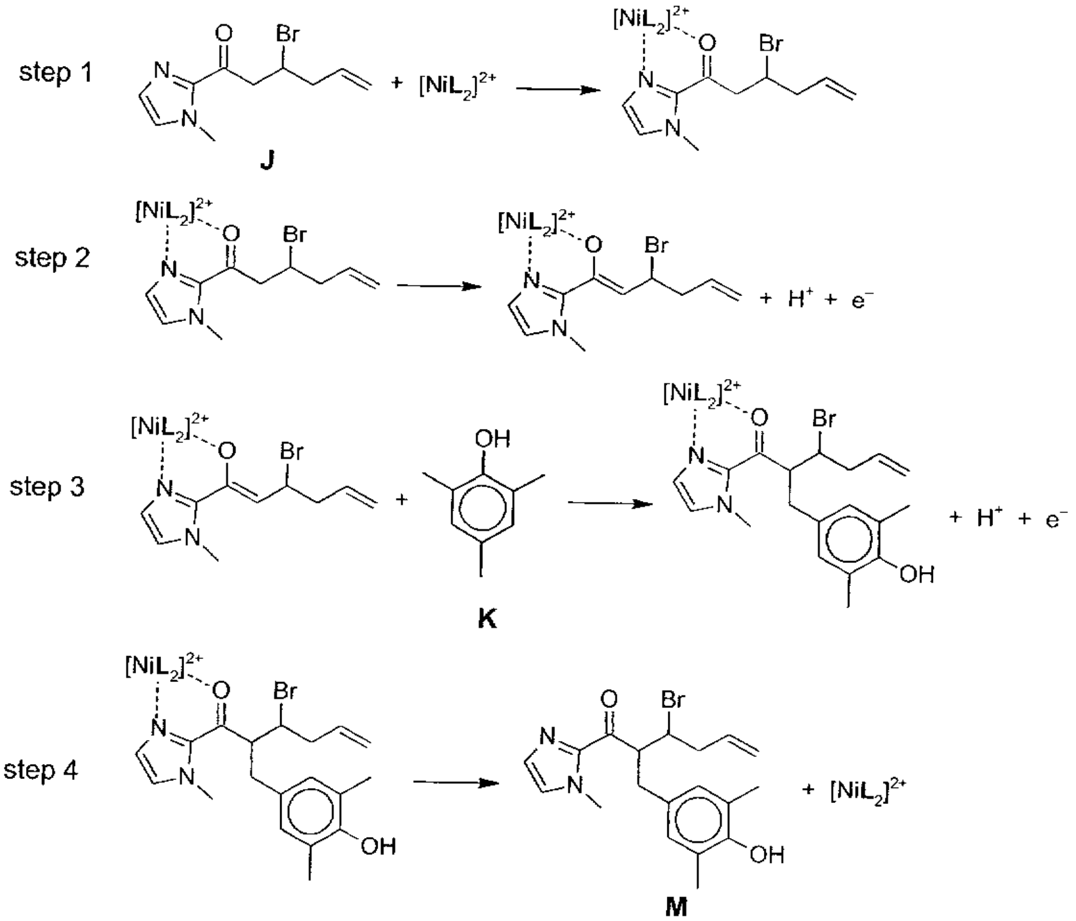

Fig. 3.3

(i) Using Fig. 3.3, suggest the half equation for the reaction occurring at electrode **T**. [1]

Ohm's law states that the current passing through a conductor between two points is directly proportional to the cell electrode potential across the two points. Introducing a proportionality constant, the mathematical equation that describes this relationship is as follows:

$$V = I \times R$$

where V is the cell electrode potential measured in volts (V)
I is the current measured in amperes (A)
R is the resistance measured in ohms (Ω)

(ii) Assuming the circuit obeys Ohm's law and the total resistance is 3.62 Ω, use your answer in **(a)(ii)** to calculate the current that passes through the electrolytic cell used for the organic electrosynthesis. [1]

(iii) The reaction occurring at electrode **S** is as follow: $2H^+ + 2e^- \rightarrow H_2$.
Determine the volume of gas evolved at electrode **S** when the electrolytic cell is run for 2.5 hours under standard temperature and pressure. [2]

(c) Copper minerals often contain copper sulfide mixed with the sulfides of silver and zinc. After roasting in air to produce the oxides and reduction to the crude metal with carbon, the solid impure copper is purified by electrolysis.

(i) Suggest two **main** changes that must be done to the setup shown in Fig. 3.2 for the purification of copper by electrolysis. [2]

(ii) With reference to the *Data Booklet*, describe the electrode reactions that take place during the electrolysis and explain in detail how each of the two impurity metals is removed. [3]

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(d) Compound **M** can be converted to compound **Q**, via intermediates **N** and **P**, as shown in Fig. 3.4.

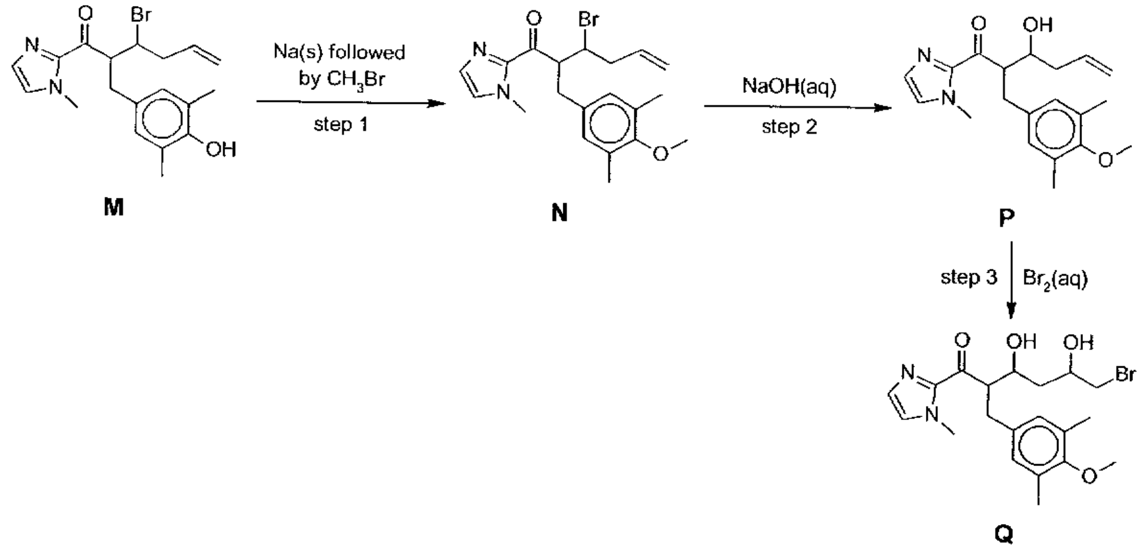


Fig. 3.4

The reaction in step 2 was investigated with other nucleophiles and the results were tabulated in Table 3.1.

Table 3.1

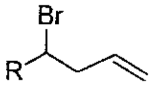
nucleophile	relative rate
NaOH	1.00
C_2H_5ONa	0.99
C_2H_5SNa	0.99
C_6H_5ONa	1.01

(i) Define the term *nucleophile*. [1]

(ii) Arrange the nucleophiles in order of increasing strength. [1]

(iii) Deduce the rate equation for the reaction in step 2. [1]

(iv) Hence, describe the mechanism of the reaction in step 2.

You may use  to represent compound **N**. In your answer, you should show all charges, lone pairs and show the movement of electrons by curly arrows. [2]

Compound **P** undergoes electrophilic addition with aqueous bromine to give compound **Q**. The first step of electrophilic addition involves the alkene being attacked by Br_2 to form a stable carbocation. However, no such reaction involving H_2O is possible.

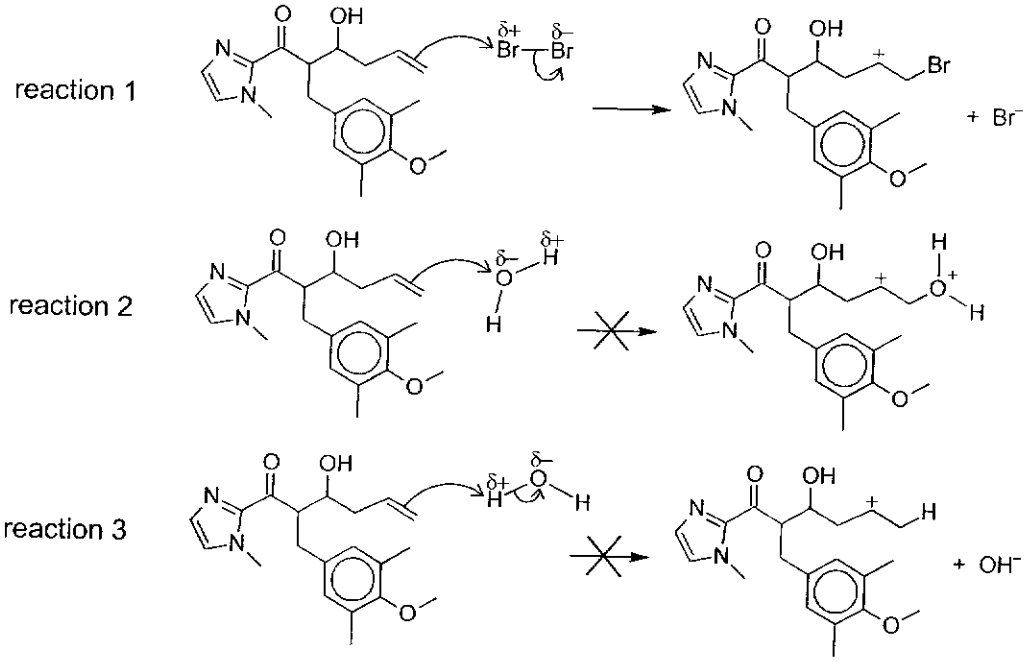


Fig. 3.5

(v) Suggest a reason to explain why reaction 2 cannot occur. [1]

(vi) With reference to the *Data Booklet*, suggest a reason to explain why reaction 1 occurs but not reaction 3. [1]

[Total: 20]

Section B

Answer **one** question from this section.

4 Carbon is one of the most abundant elements on Earth. While it is found mainly in organic substances, carbon does exist in inorganic compounds such as carbon dioxide, carbonates and hydrogencarbonates.

(a) In order to determine the pH titration curve, a student titrated 25.0 cm^3 of 0.100 mol dm^{-3} HCO_3^-(aq) against 0.100 mol dm^{-3} of HCl(aq).

The K_b for HCO_3^- is 2.34 x 10^{-8} mol dm^{-3} at 298 K.

(i) Calculate the pH of the solution before the addition of HCl(aq). [2]

(ii) Calculate the pH of the solution at the equivalence point. [2]

(iii) Calculate the pH of the solution after 37.5 cm^3 of HCl(aq) was added. [2]

(iv) Using your answers from **(a)(i)** to **(a)(iii)**, sketch the pH titration curve. Label the various key points on the curve. [2]

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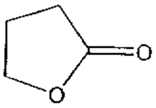
(b) A neutral compound **P** has molecular formula, $C_{15}H_{20}O_3NCl$. When **P** is refluxed with aqueous sodium hydroxide, three compounds **Q**, **R** and **S** are obtained.

Upon analysis, **Q** is found to be a straight–chain molecule having a relative molecular mass of 59.0, and its composition by mass is as follows:

61.0% C, 15.3% H, 23.7% N

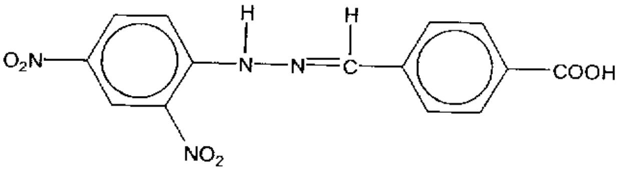
When **Q** is treated with excess iodomethane, **T** is formed. **T** has a relative formula mass of 229 and gives a yellow precipitate immediately when treated with aqueous silver nitrate.

R has the molecular formula $C_4H_7O_3Na$. Upon acidification, **R** yields **U**. **U** is also obtained when **P** is refluxed with dilute sulfuric acid. Heating **U** with a small amount of concentrated sulfuric acid produces a compound known as gamma–butyrolactone, which has the following structure:



gamma–butyrolactone

S has the molecular formula $C_8H_7O_3Na$. Upon addition of acidified potassium dichromate(VI) and heating with immediate distillation, **S** yields **V**. Treating **V** with 2,4–dinitrophenylhydrazine gives an orange precipitate which has the following structure:



(i) Determine the empirical and molecular formula of **Q**. Show your working clearly. [2]

(ii) Suggest the structures of **P** to **V**. [7]

Compound **U** can be used as a precursor of 4–aminobutanoic acid, which is also known as GABA (Gamma–AminoButyric Acid). GABA is the chief inhibitory neurotransmitter in the central nervous system and in the human retina. It also regulates muscle tone and other functions.

(iii) Both GABA and **U** have similar relative molecular masses. However, GABA is found to have a significantly higher melting point than **U**. Explain. [3]

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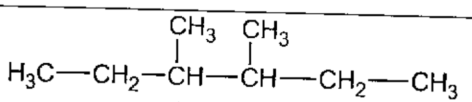
[Total: 20]

[Turn Over

5 (a) The term "octane rating" is often used in the petroleum industry for rating the ability of octane's various branched isomers in reducing engine knock in vehicles.

Compounds **A**, **B**, **C** and **D** are isomers of the hydrocarbon octane, C_8H_{18}.
Table 5.1 below shows the boiling points and data relating to the optical activity of these compounds.

Table 5.1

structure	boiling points / °C	number of chiral centres	optical activity
isomer **A**	119	1	Yes
 $H_3C-CH_2-\overset{CH_3}{\overset{\vert}{C}H}-\overset{CH_3}{\overset{\vert}{C}H}-CH_2-CH_3$ isomer **B**	118	2	No
isomer **C**	110	1	Yes
isomer **D**	107	0	No

(i) Suggest why isomer **B** has no optical activity even though it has 2 chiral centres. [1]

(ii) Draw the structural formula of each of the isomers **A**, **C** and **D**. [3]

(iii) Explain in terms of structure and bonding, why isomers **A** to **D** have different boiling points. [2]

(iv) Controlled chlorination of isomer **B** in the presence of *UV* light produces four different isomers of formula $C_8H_{17}Cl$. Draw the skeletal formula of each of the four isomers and give the mole ratio in which they are formed. [2]

(v) Monochlorination of isomer **B** in **(a)(iv)** produces many by-products, one of which has the formula $C_{16}H_{34}$. Assuming that the carbon atoms in isomer **B** do not rearrange themselves during the reaction, draw the structural formula of the isomer of $C_{16}H_{34}$ that has the lowest boiling point. [1]

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(b) The following statements involve the chemistry of Group 1 elements.

(i) "Lithium is only slowly attacked by water at 25 °C, whereas, with water, sodium reacts vigorously, potassium inflames, and rubidium and caesium reacts explosively". Explain the difference in reactivity of the Group 1 metals with water. [2]

(ii) "Lithium and sodium metals are obtained by electrolysis of their molten salts. However this method is not suitable for obtaining potassium, rubidium and caesium". Explain this observation in terms of the structure and bonding of the different metals. [2]

(iii) "Lithium is the only Group 1 metal which produces the oxide, Li_2O, when heated in oxygen. Sodium, potassium, and the other Group 1 metals produce peroxides such as Na_2O_2 and superoxides such as KO_2 when heated in oxygen."
Explain the difference in products formed. [2]

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(c) **W** is a compound of a Group 2 element **M**. When **W** was treated with dilute hydrochloric acid, a colourless gas **X** was evolved. On bubbling **X** through a small amount of limewater, a precipitate **Y** was formed, but passage of further gas resulted in a clear solution **Z**.

On strong heating, 1.9735 g of **W** decomposed, giving 1.5334 g of its oxide, which is a white solid. The white solid was dissolved in water and made up to 250 cm^3 in a standard flask. 25.0 cm^3 aliquots were titrated with acid and required 20.30 cm^3 of 0.0985 mol dm^{-3} hydrochloric acid.

(i) Identify compounds **X, Y** and **Z**. [2]

(ii) Calculate the relative molecular mass of **W**. [2]

(iii) Consider the identity of **W** and calculate the relative atomic mass of the Group 2 element **M** in **W**. Hence identify **M**. [1]

[Total: 20]

Additional answer space

If you use the following pages to complete the answer to any question, the question number must be clearly shown.

J2 H2 Chemistry Prelim Answers

Paper 1 Answer Key

1	B	**11**	C	**21**	A
2	C	**12**	A	**22**	A
3	C	**13**	C	**23**	D
4	D	**14**	D	**24**	C
5	D	**15**	B	**25**	C
6	B	**16**	B	**26**	A
7	A	**17**	C	**27**	B
8	D	**18**	A	**28**	C
9	D	**19**	B	**29**	D
10	B	**20**	B	**30**	C

Paper 1 Worked Solutions

1 (B)

100 g of mixture contains 21.25 g of Mg.

	M_r
$MgCl_2$	95.3
$Mg(NO_3)_2$	148.3

Let mass of $MgCl_2$ present in 100 g of mixture be x.

$$\frac{x}{95.3} \times 24.3 + \frac{100 - x}{148.3} \times 24.3 = 21.25$$

x = 53 g

2 (C)

$$n(M_2O_n) = 0.500 \times \frac{10.00}{1000} = 0.00500 \text{ mol}$$

$$n(KMnO_4) = 0.300 \times \frac{20.00}{1000} = 0.00600 \text{ mol}$$

Given the reduction half equation: $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$
n(e-) involved in the redox = 0.00600 × 5 = 0.0300 mol
0.00500 mol of M_2O_n contain 0.0100 mol of M^{n+}.

Hence, 0.0100 mol of M^{n+} loses 0.0300 mol of e^- to form M^{6+}.
1 mol of M^{n+} loses 3 mol of e^- to form M^{6+}.
n = 3

3 (C)

$$\begin{array}{cccccc} 1^{st} & 2^{nd} & 3^{rd} & 4^{th} & 5^{th} & 6^{th} \\ 660 & 1267 & 2218 & 3313 & 7863 & 9500 \end{array}$$

$$\underbrace{660\ \ 1267}_{607}\ \underbrace{1267\ \ 2218}_{951}\ \underbrace{2218\ \ 3313}_{1095}\ \underbrace{3313\ \ 7863}_{4550}\ \underbrace{7863\ \ 9500}_{1637}$$

Largest increase from 4th I.E.to 5th I.E. indicates that the 5th electron is removed from an inner electron shell.

Element Q is a Group 14 element with 4 valence electrons and reacts with chlorine to form QCl_4. Other statements cannot be inferred from the data given (while option D is incorrect). Since Q is ns^2np^2, element preceding it is ns^2np^1, hence it should follow the general increasing trend).

4 (D)

Statement 1 is incorrect.
van der Waals radius of chlorine is smaller than that of argon. This is because Cl_2 molecules (M_r = 71.0) have stronger instantaneous dipole-induced dipole (id-id) interactions than id-id forces between Argon atoms (A_r = 39.9).

Statement 2 is incorrect.
CH_3CH_2CHO do not have hydrogen bonds between its molecules.

Statement 3 is correct.
C-C bond length in diamond is longer and weaker than graphite due to the smaller s character of the sp^3–sp^3 overlap in diamond as compared to the sp^2–sp^2 overlap in graphite.

5 (D)

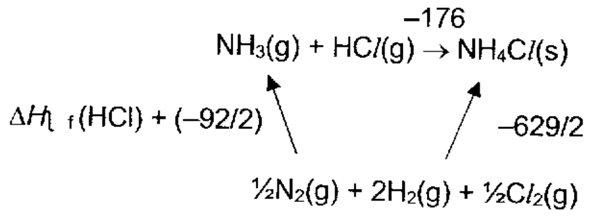
Step 1. Determine R under standard conditions:

$$R = \frac{pV}{nT} = \frac{10^5 \times 22.7 \times 10^{-3}}{1 \times 273}$$

Step 2. Substitute R into the equation

$$P = \frac{\rho RT}{M_r} = \frac{8 \times (300 + 273)}{2.0} \times \frac{10^5 \times 22.7 \times 10^{-3}}{1 \times 273} = \frac{573 \times 4 \times 22.7 \times 100}{273}$$

6 (B)



$\Delta H^{\ominus}_f(HCl) + (-92/2) + (-176) = -629/2$
$\Delta H^{\ominus}_f(HCl) = -92.5$ kJ mol^{-1}

Alternative:
$\Delta H^{\ominus}_f(NH_4Cl) = -629/2$
$\Delta H^{\ominus}_f(NH_3) = -92/2$

$$NH_3(g) + HCl(g) \xrightarrow{-176} NH_4Cl(s)$$

$-176 = -629/2 - (-92/2) - \Delta H^{\ominus}_f(HCl)$
$\Delta H^{\ominus}_f(HCl) = -92.5$ kJ mol^{-1}

7 (A)

Statement 1 is correct:

$\Delta H_r^{\ominus} = \sum n\Delta H_f^{\ominus}(\text{products}) - \sum m\Delta H_f^{\ominus}(\text{reactants})$
$= -1273 - [6\times(-394) + 6\times(-286)]$
$= +2807 \text{ kJ mol}^{-1}$

Statement 2 is correct.
The photosynthesis process has no change in number of particles of gases, but there is a change of state (liquid water in the reactant to solid $C_6H_{12}O_6$ in the product). There is a decrease in overall entropy and thus, ΔS has a negative sign (e.g. less disordered).

Statement 3 is correct.
Since $\Delta G = \Delta H\ (+\text{ve}) - T\Delta S\ (-\text{ve})$, the ΔG for the reaction will always be positive at all temperatures as ΔH and $-T\Delta S$ is always positive.

8 (D)

$t_{1/2} = \ln 2/k = \ln 2/7.70 \times 10^{-4}$
$= 900 \text{ s} = 15 \text{ min}$

no. of half-lives = 80 / 15 = 5.33

$\frac{A_t}{A_0}=\left(\frac{1}{2}\right)^n \quad \frac{0.0315}{A_0}=\left(\frac{1}{2}\right)^{5.33}$

Conc = 1.27 mol dm^{-3}

9 (D)

Statement 1 is correct.
Comparing Expt 1 and 3, when [HCl] is halved (0.20/0.10), the rate is halved (0.192/0.096). Hence it is a first order with respect to HCl.
Comparing Expt 2 and 3, when [methyl propanoate] is increased 1.5 times (0.15/0.10), the rate increased 1.5 times (0.144/0.096). Hence it is a first order with respect to methyl propanoate.
Since rate = k[methyl propanoate][HCl], when [methyl propanoate] doubles and [HCl] increases 1.5 times from expt 2 to expt 4, the rate = 0.144 × 2 × 1.5 = 0.432.

Statement 2 is incorrect as units are incorrect.
Using Expt 1: 0.192 = k(0.10)(0.20)
k = 9.6 mol^{-1} dm^{3} min^{-1}

Statement 3 is correct.
rate = k[methyl propanoate][HCl]
rate = k'[methyl propanoate] where k' = k[HCl]. Since HCl is a catalyst which gets regenerated in the reaction, the [HCl] remains constant.
$t_{1/2} = \ln 2/k' = \ln 2/k[HCl]$
Since [HCl] is decreased $\frac{0.15}{0.20} = \frac{3}{4}$, the time taken will be $\frac{4}{3} \times 6 = 8$ min.

10 (B)

	N_2O_4	$\rightleftharpoons$	$2NO_2$	
Initial amt/ mol	x		0	
Change/ mol	–0.5x		+1.0x	
Eqm amt/ mol	0.5x		1.0x	Total amount = 1.5x mol

$$P_{N_2O_4} = \left(\frac{0.5x}{1.5x}\right) \times 1 = \frac{1}{3} \text{ atm}$$

$$P_{NO_2} = \left(\frac{x}{1.5x}\right) \times 1 = \frac{2}{3} \text{ atm}$$

$$K_p \text{ for the reverse reaction} = \frac{P_{N_2O_4}}{\left(P_{NO_2}\right)^2} = \frac{\left(\frac{1}{3}\right)}{\left(\frac{2}{3}\right)^2} = \frac{3}{4} \text{ atm}^{-1}$$

11 (C)

Given $[OH^-] = 10^{-7}$

$$K_b = \frac{[OH^-][NH_4^+]}{[NH_3]} = 1.76 \times 10^{-5}$$

$$\frac{[NH_3]}{[NH_4^+]} = \frac{5.681 \times 10^{-3}}{1}$$

$$\frac{[NH_3]}{[NH_3]+[NH_4^+]} = \frac{5.681 \times 10^{-3}}{5.681 \times 10^{-3}+1} = 5.65 \times 10^{-3}$$

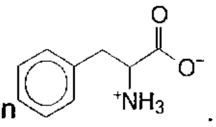
12 (A)

A buffer solution's pH will not change significantly when some alkali is added.

Statement 1 is correct.
When 0.003 mol of CH_3COOH (excess) was mixed with 0.002 mol of KOH (limiting), 0.002 mol of $CH_3COO^-Na^+$ (salt) and 0.001 mol of CH_3COOH (remaining) will be formed at equilibrium. This is a buffer solution.

Statement 2 is correct.
0.0025 mol of HPO_4^{2-} (conjugate base) is mixed with 0.00075 mol of $H_2PO_4^-$ (acid). This is a buffer solution.

Statement 3 is correct.

0.002 mol phenylalanine exist as a zwitterion  . It can act as a buffer as it has both an acidic ($-NH_3^+$) and a basic ($-COO^-$) group.

13 (C)

	Highest			Lowest
Melting point	Si	Al	Mg	P
First IE	P	Si	Mg	Al

14 (D)

Option A is incorrect. Down the group, the number of electron shell increases, shielding effect increases significantly, hence the outermost electron is further away and is less attracted by the nucleus. Hence first ionisation energies points of elements decreases.

Option B is incorrect. With increasing proton number, cationic radius increases while charge remains the same. Charge density decreases with increasing proton number of Group 2 ions. The acidity of solutions of the chlorides decreases due to the decrease in charge density.

Option C is incorrect. From $MgSO_4$ to $BaSO_4$, the $|\Delta H_{hydration}|$ of Group 2 sulphates decreases faster than the |lattice energy| of Group 2 sulphates, hence the solubility decreases down the group. We can also infer that $MgSO_4$ (soluble salt) while $BaSO_4$ (insoluble salt).

Option A is correct. The decomposition temperature of carbonates increases since the polarising power of Group 2 cations decreases with decreasing charge density. The C–O bond in carbonates is less weakened.

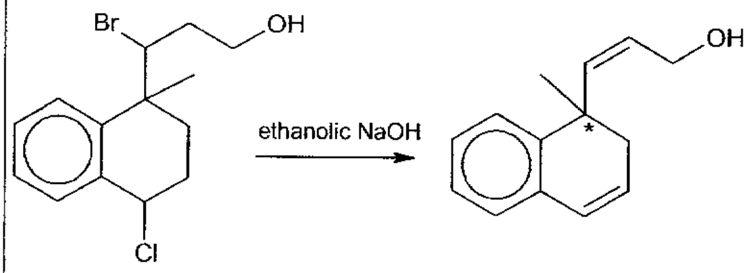
15 (B)

Statement 1 is incorrect.
The higher the boiling point, the lower its volatility.
HF has the highest boiling point as most energy is needed to overcome the strong hydrogen bonds between HF molecules. Boiling point of HI > HBr > HC*l*. Down the group, the size of electron cloud of hydrogen halides increases and become more polarisable. More energy needed to overcome the stronger instantaneous dipole – induced dipole interactions between molecules.

Statement 2 is incorrect.
The thermal stability of the hydrogen halides decreases down the group. This is due to the decreasing strength of the H–X bond. The weaker the bond, the lesser the energy required for decomposition.

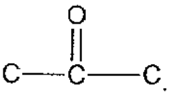
Statement 3 is correct.
Reducing strength of halide ions increases down the group. $E^\ominus(X_2/X^-)$ becomes less positive, hence X^- is more likely to be oxidised.

16 (B)

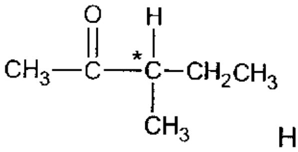


There is only 1 chiral centre (marked with *), and 1 C=C that can exhibit cis-trans isomerism.
Note that the C=C in the ring cannot exhibit cis-trans isomerism.
Hence, total number of stereoisomers → $2^2 = 4$

17 (C)

A ketone must contain a C=O between two C atoms. 
$C{-}\overset{O}{\overset{\|}{C}}{-}C$.

For a chiral centre to be present, one C present must be bonded to 4 different groups and the 4 different groups are (CH_3CO, H, CH_3 and CH_2CH_3).

i.e. 
$CH_3{-}\overset{O}{\overset{\|}{C}}{-}\overset{*}{C}H(CH_3){-}CH_2CH_3$

Hence compound must contain at least 6 C atoms (the compound could contain 6 or 7 carbon atoms).

18 (A)

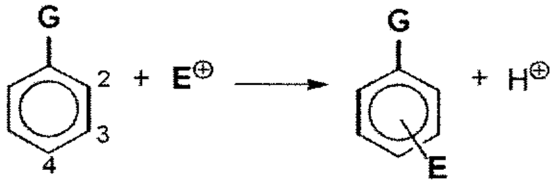
Statement 1 is correct.
Maleic acid is the cis isomer because it has a lower pK_{a1} and a higher pK_{a2} value. A lower pK_{a1} would suggest that maleic acid is more acidic as it has a more stable monoanion due to the intramolecular hydrogen bonding. It has a higher pK_{a2} value because the dianion experiences repulsion between the 2 $-COO^-$ groups, hence making the conjugate base unstable.

Statement 2 is incorrect.
Boiling point of fumaric acid is higher as it does not have intramolecular hydrogen bonding between the $-COOH$ groups and thus forms more extensive intermolecular hydrogen bonding. Hence more energy is required to overcome the stronger intermolecular forces.

Statement 3 is correct.
$CH(OH)(CO_2H)CH(Br)CO_2H$ is formed when fumaric acid reacts with aqueous Br_2.

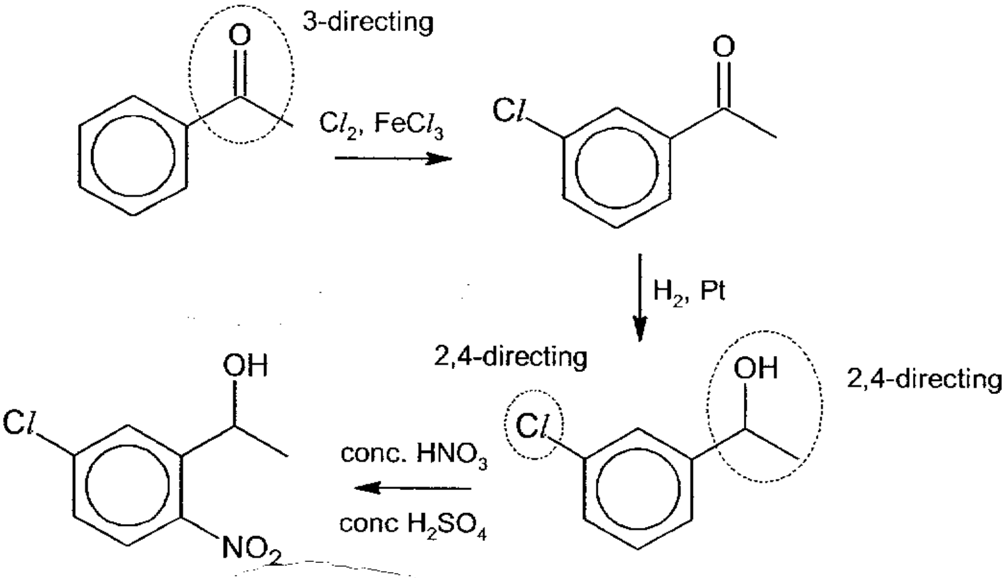
Statement 4 is incorrect.
$HO_2CCH=CHCO_2H$ reacts with alkaline $KMnO_4$ to form 4 moles of CO_3^{2-}.
Note: $(COOH)_2$ can be further [O] by $KMnO_4$.

19 (B)



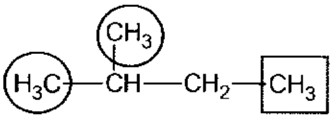
G	–alkyl ~~–OH~~ or –OR –NH$_2$, –NHR or –NR$_2$ –NHCOR	–Cl, –Br, –I	–CHO, –COR –CO$_2$H, ~~–CO$_2$~~R ~~–NH$_3^+$~~ –NO$_2$, –CN
Reactivity of ring (compared to benzene)	Activated	Deactivated	Deactivated
Position of E (relative to position of G)	2- and/or 4-	2- and/or 4-	3-

The directing effects of the circled substituents will decide the sequence of substituent entering the ring.

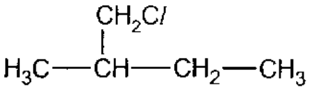
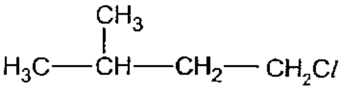


20 (B)

Statement **1** is correct.

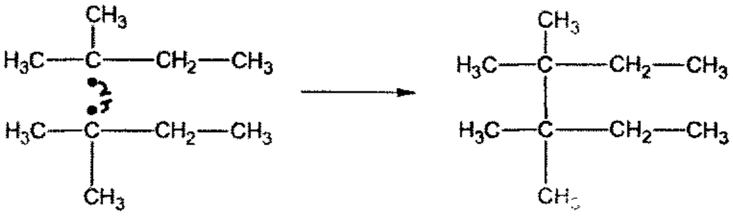


$H_3C-CH(CH_3)-CH_2-CH_3$

There are 6 H atoms that will give  $H_3C-CH(CH_2Cl)-CH_2-CH_3$ and 3 H atoms that will give  $H_3C-CH(CH_3)-CH_2-CH_2Cl$. Hence ratio is 2 : 1.

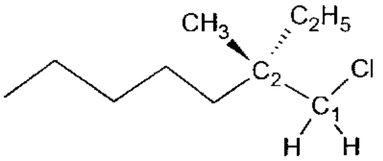
Statement 2 is incorrect.
Homolytic fission occurs in both the initiation and propagation steps.

Statement 3 is correct.



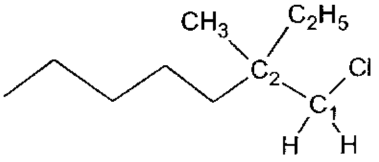
21 (A)

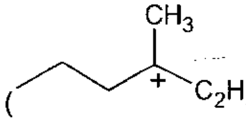
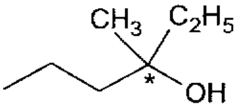
Option A is correct.



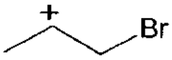
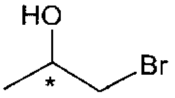
The 1° chloroalkane (at C_1) undergoes S_N2 reaction resulting in an inversion of configuration. However there is no chiral C at C_1 (as it contains 2H) so there are no enantiomers present for C_1.

There is a chiral C at C_2. However as the 3D structure is shown, only one of the enantiomers is shown/used in reactant. There is no change at C_2 during reaction, the same enantiomer remain after reaction and no mixture of enantiomers will be formed.

[NOTE: If 3D structure not used e.g.  , it would represent two enantiomers]

Option B is incorrect. The 3° chloroalkane undergoes S_N1 reaction, forming a carbocation intermediate. Th~~e OH^- can~~ th~~en attack the~~ carbocation intermediate () forming the product where there is a chiral centre (marked with *), i.e.  .

Option C is incorrect. Nucleophilic addition of ketone results in formation of two enantiomers (in equal amounts).

Option D is incorrect. The alkene undergoes electrophilic addition, forming  intermediate. H_2O can then attack the carbocation intermediate, forming the product where there is a chiral centre (marked with *), i.e.  .

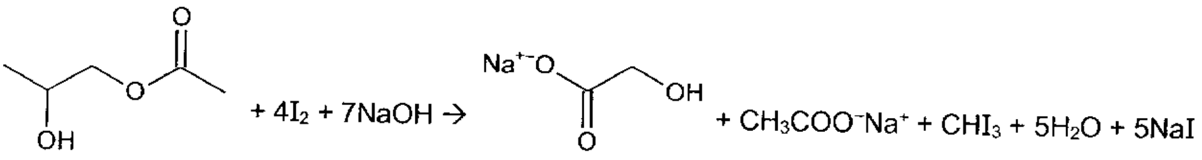
⇨ Options B, C & D will result in formation of two enantiomers.

22 (A)

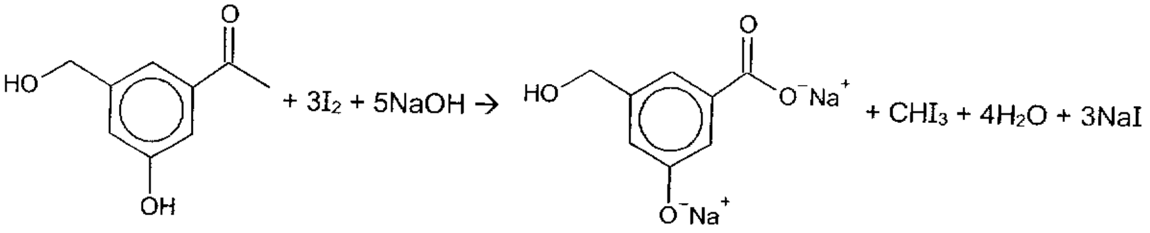
Positive test with $[Ag(NH_3)_2]^+$ (Tollens' Reagent): Presence of either aliphatic or aromatic aldehyde
Negative test with alkaline Cu(II) complex (Fehling's Solution): Absence of aliphatic aldehye (e.g. Presence of benzaldehyde)
Positive test with PCl_5: Presence of –OH group in either alcohol or carboxylic acid functional group. Phenol does not react with PCl_5.

23 (D)

For Compound S, the ester requires 1 mole of NaOH for alkaline hydrolysis while the methyl alcohol requires 6 moles of NaOH for oxidation.



For Compound T, the phenol requires 1 mole of NaOH for acid base reaction while the methyl ketone requires 4 moles of NaOH for oxidation.



24 (C)

All three species are conjugate bases of weak acids. Since the same amount of each substance is dissolved separately in the same volume of water, the higher the pH of the resultant solution, the stronger the base.

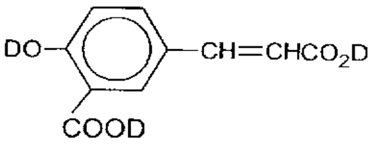
Note: The weaker the acid, the stronger its conjugate base.
In the conjugate base, $CH_2{=}CHCOO^-$, the p orbital of O overlaps with the π electron cloud of the $-C{=}O$ bond and the $C{=}C$ bond. The lone pair of electrons on the oxygen atom delocalises into the $-C{=}O$ and the $C{=}C$ bond. The negative charge is dispersed to a larger extent than CH_3COO^-, stabilising the $CH_2{=}CHCOO^-$ ion.

Strength of acid: $CH_2{=}CHCOOH > CH_3COOH > C_6H_5OH$
Strength of conjugate base: $CH_2{=}CHCOO^- < CH_3COO^- < C_6H_5O^-$
lowest pH ⟶ highest pH

25 (C)

When compound V is dissolved in D_2O, the following will take place:

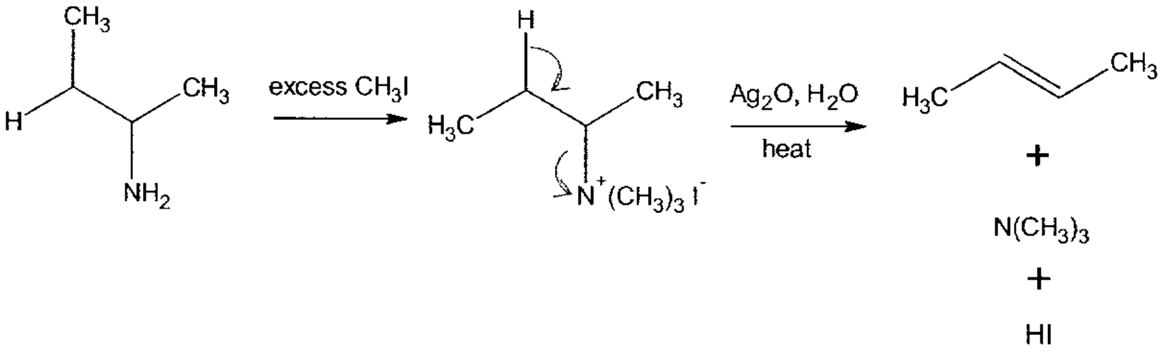
- proton exchange of the 2 acidic functional groups (phenol and carboxylic acid) and
- hydrolysis of acyl chloride $RCOCl + D_2O \rightarrow RCOOD + DCl$



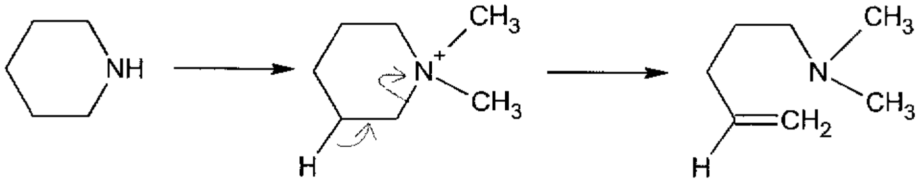
Compound W

26 (A)

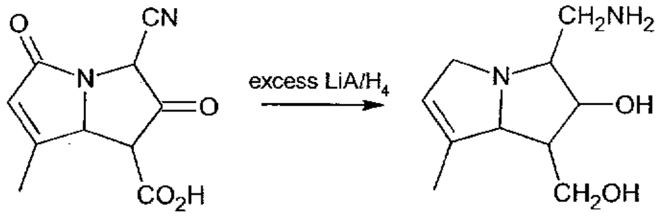
For given reaction, observe arrow movement



Similarly for piperidine



27 (B)



X Y

Option A is not correct.
Five moles of HBr is required (one mole for acid-base reaction with <u>each</u> amine group, one mole for electrophilic addition with alkene group and 2 moles for substitution with <u>each</u> alcohol group).

Option B is correct.
Two moles of $SOCl_2$ is required (one mole for nucleophilic substitution with <u>each</u> alcohol group).

Option C is not correct.

Three moles of CH_3COCl is required (one mole for condensation with <u>each</u> alcohol group, one mole for condensation with primary amine)

(Note: tertiary amines cannot form amides with CH_3COCl.)

Option D not correct.
One mole of H_2 gas is produced (Each alcohol group will react and the mole ratio of alcohol : H_2 = 1 : ½).

28 (C)

Using the mass and M_r, the amount and hence mole ratio of the amino acids can be calculated.
aspartic acid : glutamine : proline
= 2 : 1 : 1

Z is a tetrapeptide with 3 amide linkages
Hence, M_r of the polypeptide
= (2 × 133 + 146 + 115) – (3 × 18) = 473

29 (D)

$Zn^{2+} + 2e \rightleftharpoons Zn$ –0.76 V --- (1)
$Fe^{3+} + e \rightleftharpoons Fe^{2+}$ +0.77 V --- (2)
$E^\ominus_{cell} = (+0.77) - (-0.76) = +1.53$ V [$E^\ominus_{cell}$ measured is less positive than expected.]

Option A is incorrect. When water is added to the Zn^{2+}/Zn half-cell, $[Zn^{2+}]$ decreases. The position of equilibrium (1) shifts to left. $E^\ominus_{oxd}$ becomes more negative which results in a more positive $E^\ominus_{cell}$.

Option B is incorrect. When water is added to the Fe^{3+}/Fe^{2+} half-cell, $[Fe^{3+}]$ and $[Fe^{2+}]$ decreases to the same extent. The position of equilibrium (2) does not shift. $E^\ominus_{cell}$ will not change.

Option C is incorrect. The size of the Zn electrode does not affect the values of $E^\ominus_{oxd}$, hence $E^\ominus_{cell}$ will not change.

Option D is correct. When a small amount of OH^- is added, the $E^\ominus_{red}$ will change.
$Zn^{2+} + 2e \rightleftharpoons Zn$ –0.76 V --- (1)
$Fe(OH)_3 + e \rightleftharpoons Fe(OH)_2 + OH^-$ –0.56 V --- (2)
$E^\ominus_{red}$ becomes less positive. This results in a less positive $E^\ominus_{cell}$.

30 (C)

$2Cl^- \rightleftharpoons Cl_2 + 2e^-$ -------- (1)
$2H_2O \rightleftharpoons O_2 + 4H^+ + 4e^-$ -------- (2)
Since volume of oxygen collected is 1.5 times as much as the volume of chlorine gas, amount of oxygen collected is also 1.5 times as much as the volume of chlorine gas.

$n(O_2) = 1.5n(Cl_2)$
Since $Q = nzF = It$, $I = nzF/t$

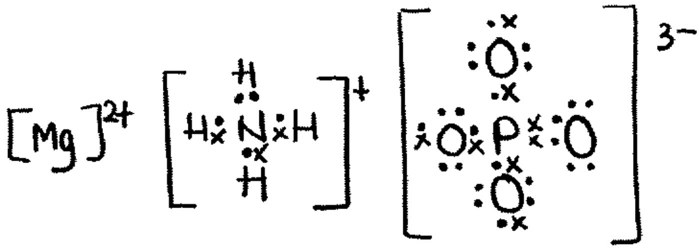
Q for (1) = $2n(Cl_2)$ F, Q for (2) = $4n(O_2)F = 4 \times 1.5n(Cl_2) \times F = 6n(Cl_2)$ F

Q for (1) : Q for (2)
$2n(Cl_2)$ F : $6n(Cl_2)$ F = 1 : 3

Since Q = It and t = 5 min for both experiments,
I for (1) : I for (2) = 1 : 3

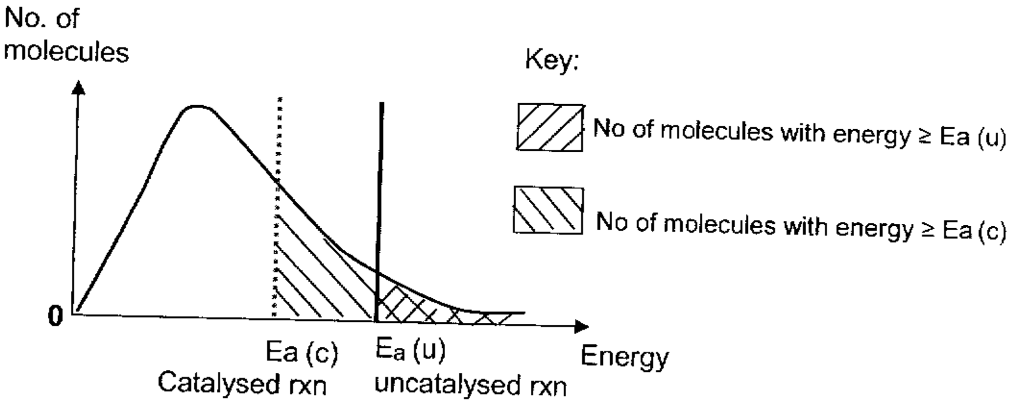
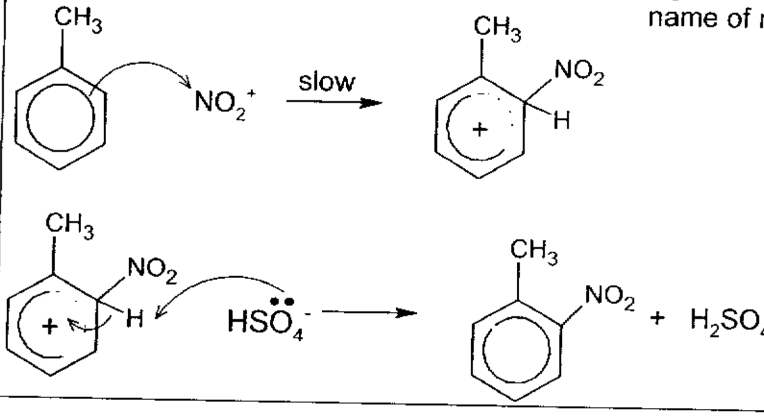
Current used for electrolysis 2 (aqueous sulfuric acid) = $3I$

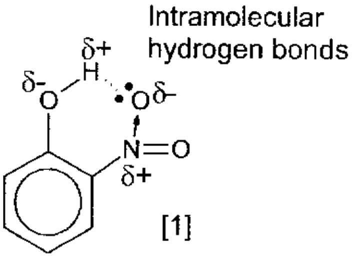
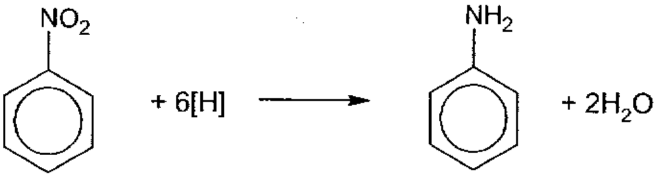
Paper 2 Answers

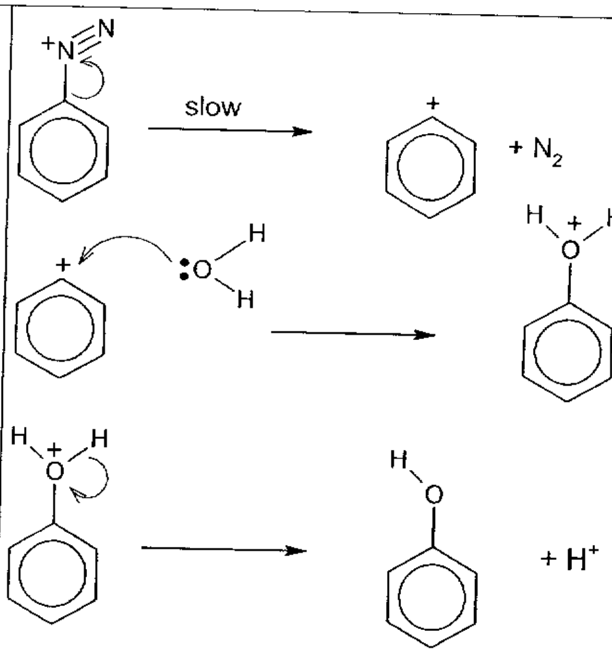
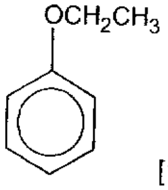
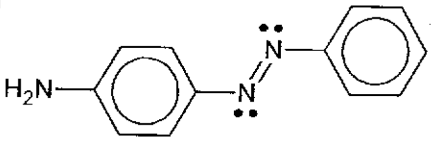
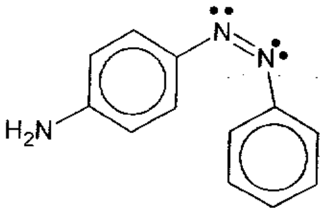
1	(a)	(i)	 1 mark for 2 correct 2 marks for all 3 correct
		(ii)	The energy released from the formation of ion-dipole interactions between ions in $MgNH_4PO_4$ and water molecules is **insufficient** to overcome the energy required to break ionic bonds between oppositely charged ions in $MgNH_4PO_4$ (and hydrogen bonds between water molecules). [1]
		(iii)	$2MgNH_4PO_4(s) \rightarrow Mg_2P_2O_7(s) + 2NH_3(g) + H_2O(l)$ [1]
	(b)	(i)	$3Mg^{2+}(g) + 2PO_4^{3-}(g) \rightarrow Mg_3(PO_4)_2(s)$ [1] It is the energy evolved when one mole of an ionic solid, $Mg_3(PO_4)_2$, is formed from gaseous Mg^{2+} and PO_4^{3-} ions under standard conditions. [1]
		(ii)	• Magnesium chloride and magnesium phosphate have giant ionic structure, with strong electrostatic forces of attraction (ionic bonds) between oppositely charged ions. • Cl^- is singly charged while PO_4^{3-} is triply charged. PO_4^{3-} has a larger ionic radius than Cl^-. • $\lvert LE \rvert \propto \frac{\lvert z_+ \cdot z_- \rvert}{r_+ + r_-}$. The lattice energy of $Mg_3(PO_4)_2$ is more exothermic than $MgCl_2$. • Contribution of ionic radius to lattice energy is less significant than that of ionic charges. • More energy is needed to break the stronger ionic bonds between Mg^{2+} and PO_4^{3-} in $Mg_3(PO_4)_2$. 1 mark for any 3 points 2 marks for all 5 points
		(iii)	$K_{sp} = [Mg^{2+}]^3\,[PO_4^{3-}]^2$ units: $mol^5\,dm^{-15}$
		(iv)	Let x be the solubility of $Mg_3(PO_4)_2$ $Mg_3(PO_4)_2(s) \rightleftharpoons 3Mg^{2+}(aq) + 2PO_4^{3-}(aq)$ x 3x 2x $K_{sp} = [Mg^{2+}]^3[PO_4^{3-}]^2$ $4.0 \times 10^{-25} = (3x)^3\,(2x)^2 = (27x^3)\,(4x^2)$ $108\,x^5 = 4.0 \times 10^{-25}$ [1] $x = 5.172 \times 10^{-6}$ $[Mg^{2+}] = 3x = 1.551 \times 10^{-5}$ mol dm^{-3} $= 1.6 \times 10^{-5}$ mol dm^{-3} [1]

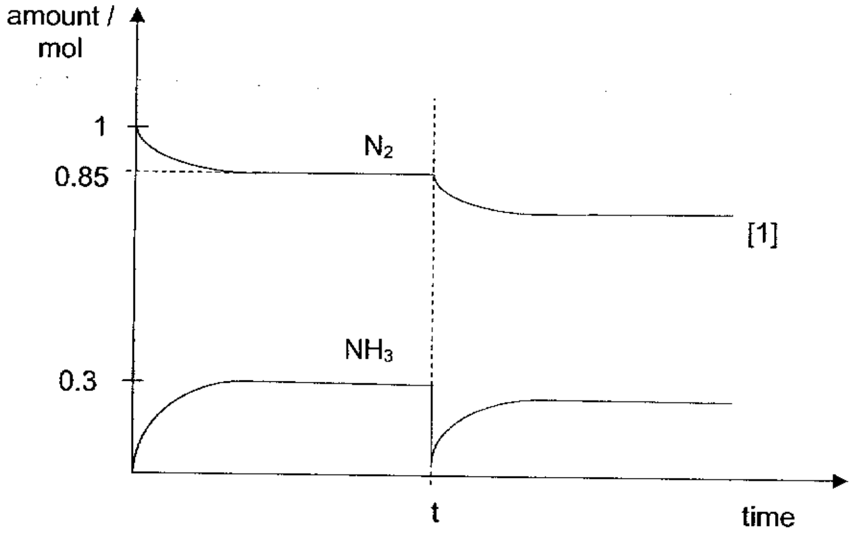
		(v)	$K_{sp} = [Mg^{2+}][OH^-]^2$ $1.8 \times 10^{-11} = [Mg^{2+}]_{min}(0.15)^2$ $[Mg^{2+}]_{min} = 4.4 \times 10^{-10}$ mol dm^{-3} $K_{sp} = [Mg^{2+}]^3[PO_4^{3-}]^2$ $4.0 \times 10^{-25} = [Mg^{2+}]^3_{min}(0.32)^2$ $[Mg^{2+}]_{min} = 1.6 \times 10^{-8}$ mol dm^{-3} [1] for $[Mg^{2+}]_{min}$ for $Mg_3(PO_4)_2$ When the first trace of $Mg_3(PO_4)_2$ appears, $[Mg^{2+}] = 1.6 \times 10^{-8}$ mol dm^{-3} To calculate the $[OH^-]$ present: $K_{sp} = [Mg^{2+}][OH^-]^2$ $1.6 \times 10^{-8}\ [OH^-]^2 = 1.8 \times 10^{-11}$ $[OH^-] = 3.4 \times 10^{-2}$ mol dm^{-3} [1] for final answer [1] for 2 sf presentation for both **(iv)** and **(v)**.
2	**(a)**	**(i)**	NO_2 functions as a homogeneous catalyst as it is in the same phase as the gaseous reactants and products. The presence of small amounts of NO_2 (g) provides an alternative mechanism of lower Ea to catalyse the oxidation of gaseous $SO_2(g)$ to $SO_3(g)$. [1] $SO_2 + NO_2 \rightarrow SO_3 + NO$ $NO + \frac{1}{2} O_2 \rightarrow NO_2$ [1]
		(ii)	Nitrogen dioxide is a pollutant that is often produced in car engine, when N_2 reacts with O_2 at high temperature condition. The Circuit Breaker of 2020 resulted in reduced usage of cars, and hence reduced production of NO_2. [1]
		(iii)	Circuit Breaker of 2020 resulted in less vehicles on the road but did not reduce as significantly usage of electricity as work from home became a necessity. Since sources of PM_{10} and $PM_{2.5}$ include power plants and industries, formation of PM_{10} and $PM_{2.5}$ did not decrease by the same extent as NO_2. [1]
	(b)		$\underline{2}NO_2 + HSO_3^- + H_2O \rightarrow \underline{3}H^+ + \underline{2}NO_2^- + SO_4^{2-}$ [1]
	(c)	**(i)**	The order of reaction with respect to a given reactant/catalyst is the power to which the concentration of that reactant/catalyst is raised in the experimentally determined rate equation. [1] The rate constant, k, is the proportionality constant in the rate equation. [1] Or In general, for any reaction, $\mathbf{aA + bB \longrightarrow mM + nN}$ The general rate equation can be written in the form $\mathbf{rate = k[A]^x[B]^y}$

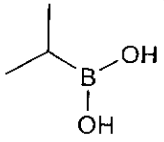
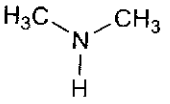
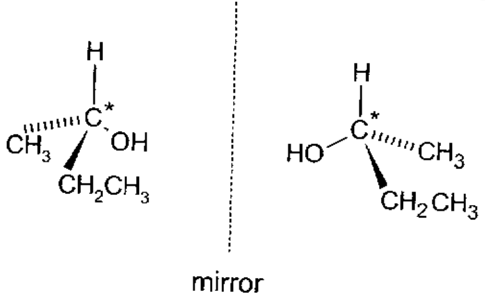
			where k is called the **rate constant**, a proportionality constant [1] x is the **order of the reaction** with respect to reactant A, y is the **order of the reaction** with respect to reactant B . [1]
		(ii)	This is to ensure that the concentration of NO remains approximately constant so that within an experiment, the rate of reaction will be independent of the concentration of NO/any change in rate is due to decrease in $[O_2]$ only. Hence the shape of the graph can be used to determine order with respect to O_2 (using continuous method / conc – time graph). [1]
		(iii)	Using Expt 1, first $t_{½} \approx$ second $t_{½} \approx$ 7 min (with clear working shown in graph). The half-lives of O_2 are approximately constant at 7 min, hence the reaction is first order with respect to O_2. [1] Using Expt 2 & 3, let rate = $k[NO]^n[O_2]^1$ $\frac{expt2}{expt3} = \frac{5.55x10^{-10}}{3.33x10^{-9}} = \frac{k(0.001)^n(0.002)^1}{k(0.002)^n(0.003)^1}$ $\frac{(0.001)^n}{(0.002)^n} = \frac{1}{4}$ ➔ n = 2 Therefore second order with respect to NO. [1] Using Expt 2 (or expt 3), $5.55 \text{ x } 10^{-10} = k(0.001)^2(0.002)$ $k = 0.2775 = 0.278 \text{ mol}^{-2} \text{ dm}^6 \text{ s}^{-1}$ [1]
		(iv)	rate of formation of NO_2 $= k[NO]^2[O_2]$ $= 0.2775 (0.002)^2(0.002)$ $= 2.22 \text{ x } 10^{-9} \text{ mol dm}^{-3} \text{ s}^{-1}$ [1] rate of depletion of O_2 = ½ x rate of formation of NO_2 $= ½ \text{ x } 2.22 \text{ x } 10^{-9}$ $= 1.11 \text{ x } 10^{-9} \text{ mol dm}^{-3} \text{ s}^{-1}$ [1]

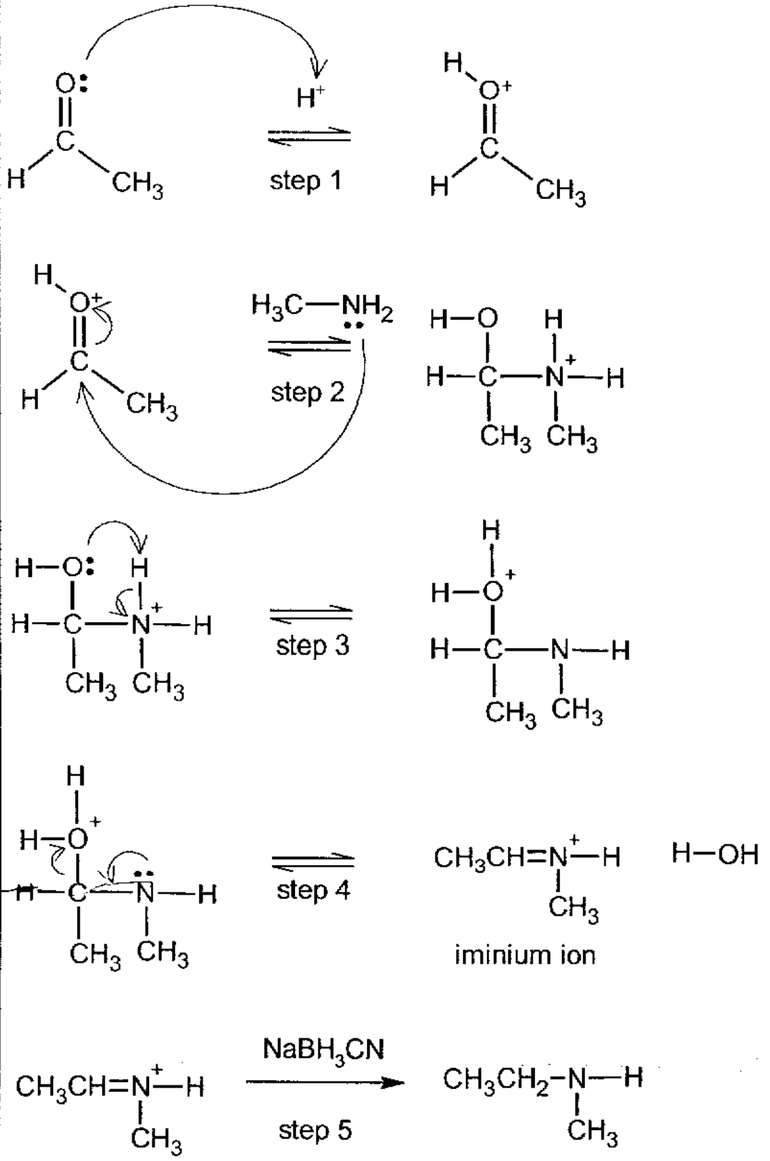
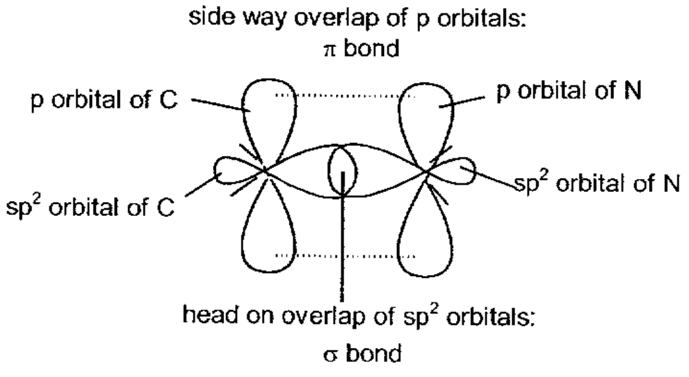
	(d)		The catalytic converter act as a (heterogenous) catalyst by providing an alternative reaction pathway with a lower activation energy, E_a (c) compared to the uncatalysed reaction, E_a (u). More molecules will possess energy greater or equal to this lowered activation energy. [1] The frequency of effective collisions increases. Hence, according to the Collision Theory, the rate of reaction increases and NO_2 is converted to harmless N_2 and O_2 more quickly. [1]  [1]
3	(a)		Relative Brønsted-Lowry acidity: Phenol < nitrophenol < ethanoic acid (most acidic) In phenoxide ion, the p orbital of O atom overlaps with the π electron cloud of benzene. The lone pair of electrons on O atom delocalises into the benzene ring. The negative charge on O atom is dispersed over the benzene ring, hence stabilising the phenoxide ion. [1] However, nitrophenol is more acidic than phenol. The electron withdrawing nitro group further delocalises the lone pair of electrons on O atom into the benzene ring. The negative charge on O atom is dispersed to a greater extent, hence the nitrophenoxide ion is more stable. [1] Ethanoic acid is most acidic. In ethanoate ion, the p orbital of the O atom overlaps with the π electron cloud of the –C=O bond. The lone pair of electrons on the O atom delocalises into the –C=O bond. The negative charge is dispersed most effectively over the carbon atom and the two electronegative O atoms, hence stabilising the ethanoate ion to the largest extent. [1]
	(b)	(i)	Electrophilic Substitution $HNO_3 + 2H_2SO_4 \rightleftharpoons NO_2^+ + 2HSO_4^- + H_3O^+$ [1] Balanced equation + name of mechanism  [1] [1]

		(ii)	The –OH group in phenol has a greater electron donating effect than –CH_3 in methylbenzene. The lone pair of electrons on O atom in phenol delocalised into the benzene ring, increasing the electron density to a larger extent. Hence, phenol is more susceptible to electrophilic substitution. [1] It is not needed to add conc. H_2SO_4 to generate a stronger electrophile NO_2^+. [1]
		(iii)	The electron donating –O-H group increases electron density in the ring at position 2 and 4 with respect to it, hence these positions are more susceptible to electrophilic attack. [1]
		(iv)	Both 2-nitrophenol and 4-nitrophenol have a simple molecular structure with hydrogen bonds between molecules. The –OH and –NO_2 groups in 2-nitrophenol are in close proximity, hence can form intramolecular hydrogen bonds. Less energy needed to overcome the less extensive intermolecular hydrogen bonds between 2-nitrophenol molecules. 2-nitrophenol has a lower boiling point than 4-nitrophenol. [1]  [1]
	(c)	**(i)**	Nitrogen atom is reduced as the oxidation number decreases from +3 in nitrobenzene to - 3 in phenylamine. [1]
		(ii)	 [1]

		(iii)	 [1] include slow step [1] 2nd and 3rd step
		(iv)	 [1] The overall rate of reaction is not affected as the nucleophile is not involved in the rate determining step (slow step) of the S_N1 mechanism. [1]
	(d)	**(i)**	 trans-isomer  cis-isomer [1] for correct azo compound [1] for showing and labelling cis and trans isomer.
		(ii)	Two bulky benzene groups in cis-azobenzene are closer together, resulting in larger steric strain or repulsion. [1]
4	**(a)**	**(i)**	$K_p=\frac{(p_{NH_3})^2}{(p_{N_2})(p_{H_2})^3}$, atm^{-2} [1]

		(ii)	$\begin{array}{lcccc} \text{n} & N_2(g) & + \; 3H_2(g) & \rightleftharpoons & 2NH_3(g) \\ \text{Initial / mol} & 1 & 3 & & 0 \\ \text{Change / mol} & -0.15 & -0.45 & & +0.30 \\ \text{Equilibrium / mol} & 0.85 & 2.55 & & 0.30 \end{array}$ Total amount at eqm = 0.85 + 2.55 + 0.30 = 3.70 mol $p_{N_2}=\frac{0.85}{3.70}\times197=45.25$ atm $p_{H_2}=\frac{2.55}{3.70}\times197=135.7$ atm $p_{NH_3}=\frac{0.30}{3.70}\times197=15.97$ atm [1] equilibrium partial pressure $K_p=\frac{(p_{NH_3})^2}{(p_{N_2})(p_{H_2})^3}=\frac{15.97^2}{(45.25)(135.7)^3}=2.25\times10^{-6}$ atm^{-2} [1] K_p value (allow ecf)
		(iii)	All three gases have simple molecular structure. The hydrogen bonds between the NH_3 molecules are stronger and more significant than the instantaneous dipole-induced dipole (id-id) interactions between N_2 molecules and H_2 molecules respectively. Hence, NH_3 deviates the most from ideal gas behaviour. [1] N_2 has a larger M_r, greater number of electrons, hence larger electron cloud that is more polarisable. Hence, the id-id interactions between N_2 molecules is stronger. So, N_2 behaves less ideally than H_2 molecules. [1]
		(iv)	
		(v)	Effect on yield of ammonia: Decreasing the volume of container increases the total pressure. By Le Chatelier's Principle, the forward reaction is favoured to reduce the pressure by producing lesser amount of gas particles. Hence the position of equilibrium will shift to the right, increasing the yield of ammonia. [1] Effect on the value of K_p: Since there is no change in temperature, K_p remains constant. [1]

	(b)	**(i)**	G:  [1]
		(ii)	step 1: $LiAlH_4$ in dry ether, room temp or $NaBH_4$, room temp or H_2(g), Ni catalyst, heat or H_2(g), Pt or Pd catalyst, room temp [1] step 2: excess concentrated H_2SO_4, 170 °C or Al_2O_3, 350 °C [1] step 3: steam, concentrated H_3PO_4, 300 °C , 60 atm or concentrated H_2SO_4, room temp followed by H_2O(l), heat [1] step 5:  ,  , room temp [1]
		(iii)	type of stereoisomerism: Enantiomerism [1]  [1] must show 3D representation

	(c)	(i)	 [1] every two correct steps
		(ii)	type of stereoisomerism: cis-trans isomerism  • correct type of stereoisomerism • correct orbitals used for overlapping

- correct arrangement of orbitals

3 points – 2 marks
2 points – 1 mark

There is restricted rotation about C=N bond and two different groups on C and on N atom of the C=N double bond [1]

(iii) test: Add Fehling's solution and warm
observations: Ethanal: Brick-red ppt of Cu_2O formed.
Benzaldehyde: No brick-red ppt of Cu_2O formed.

balanced equation:

[1] for test & observation
[1] for balanced equation

(d) (i) N-ethylmethylamine and N-methylethanimine are Lewis bases as they are <u>electron pair donor</u>.

$CH_3CH_2NHCH_3 + H^+ \rightarrow CH_3CH_2(CH_3)NH_2^+$ or

$CH_3CH{=}NCH_3 + H^+ \rightarrow CH_3CH{=}\overset{+}{N}HCH_3$ [1]

Alternative: $AlCl_3$, BH_3

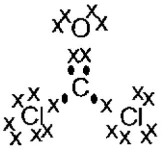
(ii)

Lewis base	type of hybridisation of N atom
$CH_3CH_2NHCH_3$ N-ethylmethylamine	sp^3
$CH_3CH{=}NCH_3$ N-methylethanimine	sp^2

[1] for both correctly identified type of hybridisation

Since the lone pair in the sp^3 orbital has lower s character (the lone pairs are further from the nucleus), the lone pair on N atom of N-ethylmethylamine will be less strongly attracted to the nucleus and thus more available for donation into an empty orbital.
Or
Since the lone pair in the sp^3 orbital has higher p character (the lone pairs are further from the nucleus), the lone pair on N atom of N-ethylmethylamine will be less strongly attracted to the nucleus and thus more available for donation into an empty orbital. [1]

Paper 3 Answers

1	**(a)**	**(i)**	 [1]
		(ii)	Expected Cl-C-Cl bond angle is 120 ° as there are 3 bond pairs, 0 lone pairs and the three bond pairs will arrange themselves as far apart as possible to minimise repulsion. [1] The actual Cl-C-Cl bond angle is smaller as there is greater repulsion between the C=O bond pair and C-Cl bond pair than that between the two C-Cl bond pairs as there is higher electron density in a double bond. [1]
	(b)		[phosgene] = 1.87 dm^3 per 10^6 dm^3 of air = 1.87 / 24 mol per 10^6 dm^3 •convert vol to amt = 0.07791 mol per 10^6 dm^3 = 0.07791 / 10^6 mol per dm^3 •convert per 10^6 dm^3 to per dm^3 = 7.791×10^{-8} mol dm^{-3} = $7.791 \times 10^{-8} \times 99.0$ g dm^{-3} •convert mol to g = 7.713×10^{-6} g dm^{-3} = 7.71×10^{-3} mg dm^{-3} •convert g to mg Any 2 • [1], All 4 • (i.e. correct ans) [2]
	(c)	**(i)**	Urea is a very weak base as p orbital of N overlaps with π electron cloud of C=O hence lone pair of electron on N is delocalised into C=O and hence, less available to form dative bond to accept/with H^+. [1]
		(ii)	NO_2 is harmful as it catalyses formation of acid rain / forms photochemical smog. [1]
	(d)	**(i)**	$\Delta H_{reaction} = +1077 + 244 - (740 + 340(2))$ [1] = – 99 kJ mol^{-1} [1]
		(ii)	BE (C-Cl) in $COCl_2$ differs most from than the average value in the data booklet. The C-Cl bond in $COCl_2$ as it is stronger than average C-Cl bonds as the C is sp^2 hybridised hence the greater degree of s character give rise to more effective orbital overlap in forming the C-Cl bond. Thus, actual value is more exothermic as more energy is released in forming the stronger C-Cl bond in $COCl_2$. [1]
		(iii)	ΔS is negative as there is a decrease in number of gaseous particles (2 to 1) during reaction, hence less ways to arrange the particles. Disorder and entropy decreases. [1] ΔH is negative, – TΔS is positive. Since ΔG = ΔH – TΔS, ΔG is more negative at low temperature **as |– TΔS| < |ΔH| or – TΔS is less positive at low temp. [1]** Reaction is thus more feasible at low temperature resulting in greater yield of phosgene. However, rate of reaction is too slow at low temperature hence an optimal temperature of 150 °C and catalyst is used to increase rate. [1]
		(iv)	Rate = $k_3[COCl][Cl_2]$ = $k_3k_2[Cl][CO][Cl_2]$ = $k_3k_2k_1[Cl_2]^{½}[CO][Cl_2]$ Rate = k $[CO][Cl_2]^{\frac{3}{2}}$ [1]

(v) It is the energy change when one mole of phosgene liquid $COCl_2$ (or a cpd) is formed from its constituent elements in their standard states under standard conditions. [1]

$C(s) + Cl_2(g) + ½O_2(g) \rightarrow COCl_2(l)$ [1]

(vi) $\Delta H_{reaction} = \sum \Delta H_f(prdts) - \sum \Delta H_f(rxt)$
$-107.6 = \Delta H_f\ (COCl_2(g)) - (-110.5)$ [1]
$\Delta H_f\ (COCl_2(g)) = -218.1$ kJ mol^{-1}

As energy is lost when $COCl_2$ condenses from (g) to (l)
(or verify using E cycle below).

$$\begin{tikzcd}
C(s) + Cl_2(g) + ½O_2(g) \arrow[rr, "-218.1"] \arrow[dr, "\Delta H_f\ (COCl_2(l))"'] & & COCl_2(g) \\
& COCl_2(l) \arrow[ur, "+33.3"'] &
\end{tikzcd}$$

$\Delta H_f\ (COCl_2(l)) = \Delta H_f\ (COCl_2(g)) - \Delta H_{vap}\ (COCl_2(l))$
$= -218.1 - (+33.3)$
$= -251.4$ kJ mol^{-1} [1]

(e) Al_2O_3 behaves as an acidic oxide: $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$ [1]
P_4O_{10} behaves as an acidic oxide: $P_4O_{10} + 6Ba(OH)_2 \rightarrow 2Ba_3(PO_4)_2 + 6H_2O$ [1]

Behaviour of P_4O_{10} is expected since P is in Group 15/right of Periodic Table and thus a non-metal which typically forms covalent oxide (as electronegativity difference between P and O is small) that are acidic. Behaviour of Al_2O_3 is not expected as Al is in Group 13/left of Periodic Table and metals typically forms ionic oxide that are basic. (or does not typically form covalent oxide).[1]

However, Al_2O_3 is expected to exhibit amphoteric behavior as Al_2O_3 is an ionic oxide with covalent character as it is in Period 3 and has a small size thus high charge density of the Al^{3+} ion which polarises the electron cloud of O^{2-} anion to a large extent, giving some covalent nature to the ionic Al-O interaction. [1]

2 (a) (i)

$Cl_2 + 2e \rightleftharpoons 2Cl^-$ $E^o = +1.36$ V
$Br_2 + 2e \rightleftharpoons 2Br^-$ $E^o = +1.07$ V
$I_2 + 2e \rightleftharpoons 2I^-$ $E^o = +0.54$ V

OR

$E^o\ (Cl_2/Cl^-) = +1.36$ V
$E^o\ (Br_2/Br^-) = +1.07$ V
$E^o\ (I_2/I^-) = +0.54$ V

The oxidising power of the halogens decreases down the group [1] as the $E^\ominus (X_2/X^-)$ become less positive and the halogens are less easily reduced down the group. [1]

(ii) React both Br_2 and I_2 separately with Fe^{2+}. Br_2 is stronger oxidising agent than I_2 and it oxidises Fe^{2+} to Fe^{3+} as $E_{cell} > 0$, but iodine is unable to do so as $E_{cell} < 0$. [1]

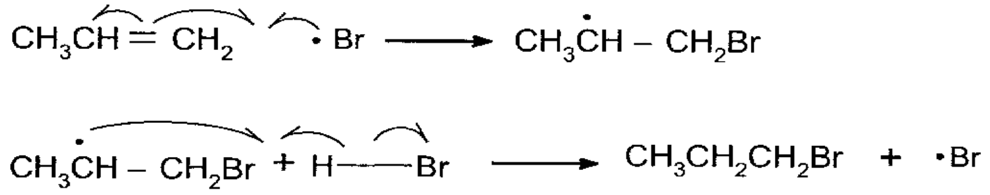
(b) (i) pV = nRT

$$V = \frac{0.40 \times 8.31 \times (25 + 273)}{12 \times 101325} = 8.15 \times 10^{-4}\ m^3 = 0.815\ dm^3\quad [1]$$

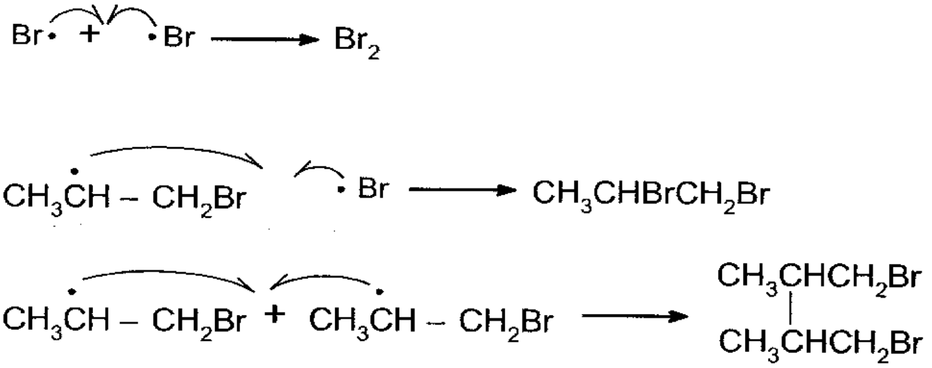
(ii)

Pressure, p / atm	V / dm^3	pressure x volume, pV / atm dm^3
5	1.924	9.62

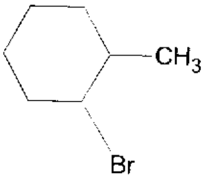
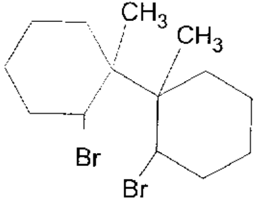
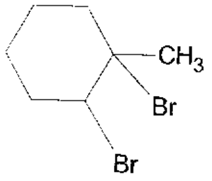
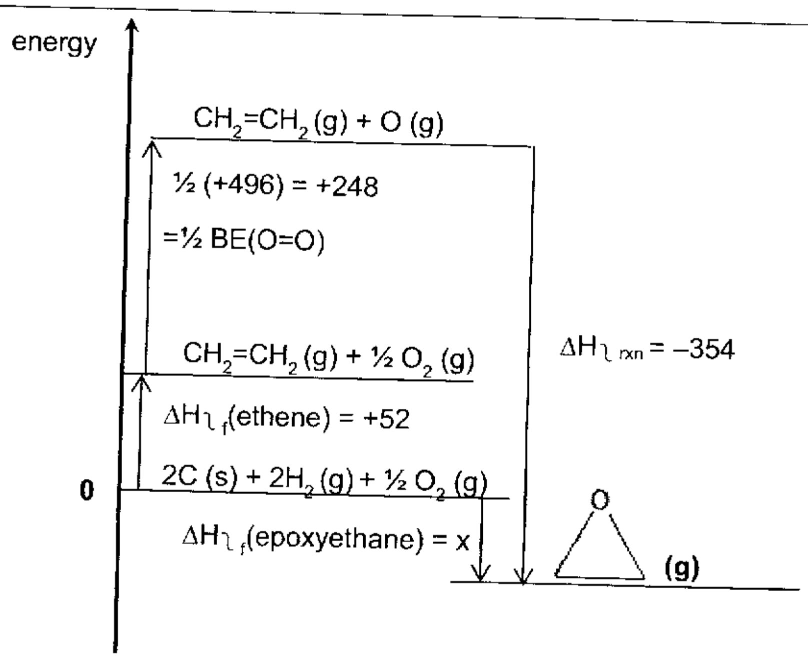
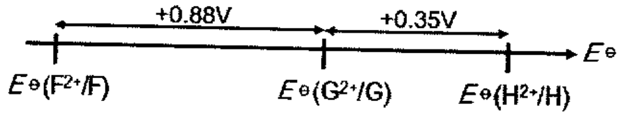
<table>
<tr><td></td><td></td><td></td><td>
<table>
<tr><td>10</td><td>0.926</td><td><i>9.26</i></td></tr>
<tr><td>15</td><td>0.592</td><td><i>8.88</i></td></tr>
</table>
[1]
Accept any value of x in the range of 8.88 < x < 9.26 :
When p = 12 atm, pV = 9 [1]

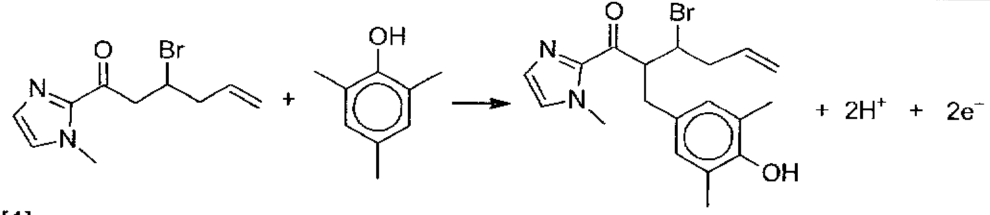
since pV = 9, V = 9 ÷ 12 = 0.750 dm³ [1]
</td></tr>
<tr><td></td><td></td><td>(iii)</td><td>HC<i>l</i> has significant permanent dipole-permanent dipole interactions between its molecules, and its molecules are closer and occupy a smaller volume than an ideal gas. [1]</td></tr>
<tr><td></td><td>(c)</td><td>(i)</td><td>
Propagation


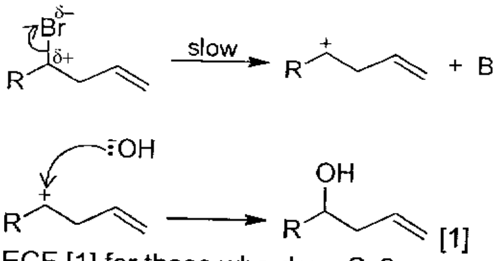
[1] for both propagation steps with arrows

Termination


[1] for any 2 correct termination steps with arrows
[1] for naming the propagation and termination steps
</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>The brief exposure to bright lights produces peroxide and Br radicals that initiate the chain reactions of the propagation steps to produce more radicals [1] for reaction to proceed.
The exothermic reaction will result in an increase in temperature [1], hence rate of reaction increases.</td></tr>
<tr><td></td><td></td><td>(iii)</td><td>The HC<i>l</i> bond is stronger than the HBr bond, hence the propagation step involving the breaking of the HC<i>l</i> bond is very slow/requires a high activation energy. [1]
OR
The HC<i>l</i> bond is stronger than the HBr bond, hence the propagation step involving the breaking of the HC<i>l</i> bond is endothermic, and the reaction not favoured. [1]</td></tr>
</table>

		(iv)	   [1] for 1 or 2 correct structures [2] for all 3 structures
	(d)		 $\Delta H^{\ominus}_{f}$(epoxyethane)= x = +52 +1/2 (496) -354 = -54 kJmol^{-1} [1] [2] for energy level diagram • Labelling '0' • Labelling all arrows either with value or enthalpy change • All energy states are balanced
3	**(a)**	**(i)**	From least positive to most positive: $E^{\ominus}$(**F**$^{2+}$/**F**), $E^{\ominus}$(**G**$^{2+}$/**G**) and $E^{\ominus}$(**H**$^{2+}$/**H**) [1]  In Fig 3.1, when **F** and **G** are connected, **G** is the cathode and **F** is the anode. Hence, $E^{\ominus}$(**G**$^{2+}$/**G**) is more positive than $E^{\ominus}$(**F**$^{2+}$/**F**). When **G** and **H** are connected, **H** is the cathode and **G** is the anode. Hence, $E^{\ominus}$(**H**$^{2+}$/**H**) is more positive than $E^{\ominus}$(**G**$^{2+}$/**G**). (Explanation not necessary)
		(ii)	$E^{\ominus}_{cell}$ = (+0.88) + (+0.35) = +1.23 V [1] **H**$^{2+}$(aq) + **F**(s) $\rightarrow$ **H**(s) + **F**$^{2+}$(aq) [1]
		(iii)	ΔG = −(2)(96500)(+1.23) = −237390 J mol^{-1} = −237 kJ mol^{-1} [1] allow ecf

	(b)	**(i)**	 [1]
		(ii)	I = $\frac{1.23}{3.62}$ = 0.340 A [1] allow ecf
		(iii)	Using Q = nZF, (0.340)(2.5 × 60 × 60) = n_{H2} × 2 × 96500 n_{H2} = 0.01584 mol [1] allow ecf V_{H2} = 0.01584 × 22.7 = 0.3597 dm^3 = 360 cm^3 [1] allow ecf
	(c)	**(i)**	• Change electrode **T** to impure copper • Change electrolyte to aqueous $CuSO_4$ / $Cu(NO_3)_2$ / Cu^{2+} [1] for each change Reject answer that says • change electrode S to pure copper as purification of copper can still be done with inert cathode. • change the electrochemical cell to a battery or regulate the voltage to suit the voltage of purification of copper.
		(ii)	$Ag^+ + e^- \rightleftharpoons Ag$ (+0.80V) $Cu^{2+} + 2e^- \rightleftharpoons Cu$ (+0.34V) $Zn^{2+} + 2e^- \rightleftharpoons Zn$ (–0.76V) <u>At electrode T (or anode)</u> Cu is preferentially oxidised to Cu^{2+} and dissolve in the electrolyte. Zn will be oxidised to Zn^{2+} and dissolve in the electrolyte as well since $E^\ominus(Zn^{2+}/Zn)$ is more negative than $E^\ominus(Cu^{2+}/Cu)$. [1] Ag will not be oxidised to Ag^+ as $E^\ominus(Ag^+/Ag)$ is more positive than $E^\ominus(Cu^{2+}/Cu)$ and will be collected as anode sludge. [1] <u>At electrode **S** (or cathode)</u> Cu^{2+} is preferentially reduced to Cu and deposited at electrode S as $E^\ominus(Cu^{2+}/Cu)$ is more positive than $E^\ominus(Zn^{2+}/Zn)$. Zn^{2+} have less positive $E^\ominus$ than $E^\ominus(Cu^{2+}/Cu)$, Zn^{2+} will remain dissolve in the electrolyte. [1]
	(d)	**(i)**	Nucleophiles are "electron-rich" species that forms a bond by donating a lone pair of electrons to an electron-deficient species. [1]
		(ii)	C_6H_5ONa < NaOH < C_2H_5ONa < C_2H_5SNa [1]
		(iii)	rate = k[N] The relative rate is almost constant. The rate of the reaction is independent of nucleophile. [1]
		(iv)	Nucleophilic Substitution (S_N1)

			 [1] [1] ECF [1] for those who draw S_N2
		(v)	The δ– in oxygen atom of water causes an electrostatic repulsion with the π electron cloud of alkene C=C double bond. [1] Hence, alkene double bond cannot attack the oxygen atom of water.
		(vi)	$\Delta H_{reaction\ 1} = (610+193) - (350+280) = +173$ kJ mol^{-1} $\Delta H_{reaction\ 2} = (610+460) - (350+410) = +310$ kJ mol^{-1} Since $\Delta H_{reaction\ 1}$ is less endothermic than $\Delta H_{reaction\ 2}$, $\Delta H_{reaction\ 1}$ is more spontaneous. [1] or Bond energy of Br–Br = 193 kJ mol^{-1} Bond energy of O–H = 460 kJ mol^{-1} Br–Br bonds are weaker and require less energy to break compared to O–H bond. Hence, reaction 1 occurs much faster than reaction 3. [1]
4	(a)	(i)	K_b of HCO_3^- $= \dfrac{[H_2CO_3][OH^-]}{[HCO_3^-]} = \dfrac{y^2}{(0.100)} = 2.34 \times 10^{-8}$ mol dm^{-3} $y = (2.34 \times 10^{-9})^{1/2} = 4.84 \times 10^{-5}$ $[OH^-] = 4.84 \times 10^{-5}$ mol dm^{-3} [1] $pOH = -\lg(4.84 \times 10^{-5}) = 4.32$ $pH = 14 - 4.32 = 9.68$ [1]
		(ii)	At the equivalence point, the resultant solution contained $H_2CO_3(aq)$. $H_2CO_3(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)$ K_a of $H_2CO_3 = \dfrac{K_w}{K_b \text{ of } HCO_3^-} = \dfrac{1.0 \times 10^{-14}}{2.34 \times 10^{-8}} = 4.27 \times 10^{-7}$ mol dm^{-3} [1] K_a of H_2CO_3 $= \dfrac{[HCO_3^-][H_3O^+]}{[H_2CO_3]} = \dfrac{w^2}{0.0500} = 4.27 \times 10^{-7}$ mol dm^{-3} $\Rightarrow w = 1.46 \times 10^{-4}$ $[H_3O^+] = 1.46 \times 10^{-4}$ mol dm^{-3} $pH = -\lg(1.46 \times 10^{-4}) = 3.84$ [1]

(iii)

Volume of HC*l* needed to reach equivalence point = 25.0 cm^3

Excess volume of HCl added = 37.5 – 25.0 = 12.5 cm^3

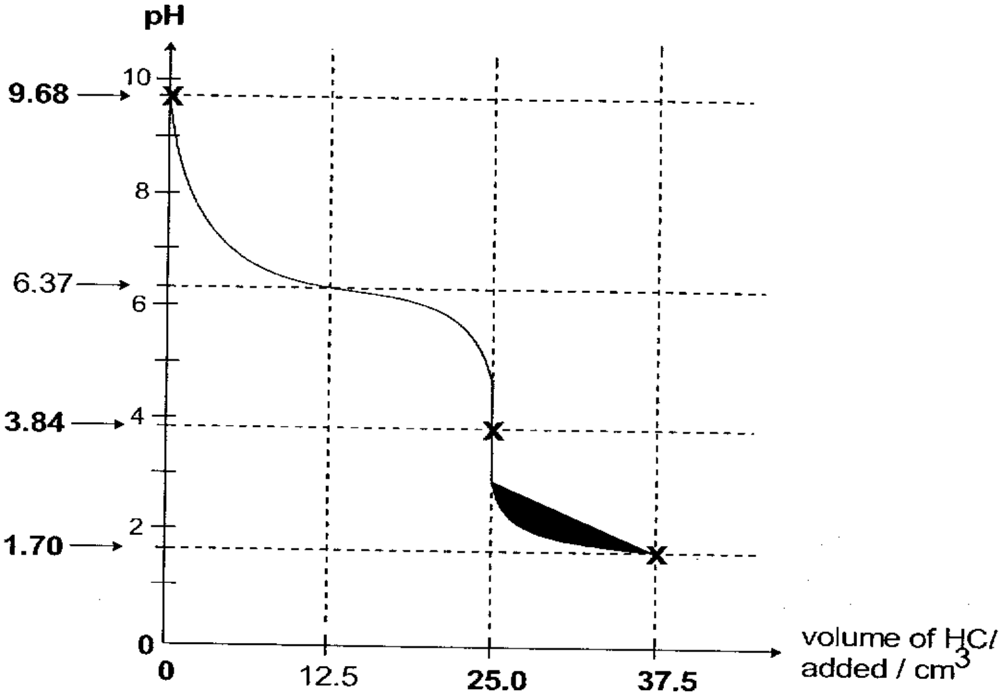
Amount of H^+ from HC*l*(aq) = Amount of HC*l* = (12.5/1000)(0.100) = 1.25×10^{-3} mol

Total volume of resultant solution = 25.0 + 37.5 = 62.5 cm^3 [1]

$[H^+] = 1.25 \times 10^{-3}/0.0625 = 0.0200$ mol dm^{-3}

pH = –lg $[H^+]$ = –lg(0.0200) = 1.70 [1]

(iv)



- Both axes labelled correctly with units for volume
- Three points determined from **(i)**, **(ii)** & **(iii)** plotted correctly and
- connected with smooth curve
- Point plotted correctly at MBC

[1] for any 3 points
[2] for all 6 points

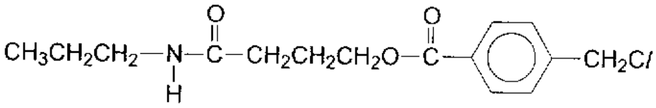
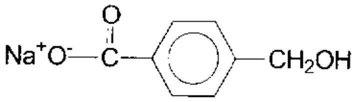
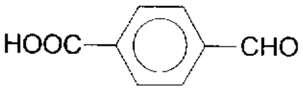
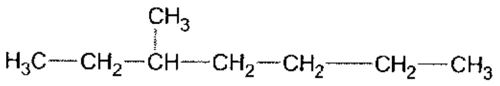
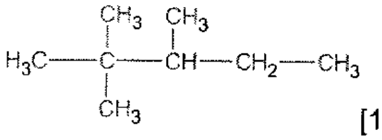
(b) **(i)**

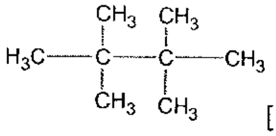
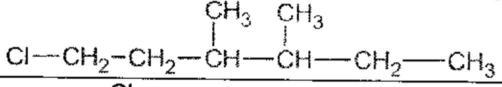
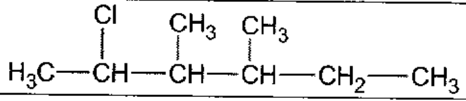
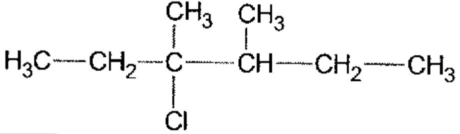
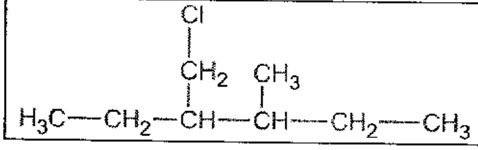
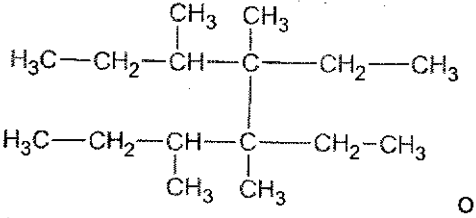
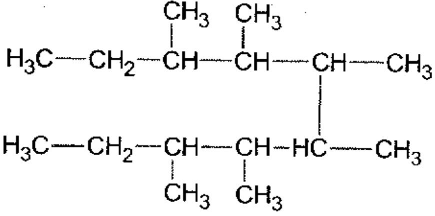
Element	C	H	N
Amount/mol	61.0/12.0	15.3/1.0	23.7/14.0
Mole ratio	5.08	15.3	1.7
Simplest ratio	3	9	1

Hence the empirical formula of Q is C_3H_9N. [1]

The M_r of Q is 59.

Let Q be $(C_3H_9N)_n$.

			Then M_r of Q = (3n)(12.0) + (9n)(1.0) + (n)(14.0) = 59 59n = 59 i.e. n = 1 Hence the molecular formula of Q is C_3H_9N. [1]
		(ii)	P:  Q: $CH_3CH_2CH_2NH_2$ R: $Na^+ {}^-O_2C–CH_2CH_2CH_2OH$ S:  T: $[CH_3CH_2CH_2N(CH_3)_3]^+I^-$ U: $HO_2C–CH_2CH_2CH_2OH$ V:  [1] for each correct structure
		(iii)	Solid GABA, 4–aminobutanoic acid, exists as zwitterions in a giant ionic structure with strong ionic bonds between the zwitterions. [1] $H_3\overset{+}{N}-CH_2CH_2CH_2-COO^-$ zwitterionic form of GABA (4-aminobutanoic acid) U has a simple molecular structure with intermolecular hydrogen bonds. [1] The ionic bonds in GABA are much stronger than the H–bonds in U. Thus, a larger amount of heat energy is required to melt GABA and hence GABA has a much higher melting point. [1]
5	(a)	(i)	The meso compound has a plane of symmetry in the molecule (or both chiral centres contain the same groups attached to it). The two chiral centres each rotate the plane of polarised light to the same extent but in the opposite direction hence the rotating power cancels out. [1]
		(ii)	isomer A (1 branch)  $H_3C-CH_2-\overset{CH_3}{\overset{\mid}{C}H}-CH_2-CH_2-CH_2-CH_3$ [1] isomer C: (3 branches)  $H_3C-\underset{CH_3}{\underset{\mid}{\overset{CH_3}{\overset{\mid}{C}}}}-\overset{CH_3}{\overset{\mid}{C}H}-CH_2-CH_3$ [1]

<table>
<tr><td></td><td></td><td></td><td>isomer D:
(4 branches)
$\mathrm{H_3C-C(CH_3)_2-C(CH_3)_2-CH_3}$
[1]</td></tr>
<tr><td></td><td></td><td>(iii)</td><td>Isomers A to D are simple molecular structure with weak instantaneous dipole – induced dipole (id-id) interaction between molecules. [1]
From isomer A to D, the degree of branching of the molecules increases. The molecules have less surface area of contact, resulting in weaker id-id interaction between molecules. [1]
Hence less energy is required to overcome the weaker id-id interaction between molecules, resulting in lower boiling points from isomer A to D.</td></tr>
<tr><td></td><td></td><td>(iv)</td><td>
<table>
<tr><th>Structural formula</th><th>No. of H</th><th>Simplest ratio</th></tr>
<tr><td>$\mathrm{Cl-CH_2-CH_2-CH(CH_3)-CH(CH_3)-CH_2-CH_3}$</td><td>6</td><td>3</td></tr>
<tr><td>$\mathrm{H_3C-CH(Cl)-CH(CH_3)-CH(CH_3)-CH_2-CH_3}$</td><td>4</td><td>2</td></tr>
<tr><td>$\mathrm{H_3C-CH_2-C(CH_3)(Cl)-CH(CH_3)-CH_2-CH_3}$</td><td>2</td><td>1</td></tr>
<tr><td>$\mathrm{H_3C-CH_2-CH(CH_2Cl)-CH(CH_3)-CH_2-CH_3}$</td><td>6</td><td>3</td></tr>
</table>
[1]
structures [1] ratio</td></tr>
<tr><td></td><td></td><td>(v)</td><td>$\mathrm{H_3C-CH_2-CH(CH_3)-C(CH_3)(CH_2CH_3)-C(CH_3)(CH_2CH_3)-CH(CH_3)-CH_2-CH_3}$
(preferred, more branched) [1]
or
$\mathrm{H_3C-CH_2-CH(CH_3)-CH(CH_3)-CH(CH_3)-CH(CH_3)-CH(CH_3)-CH(CH_3)-CH_2-CH_3}$</td></tr>
<tr><td></td><td>(b)</td><td>(i)</td><td>• As number of protons increases, nuclear charge increases.
• As number of electron shells also increases, shielding effect increases significantly.
• The outermost electron is further away from the nucleus.
• Hence attraction between the nucleus and outermost electron decreases.
• Less energy is required to remove the outermost electron hence ease of losing electrons increases, first ionisation energy decreases.
• The reactivity of Group 1 metals increases down the group.
[2] 6 points
[1] 4-5 points</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>All the metals have <u>giant metallic structure</u> with <u>metallic bonds</u> between delocalized <u>sea of valence electrons</u> and <u>metallic cations</u>.</td></tr>
</table>

			Lithium and sodium metals have smaller ionic radius, resulting in stronger electrostatic attraction between the cations and the sea of delocalised valence electrons. More energy needed to break the stronger metallic bonds, hence higher boiling points and can be obtained via electrolysis in molten state even in a high temperature environment. [1] Potassium, rubidium and caesium having larger ionic radius and weaker metallic bonding and vaporises in the high temperature environment. [1]
		(iii)	Down the group, Group 1 ions have larger ionic radii and hence have a lower charge density and polarising power [1] Li^+ has the highest charge density and highest polarising power. It is able to polarise the electron cloud of peroxide or superoxide and weaken the O–O/O=O bond to a large extent. Hence the bond is easily broken to form oxide ion in the final product [1].
	(c)	**(i)**	**X** CO_2 **Y** $CaCO_3$ [1] for **X** and **Y** **Z** $Ca(HCO_3)_2$ [1]
		(ii)	$MO + H_2O \rightarrow M(OH)_2$ $M(OH)_2 + 2HCl \rightarrow MCl_2 + 2H_2O$ n_{HCl} for 25.0 cm^3 aliquots = 0.0985 x 20.30/1000 = 0.0020 mol n_{HCl} reacting with white solid = 0.0020 x 250/25 = 0.020 mol [1] $n_{MO} = n_{M(OH)_2} = ½ \times 0.020 = 0.010$ mol M_W = 1.9735 / 0.010 = 197.4 [1]
		(iii)	**W** is a carbonate (since gas X CO_2 is evolved upon reaction of W with acid) Hence formula will be **MCO_3** Hence *Ar* of **M** will be 197.35 – 12.0 – 3(16.0) = 137.35 [1] **M** is Barium.