NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CHEMISTRY

9729/01

Paper 1 Multiple Choice

September 2025

1 hour

Additional Materials: Multiple Choice Answer Sheet
Data Booklet

READ THESE INSTRUCTIONS FIRST

Write in soft pencil.
Do not use staples, paper clips, glue or correction fluid.
Write your name, CT and NRIC / FIN on the Answer Sheet in the spaces provided.

There are **thirty** questions in this paper. Answer **all** questions. For each question there are four possible answers **A**, **B**, **C** and **D**.
Choose the **one** you consider correct and record your choice in **soft pencil** on the separate Answer Sheet.

Read the instructions on the Answer Sheet very carefully.

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.
Any rough working should be done in this booklet.
The use of an approved scientific calculator is expected, where appropriate.

1 X is a transition element that forms ions of various oxidation states. One ion, X^{2+}, reduces $Cr_2O_7^{2-}$ in acid solution.

If 1 mol of $Cr_2O_7^{2-}$ is reduced by 2 mol of X^{2+}, which of the following species is formed in the reaction?

A XO_4^{2-} **B** XO_2^{+} **C** XO^{2+} **D** X^{3+}

2 M and T are cations. M contains n protons and has a charge of 3+. T contains (n–2) protons and has the same number of electrons as M.

What is the formula of the oxide formed by T?

A TO

B T_2O

C T_2O_3

D TO_2

3 The boiling point of methane is –161.5 °C while that of neon is –264 °C.

Why is the boiling point of methane greater than that of neon?

A Molecules of methane have a larger surface area to form stronger intermolecular forces than those of neon

B A molecule of methane has more electrons than an atom of neon.

C A molecule of methane has a greater relative molecular mass than an atom of neon.

D Molecules of methane form hydrogen bonds, but those of neon do not.

4 Boron trifluoride is a highly reactive gas at room temperature and hence it is difficult to handle. To store it in liquid form, 2 mol of BF_3 reacts with 1 mol of $CH_3CH_2OCH_2CH_3$ to form compound N. Which of the following statements is correct?

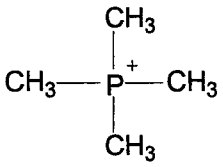
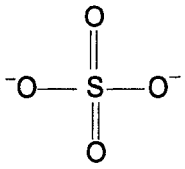
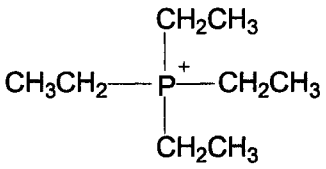
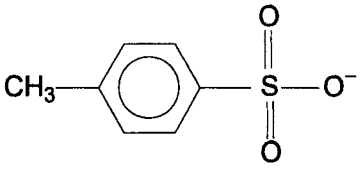
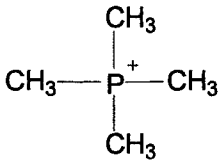
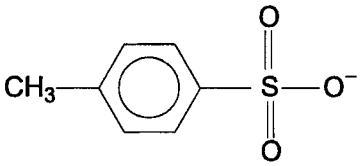
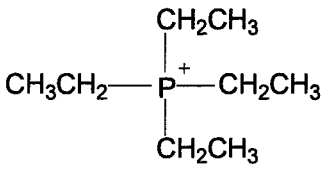
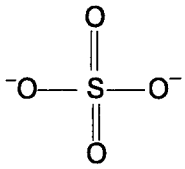
A The boron atom in compound N has an incomplete octet.

B 2 mol of AlF_3 can also react with 1 mol of $CH_3CH_2OCH_2CH_3$ to form a similar compound.

C Two dative bonds are formed from the boron atom in two BF_3 molecules towards the O atom in $CH_3CH_2OCH_2CH_3$.

D The bond angle with respect to boron atom in BF_3 is bigger than the bond angle with respect to boron in compound N.

5 Which pairs of ions give an ionic compound with the lowest melting point?

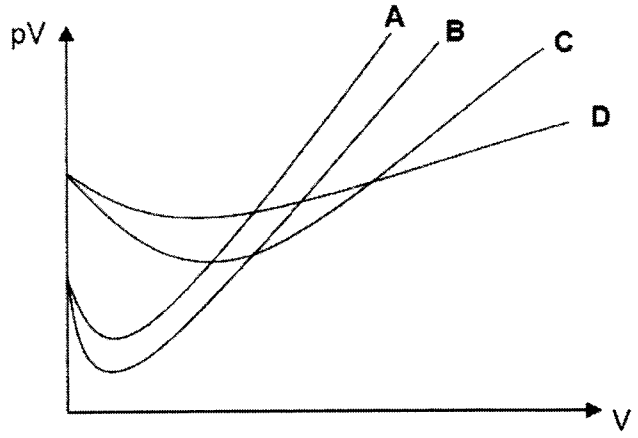
	cation	anion
A		
B		
C		
D		

6 When aqueous copper (II) sulfate is mixed with potassium iodide, a white precipitate in a brown solution is formed. The brown solution is decolorised when aqueous sodium thiosulfate is added to it.

What is the formula and the electronic configuration of the copper cation in the white precipitate?

	formula of white precipitate	electronic configuration of the copper cation
A	CuI_2	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9$
B	CuI_2	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^7\ 4s^2$
C	CuI	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}$
D	CuI	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^9\ 4s^1$

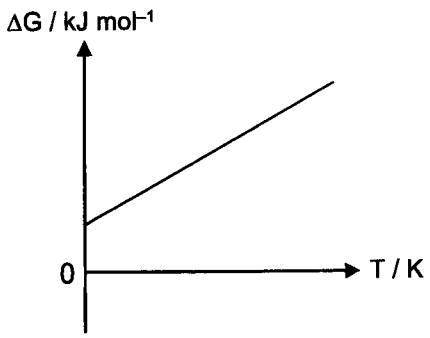
7 The volumes and pressures of equal masses of four gaseous compounds H_2O, CH_4, $C_{16}H_{32}O_2$ and I_2, are separately investigated, at constant temperature. The results are plotted on a graph of pV against V. Which of the following plot shows the result for CH_4?



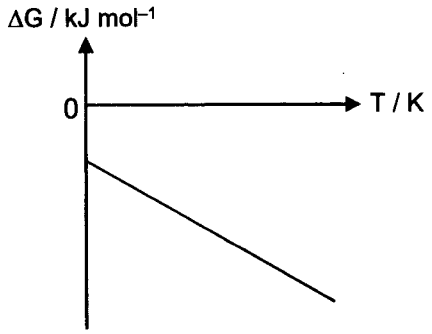
8 Which graph corresponds to the combustion of liquid ethanedioic acid, $(COOH)_2$ at room temperature?

$$(COOH)_2(l) + \tfrac{1}{2}O_2(g) \rightarrow 2CO_2(g) + H_2O(l)$$

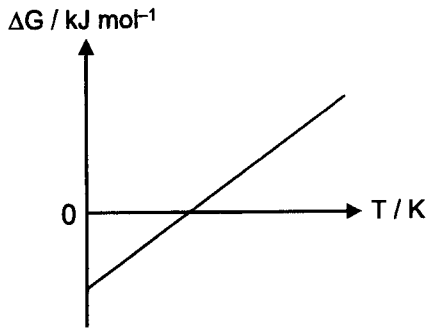
A



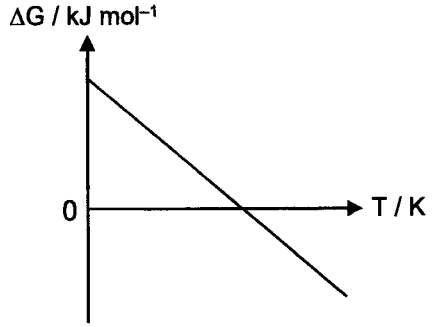
B



C



D



9 When equal volumes of 1.00 mol dm^{-3} hydrochloric acid and v mol dm^{-3} of sulfuric acid were separately neutralised by excess dilute sodium hydroxide, the heat liberated was 2a kJ and a kJ respectively.

What is the concentration, v, of the sulfuric acid?

A 0.25 mol dm^{-3}

B 0.50 mol dm^{-3}

C 1.00 mol dm^{-3}

D 2.00 mol dm^{-3}

10 Consider the following reaction.

$$3R + S \rightarrow R_3S$$

The mechanism involves the following steps:

Step 1: $2R \rightleftharpoons R_2$

Step 2: $R_2 + S \rightarrow R_2S$

Step 3: $R_2S + R \rightarrow R_3S$

The overall kinetics is found to be third order. Based on the information, which is the slow step in the mechanism?

A Step 1

B Step 2

C Step 3

D None of the above

11 The kinetics of the reaction below were studied using the initial rate method.

$$I^-(aq) + ClO^-(aq) \xrightarrow{OH^-} IO^-(aq) + Cl^-(aq)$$

experiment	initial $[I^-]$ / mol dm^{-3}	initial $[ClO^-]$ / mol dm^{-3}	initial $[OH^-]$ / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.0013	0.012	0.100	9.4×10^{-3}
2	0.0026	0.012	0.100	18.7×10^{-3}
3	0.0013	0.018	0.100	14.0×10^{-3}
4	0.0026	0.018	0.050	c

The unit of k is found to be s^{-1}.

Which statements are correct?

1 The order of reaction with respect to $[OH^-]$ is –1.

2 OH^- functions as a catalyst in this reaction.

3 The value of c is 56.0×10^{-3}.

A 1, 2 and 3

B 1 and 3 only

C 2 and 3 only

D 3 only

12 Consider the equilibrium $3P_2(g) + 2OP(g) \rightleftharpoons 2OP_4(g)$.

When 4 mol of OP_4 was put into a 2 dm^3 container and heated, the equilibrium mixture contained 0.8 mol of OP.

What is the numerical value of the equilibrium constant, K_c?

A 74.1

B 9.26

C 0.108

D 0.0135

13 Due to its radioactive nature, the properties of astatine, At, have to be predicted based on its position in the Periodic Table.

Which of the predictions concerning At or its compounds is correct?

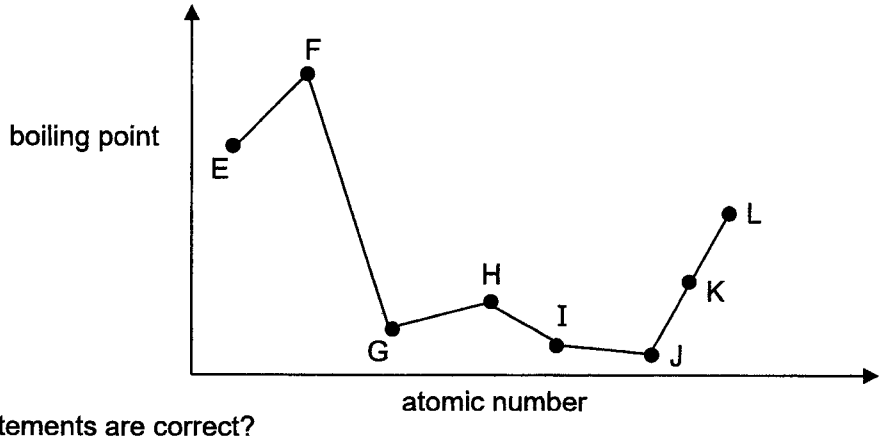
A Hydrogen astatide has a higher decomposition temperature than hydrogen bromide.

B Astatine is a light coloured solid at room temperature.

C Silver astatide is soluble in $NH_3(aq)$.

D Astatine is a weaker oxidising agent than iodine.

14 The graph below shows the variation in the boiling point for 8 consecutive elements in the Periodic Table, all with atomic number less than 21.



Which statements are correct?

1 The chloride of E reacts with aqueous sodium hydroxide to give a precipitate which is soluble in excess sodium hydroxide.

2 The oxide of F is neutral in aqueous solution.

3 The oxide of K dissolves readily in water to give a strongly alkaline solution.

A 1, 2 and 3

B 1 and 2 only

C 2 and 3 only

D 1 only

15 The values of solubility products at 25 °C of three metal sulfides are shown in the table below. ΔH_{soln} of these metal sulfides is endothermic.

compound	value of K_{sp}
ZnS	1.1×10^{-21}
CuS	6.3×10^{-36}
Ag_2S	6.0×10^{-51}

Which statements are correct?

1 Addition of S^{2-} to the solution of Bi_2S_3 decreases the K_{sp} of Bi_2S_3.

2 Ag_2S is more soluble than CuS.

3 Given a solution with $[Cu^{2+}] = [Zn^{2+}]$, CuS is precipitated out first on addition of S^{2-}.

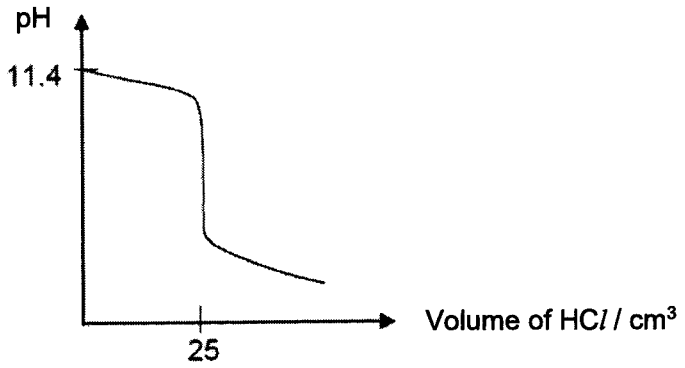
A 1, 2 and 3

B 1 and 2 only

C 2 and 3 only

D 3 only

16 25.0 cm^3 of a 0.1 mol dm^{-3} monoprotic base, U, was titrated with a 0.1 mol dm^{-3} HC*l* and the following titration graph was obtained.



Which statements about the above graph are correct?

1 When 25.0 cm^3 of HC*l* is added, the pH of the resulting solution is < 7.

2 Methyl orange is a suitable indicator for the titration.

3 When 0.1 mol dm^{-3} NaOH is used in place of U, the titre value is 25.0 cm^3.

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

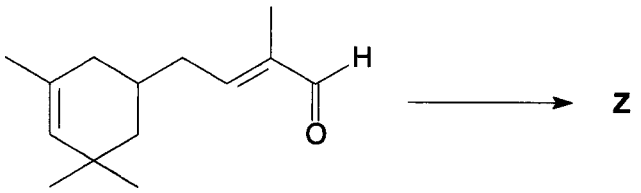
17 HF is a weak acid that dissociates partially in water.

When 50.0 cm^3 of 0.100 mol dm^{-3} HF(aq) is added to 50.0 cm^3 of 0.100 mol dm^{-3} KF(aq), the pH of the resulting solution formed is 3.20.

Calculate the pH of 0.100 mol dm^{-3} HF(aq) at 298 K.

A 1.00 **B** 2.10 **C** 3.20 **D** 10.8

18 Y can be reduced by $LiAlH_4$ in dry ether to form Z.



Y

How many stereoisomers exist for Y and Z?

	Y	Z
A	4	4
B	4	8
C	8	8
D	16	16

19 G, H and J are three different organic compounds. H and G can react together to form an ester. J can also react with G to form an ester but much less readily than H. When G is added into water, white fumes are observed.

Which of the following could be J?

A butan-1-ol

B butan-2-ol

C phenol

D phenylamine

20 A few drops of ethanolic $AgNO_3$ were added separately to five test-tubes containing the following halogen derivatives.

halogen derivatives	structural formula
benzoyl bromide	C_6H_5COBr
2-chlorobutane	$CH_3CH(Cl)CH_2CH_3$
2-iodobutane	$CH_3CH(I)CH_2CH_3$
iodobenzene	C_6H_5I

Which statements are correct?

1 A white precipitate will be seen before the yellow precipitate because C–C*l* bond is more polar than C–I bond

2 A cream precipitate of AgBr will take the shortest time to form.

3 No yellow precipitate will be observed for iodobenzene.

A 1, 2 and 3 only

B 2 and 3 only

C 2 only

D 3 only

21 L reacts with excess hot concentrated acidified $KMnO_4$ to produce three different organic molecules, CH_3CO_2H, $(CH_3)_2CO$ and HO_2CCOCH_3. Which statements are correct?

1 L can be 2,4-dimethylhexa-2,4-diene or 2,3-dimethylhexa-2,4-diene.

2 The three products formed can be distinguished from one another by using Na_2CO_3(s) followed by 2,4-DNPH.

3 L can also react with excess hot acidified $K_2Cr_2O_7$ to produce the same three organic molecules.

A 1, 2 and 3

B 1 and 2 only

C 2 and 3 only

D 1 only

22 Which compound will give the lowest pH in aqueous solution?

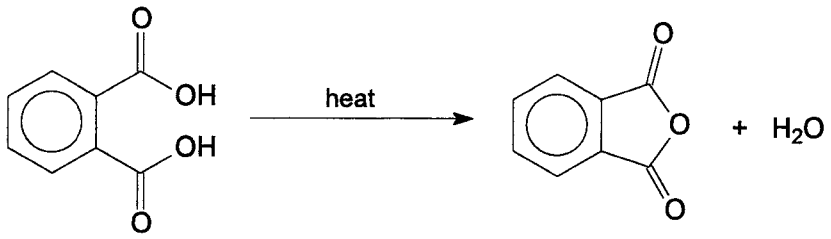
A $(CH_3)_2NH_2^+Cl^-$

B $CH_3CONH(CH_3)$

C $NH_4^+Cl^-$

D $C_6H_5N(CH_3)H_2^+Cl^-$

23 When heated strongly, phthalic acid undergoes condensation reaction to form phthalic anhydride.

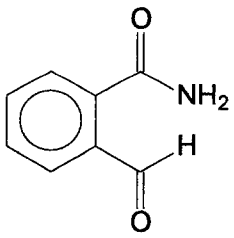


phthalic acid phthalic anhydride

On reaction with water, phthalic anhydride gives phthalic acid.

What would be formed when phthalic anhydride reacts with ammonia?

A



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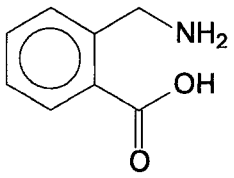

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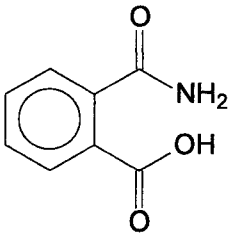

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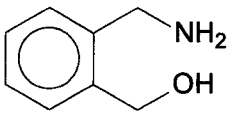


24 Which organic compound will give a positive test with warm aqueous alkaline iodine?

A CH_3OH

B CH_3CONH_2

C $C_6H_5COCH_2I$

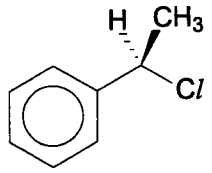
D CH_3CH_2CHO

25 Which reaction will **not** produce a mixture of two enantiomers?

A $CH_3CH{=}CHCH_3$ + HBr

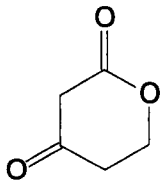
B $CH_3COCH_2CH_3$ + HCN with trace amount of KOH at 10–20 °C

C



+ OH^-

D



+ $H_2SO_4(aq)$; heat under reflux followed by $LiAlH_4$

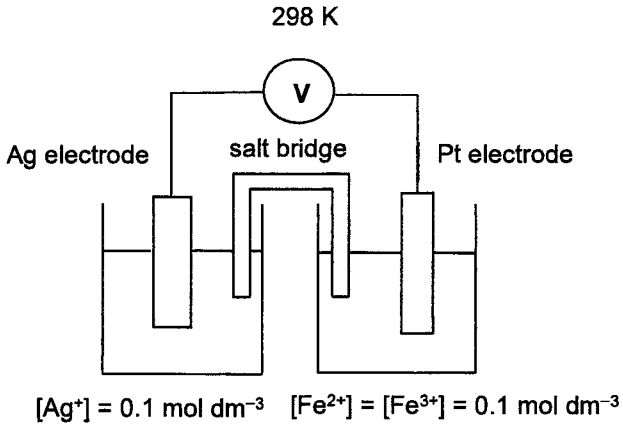
26 Upon complete hydrolysis of a tetrapeptide, only the following amino acids were obtained.

$NH_2CH(CH_2C_6H_5)CO_2H$	$NH_2CH(CH_2CONH_2)CO_2H$	$NH_2CH_2CO_2H$
phenylalanine (M_r = 165.0)	asparagine (M_r = 132.0)	glycine (M_r = 75.0)

What is the mole ratio of phenylalanine : asparagine : glycine and the M_r of the tetrapeptide?

	ratio	M_r
A	1 : 1 : 1	372.0
B	1 : 1 : 2	447.0
C	1 : 2 : 1	450.0
D	2 : 1 : 1	537.0

27 Which statements about the electrochemical cell below are correct?



1 The e.m.f of the cell is +0.03 V.

2 Addition of water to the Fe^{3+} / Fe^{2+} half–cell increases the e.m.f of the cell.

3 Increasing the mass of the Ag electrode does not affect the e.m.f of the cell.

4 Addition of excess NaOH(aq) to the Fe^{3+} / Fe^{2+} half–cell increases the e.m.f of the cell.

A 1, 2 and 4 only

B 1, 3 and 4 only

C 3 and 4 only

D 3 only

28 *Use of the Data Booklet is relevant to this question.*

A zinc-air battery uses oxygen gas in the air as an oxidising agent and zinc metal as a reducing agent. The electrolyte circulating through the battery is NaOH(aq).

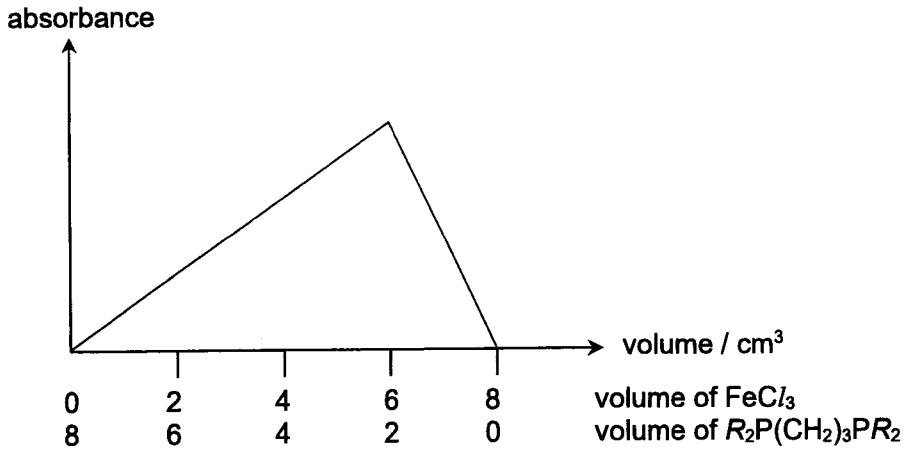
An experiment was conducted at room temperature to study the volume of oxygen consumed by the zinc-air battery. It was found that 0.12 cm^3 of oxygen gas was consumed by the battery per minute. What is the E^{θ} value for the cathode and the current, I?

	E^{θ} value for the cathode / V	current, I / A
A	+1.23	0.0322
B	+0.40	1.93
C	+1.23	1.93
D	+0.40	0.0322

29 In this question, *R*' represents a phenyl group.

2-bis(diphenylphosphino)propane, $R_2P(CH_2)_3PR_2$, is a commonly used ligand which forms a complex with many metal ions.

In the graph below, the intensity of visible light absorbance for different mixtures containing 1.00×10^{-3} mol dm^{-3} $FeCl_3$(aq) and 9.00×10^{-3} mol dm^{-3} $R_2P(CH_2)_3PR_2$ are shown.



Which statement is incorrect?

A When excess aqueous silver nitrate is added to the mixture with the highest absorbance, 1.8×10^{-5} mol of AgCl is formed.

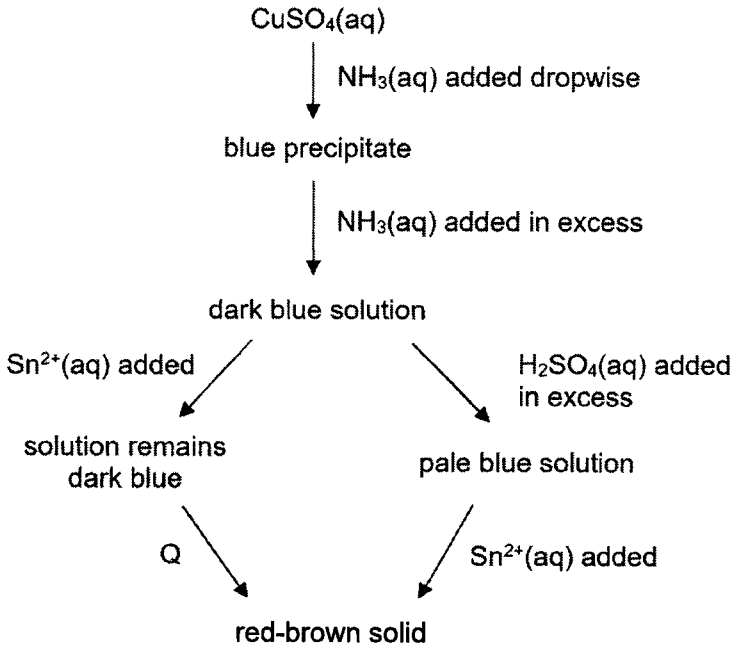
B H_2O molecule is a weaker ligand than $R_2P(CH_2)_3PR_2$.

C The coordination number of the complex formed is 6.

D The overall charge of the complex formed is 0.

30 *Use of the Data Booklet is relevant to this question.*

A series of tests were performed on a sample of $CuSO_4(aq)$ as shown below.



Which statement is incorrect?

A Q could be silver metal.

B The red-brown solid formed is copper metal.

C Addition of limited $NH_3(aq)$ to $CuSO_4(aq)$ is an acid base reaction.

D Addition of excess $H_2SO_4(aq)$ causes the reformation of $Cu^{2+}(aq)$.

H

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME

CLASS

TUTOR'S NAME

CHEMISTRY
Paper 2 Structured Questions

9729/02
September 2025
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.

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

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	/ 9
2	/ 12
3	/ 8
4	/ 21
5	/ 25
Total	/ 75

This document consists of **19** printed pages.

[Turn Over

Answer **all** the questions in the spaces provided.

1 **(a)** Fig. 1.1 below can be used to plot the first ionisation energy of the elements from proton number 12 to 20. Six of these elements have been plotted already.

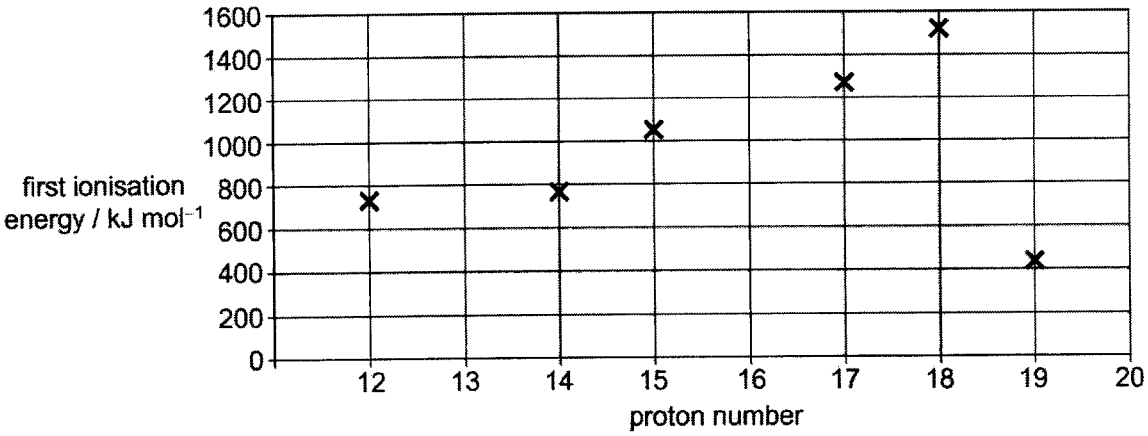


Fig. 1.1

(i) Estimate and plot, on Fig. 1.1 above, the first ionisation energies of elements with proton numbers 13, 16 and 20. [1]

(ii) Explain the general increase in first ionisation energy across elements with proton numbers 12 to 18.

.....

.....

.....

.....[2]

(iii) Write the electronic configurations of the elements with proton numbers 15 and 16, and hence, explain the trend in their first ionisation energies.

.....

.....

.....

.....[2]

(b) Electric cables used in fire alarm systems have copper wire surrounded by magnesium oxide, which acts as insulator.

(i) In terms of structure and bonding, explain why copper can conduct electricity. Draw a labelled diagram to illustrate your answer.

.....

.....

.....[2]

(ii) Suggest, in terms of structure and bonding, why magnesium oxide is a better insulator than sodium oxide.

.....

.....

.....

.....[2]

[Total: 9]

2 **(a)** 2-bromobutane, $CH_3CHBrCH_2CH_3$, undergoes nucleophilic substitution with aqueous sodium hydroxide to form butan-2-ol, $CH_3CH(OH)CH_2CH_3$.

$$CH_3CHBrCH_2CH_3 + NaOH \rightarrow CH_3CH(OH)CH_2CH_3 + NaBr$$

Two experiments were performed to determine the order of reaction with respect to the reactants. Fig. 2.1 shows the graph of [NaOH] against time when different initial concentrations of 2-bromobutane were used. The initial concentration of NaOH was kept at 0.010 mol dm^{-3}.

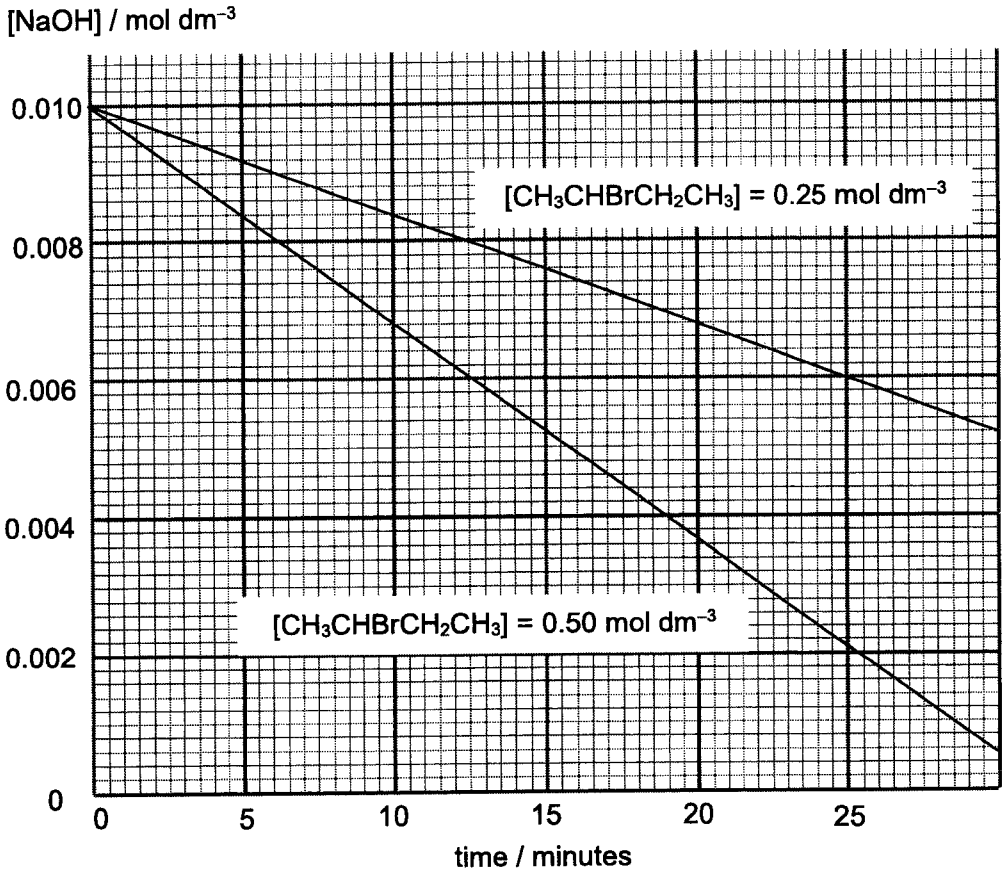


Fig. 2.1

(i) Explain what is meant by the term *order of reaction with respect to the reactant.*

.....

.....[1]

(ii) Use the graph in Fig. 2.1 to prove that the order of reaction with respect to NaOH is zero and that of $CH_3CHBrCH_2CH_3$ is one.

.....

.....

.....

.....[2]

(iii) Calculate the value of rate constant of the reaction. Include its units.

[1]

(iv) With reference to the order of reactions in **(ii)**, suggest a mechanism for the nucleophilic substitution of 2-bromobutane. Show all relevant lone pairs, dipoles, curly arrows and charges.

[2]

(v) Explain why the butan-2-ol formed via the mechanism in **(iv)** does not rotate the plane polarised light.

.....

.....

.....

.....[2]

(b) 2-bromobutane, $CH_3CHBrCH_2CH_3$ exhibits stereoisomerism. It also reacts with NaOH in ethanol to form two constitutional isomers **W** and **X**.

(i) Describe what is meant by stereoisomerism.

.....

.....[1]

(ii) Draw the pair of stereoisomers for 2-bromobutane, $CH_3CHBrCH_2CH_3$.

[1]

(iii) Draw the structures of **W** and **X**.

W

X

[1]

(iv) State which product **W** or **X** makes up a larger proportion of the reaction mixture. Explain your answer.

.....

.....

.....[1]

[Total: 12]

3 A student wants to plate a leaf with a thin layer of cobalt. He first coated the leaf with graphite. The leaf and a platinum electrode were then immersed into an aqueous solution of cobalt(II) sulfate and electroplating was carried out.

(a) Draw a fully labelled diagram of the set-up.

[1]

(b) State the equations, with state symbols, for the processes occurring at the anode and cathode.

cathode: .....

anode: .....[2]

(c) After some time, the leaf was coated with a 0.20 mm layer of cobalt. Given that the surface area of the leaf was 10 cm^2 and the density of cobalt metal is 8.90 g cm^{-3}, calculate the volume of gas produced at the platinum electrode at room temperature.

[2]

(d) Calculate the time taken, in hours, to coat the leaf in **(c)** if the current used was 0.5 A.

[1]

(e) Use data in the *Data Booklet* to explain any observations at each electrode **over a long period of time** when the platinum electrode is replaced with a dull grey solid lead.

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.....

.....

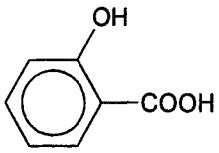
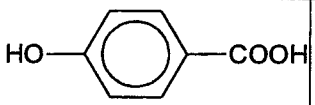
.....[2]

[Total: 8]

4 2-hydroxybenzoic acid and 4-hydroxybenzoic acid are aromatic carboxylic acids with phenol groups. Both compounds are commonly used in pharmaceuticals and industrial applications.

(a) The relative positions of the carboxylic acid and phenol functional groups influence their acidity. Table 4.1 shows the pK_a values of 2-hydroxybenzoic acid and 4-hydroxybenzoic acid.

Table 4.1

	pK_a (COOH)	pK_a (phenol)
 2-hydroxybenzoic acid	2.98	13.4
 4-hydroxybenzoic acid	4.58	9.51

(i) Explain why the pK_a (COOH) values are smaller than pK_a (phenol).

.....

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.....[2]

(ii) Draw the conjugate base of 2-hydroxybenzoic acid. Hence, suggest why the pK_a (COOH) value of 2-hydroxybenzoic acid is lower than that of 4-hydroxybenzoic acid.

.....

.....

.....[2]

2.76 g of 4-hydroxybenzoic acid (M_r = 138.0) is dissolved in 100 cm^3 of water to prepare solution **P**. 0.35 g of solid sodium hydroxide is then added to solution **P** to form solution **Q**.

(iii) Calculate the pH of solution **P**. Assume that the second dissociation from the phenol group is negligible.

[2]

(iv) Calculate the pH of solution **Q**.

[3]

11

Electrophoresis separates charged compounds by their movement in an electric field. Under a specific pH, molecules migrate toward the opposite electrode. The migration distance depends on net charge and molecular mass. This allows compounds with similar mass but different charges to be separated and analysed.

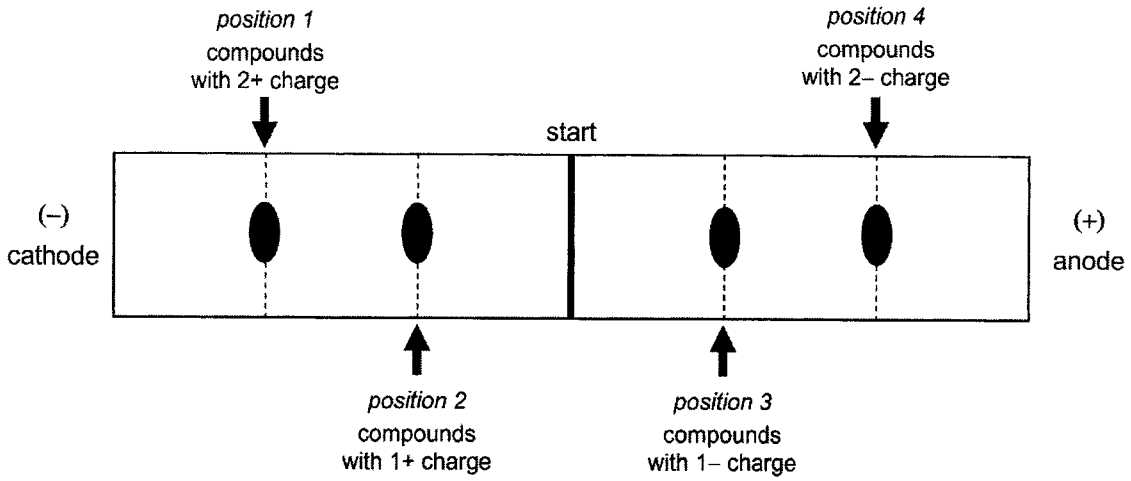

Fig. 4.1

(v) With reference to Table 4.1 and Fig. 4.1, draw the structures of the major species of 2-hydroxybenzoic acid and 4-hydroxybenzoic acid at pH 12. State their relative positions in Fig. 4.1 when subjected to electrophoresis.

	2-hydroxybenzoic acid	4-hydroxybenzoic acid
major species at pH 12		
position on Fig. 4.1		

[2]

(vi) State a pH at which both 2-hydroxybenzoic acid and 4-hydroxybenzoic acid will move towards position 3 in Fig. 4.1.

.....[1]

(b) 4-hydroxybenzoic acid undergoes a series of reactions as shown in Fig. 4.2.

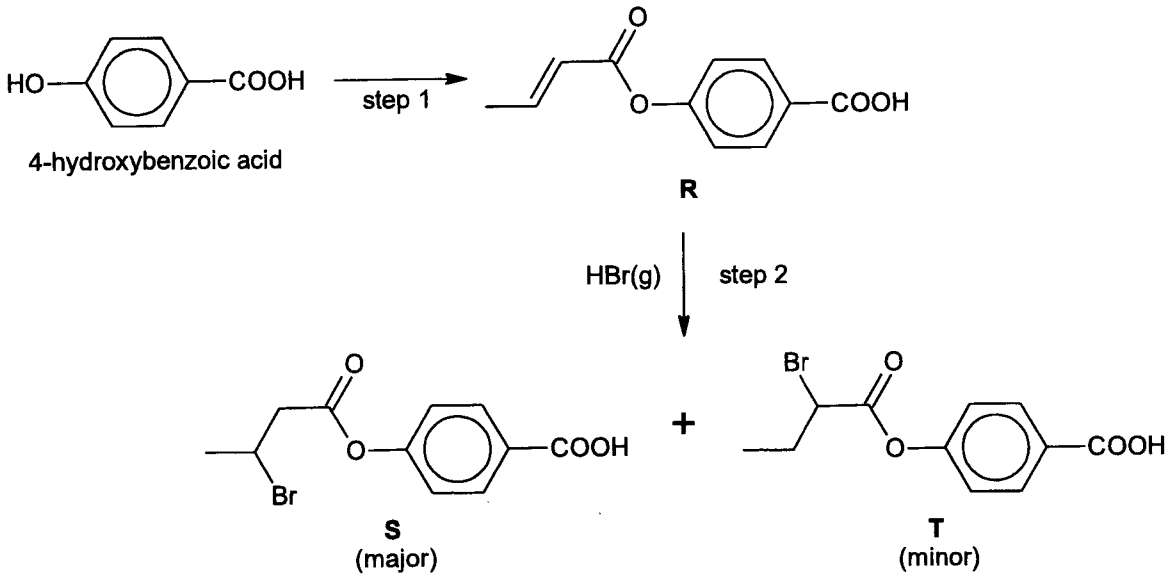

Fig. 4.2

(i) Suggest the reagent used in step 1.

.....[1]

(ii) Describe the mechanism of the formation of **S** from **R** in step 2. Show relevant lone pairs and dipoles, and use curly arrows to indicate the movement of electron pairs.

[2]

(iii) Suggest why **T** is formed as the minor product.

.....

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.....[1]

(c) When aqueous ammonia is added to an iron(III) chloride solution, a reddish-brown precipitate forms. The precipitate dissolves upon the addition of excess iron(III) chloride. Subsequent addition of 4-hydroxybenzoic acid leads to deprotonation of its phenol group, forming phenoxide ion. The phenoxide ion acts as ligand, and six of them coordinate with the iron(III) centre, resulting in the formation of an octahedral complex, which is violet in colour.

(i) Suggest the identity of the reddish-brown precipitate formed when aqueous ammonia is added to iron(III) chloride solution.

.....[1]

(ii) Explain what is meant by the term *complex.*

.....

.....[1]

(iii) Suggest why the phenol group deprotonates to form a phenoxide ion that coordinates to the iron(III) centre as a ligand, rather than the carboxylic acid group.

.....

.....[1]

(iv) Draw the structure of the complex formed, showing clearly the shape and overall charge.

[2]

[Total: 21]

5 Lake Tekapo in New Zealand's South Island is famous for its milky turquoise water. This is caused by fine rock particles, known as glacial flour, suspended in the water. These particles are created when nearby glaciers grind against the bedrock, and are carried into the lake by meltwater from the Southern Alps. Glacial flour, rich in minerals, has various commercial applications. Table 5.1 lists the elements found in a water sample from the lake.

Table 5.1

element	%w/w
calcium	6.44
iron	10.5
copper	6.54
sulfur	0.21
zinc	1.25
silicon	21.6

"%w/w" stands for percentage weight-by-weight and is a way of indicating the concentration of a solution. It indicates the mass of solute compared to the total mass of the solution. For example, a 10 %w/w solution of a substance means 10 g of that substance is dissolved in 100 g of the total solution. It is commonly used in scientific fields to represent the amount of a specific component in a solution.

Selective precipitation of sulfides may be used to extract the Cu^{2+} and Zn^{2+} ions present in a sample of lake water. Hydrogen sulfide gas, which behaves as a dibasic (diprotic) weak acid when in aqueous solution, is first added to generate sulfide ions, S^{2-}.

reaction 5.1 $H_2S(g) + aq \rightleftharpoons H^+(aq) + HS^-(aq)$

reaction 5.2 $HS^-(aq) + aq \rightleftharpoons H^+(aq) + S^{2-}(aq)$

Sodium hydroxide powder, NaOH, is then slowly added until the respective metal sulfides are all precipitated.

reaction 5.3 $M^{2+}(aq) + S^{2-}(aq) \rightarrow MS(s)$

Relevant K_{sp} values and colours of the precipitates are given in Table 5.2.

Table 5.2

metal sulfide	K_{sp}	colour of precipitate
CuS	6.3×10^{-36}	black
ZnS	1.6×10^{-24}	white

(a) **(i)** Explain why adding sodium hydroxide powder helps to cause the precipitation of the respective metal sulfides.

.....

.....

.....[2]

(ii) Assuming all the copper and zinc in a 100 g sample of lake water exists as Cu^{2+} and Zn^{2+} ions, use information from Table 5.1 to determine the concentration of Cu^{2+} and Zn^{2+} ions in mol dm^{-3}.

The density of the lake water can be taken to be 1.02 g cm^{-3}.

[2]

(iii) Write an expression for K_{sp} for ZnS, giving its units.

.....[1]

(iv) Use your knowledge of solubility products and the information in Table 5.2 to determine the minimum $[S^{2-}]$ needed for precipitation of CuS and ZnS respectively. Hence describe what you expect to observe as sodium hydroxide powder is slowly added to the solution.

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.....[3]

(v) A student suggests that both the solubility and solubility product of CuS will decrease with addition of some solid copper(II) nitrate, $Cu(NO_3)_2$.

Comment on the student's suggestion, assuming temperature remains constant.

Effect on solubility: .....

.....

.....

Effect on solubility product: .....

.....

.....[2]

(b) Glacial flour is rich in silicon, often in the form of silica, SiO_2. This high silica content is a key factor in glacial flour's beneficial effects on plants and soil, contributing to increased plant growth and improving soil structure.

Silica has a melting point of 1713 °C and is insoluble in water.

(i) Suggest the structure and describe the bonding in silica.

.....

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.....

.....[2]

(ii) With reference to your answer in **(i)**, explain silica's insolubility in water.

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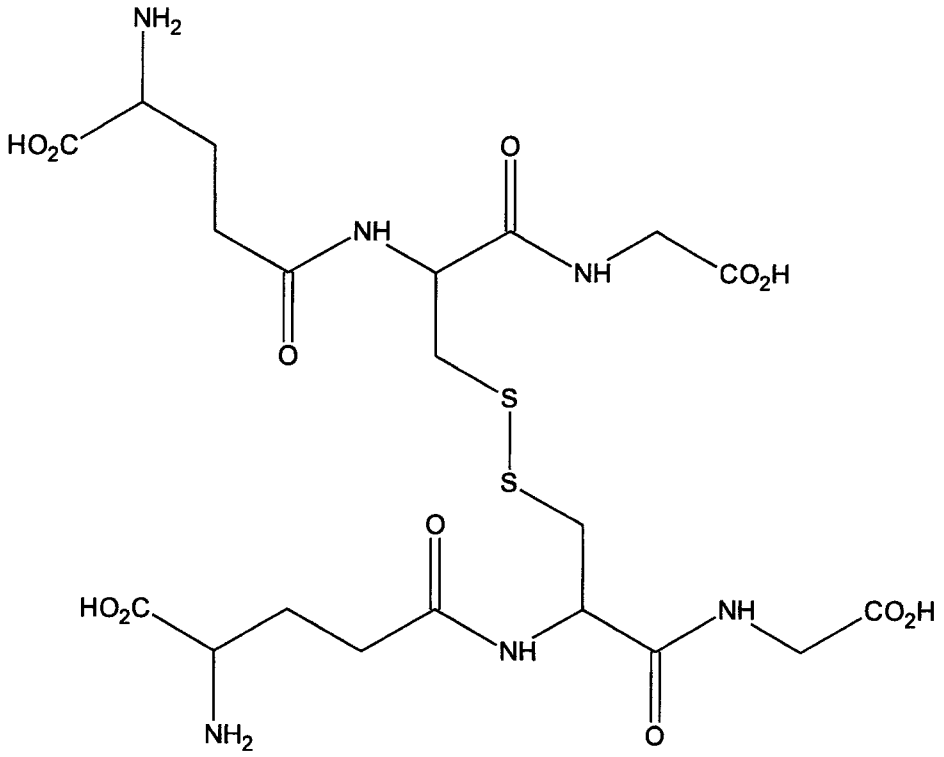
.....

.....[2]

(c) Sulfur is an essential element in the human body, mainly obtained from sulfur-rich vegetables like broccoli, cabbage and kale. Using glacial flour as fertiliser can enhance the sulfur content in plants and improve crop yields.

Sulfur is a key component of glutathione (GSH), a powerful antioxidant that protects cells from damage and reduces inflammation. GSH works by losing hydrogen ions and donating electrons to free radicals, and in the process two GSH molecules form one glutathione disulfide (GSSG) through a bond between their sulfur atoms.



Glutathione disulfide (GSSG)

(i) Write an ionic equation to show how glutathione (GSH) transforms into glutathione disulfide (GSSG). Represent glutathione as GSH and glutathione disulfide as GSSG.

Hence suggest and explain the type of reaction that has taken place.

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.....

.....[2]

(ii) Draw the structure of the glutathione (GSH) molecule.

[1]

(d) Glacial lakes, fed by melting glaciers, can release halogen gases (like chlorine, bromine, and iodine) into the atmosphere. The resulting halogen gases can impact atmospheric composition and potentially contribute to ozone depletion.

(i) Halogen gases tend to behave as non-ideal gas at sea level. Under what conditions will halogen gases approach ideal gas behaviour? Explain your answer.

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.....[2]

(ii) In the presence of chlorine atoms, ozone decomposes exothermically to produce oxygen. The reaction mechanism has two steps as shown.

Step 1 $O_3 + Cl\bullet \rightarrow ClO\bullet + O_2$
Step 2 $O_3 + ClO\bullet \rightarrow Cl\bullet + 2O_2$

Use this mechanism to state and explain the role of $Cl\bullet$.

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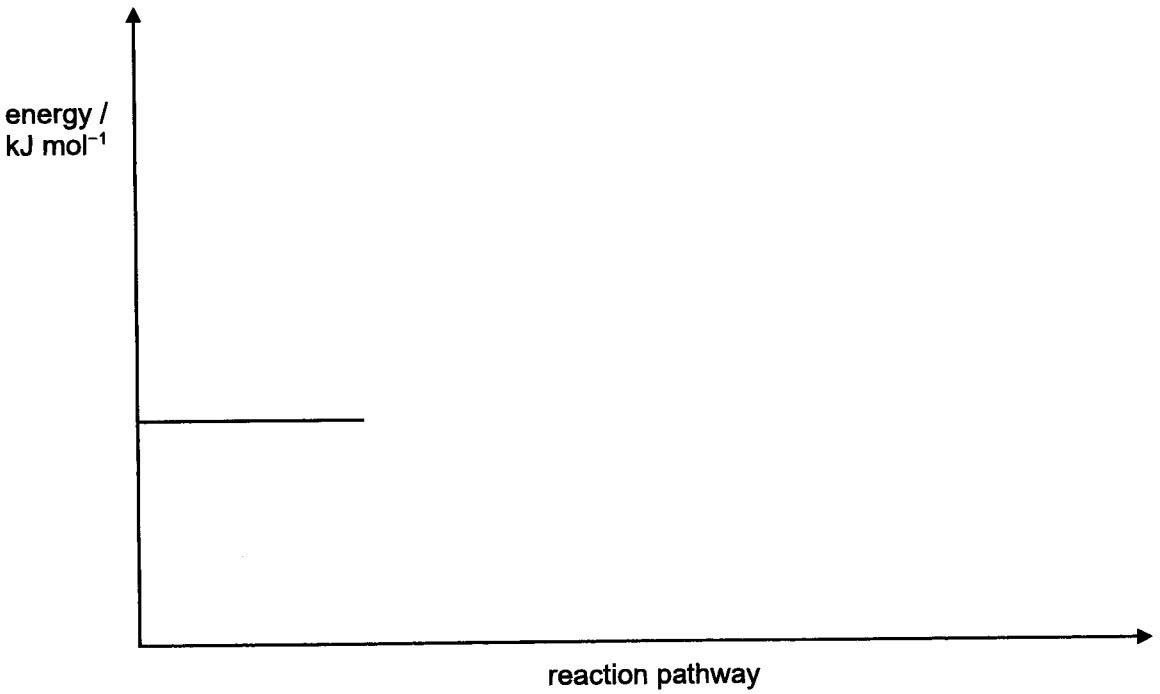
.....

.....[1]

(iii) Complete the labelled energy profile diagram for this reaction.



[2]

(e) The reaction between aqueous iodine, $I_2(aq)$, and aqueous thiosulfate ions, $S_2O_3^{2-}(aq)$, is an important redox titration method used in analytical chemistry. Chlorine is a stronger oxidising agent than iodine and, unlike iodine, can oxidise the aqueous thiosulfate ions to the sulfate ion, $SO_4^{2-}(aq)$.

(i) Use the *Data Booklet* to write an equation for the reaction of $I_2(aq)$ with $S_2O_3^{2-}(aq)$ and calculate the $E^{\ominus}_{cell}$.

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.....[1]

(ii) Construct an equation for the reaction of chlorine, $Cl_2(aq)$, with $S_2O_3^{2-}(aq)$.

.....

.....

.....[2]

[Total: 25]

H

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME

CLASS

TUTOR'S NAME

CHEMISTRY
Paper 3 Free Response

9729/03
September 2025
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	/ 20
3	/ 18
4	/ 20
5	/ 20
Total	/ 80

This document consists of **28** printed pages.

Section A

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

1 (a) The pH values of the solutions of four chlorides are given in Table 1.1.

Table 1.1

compound	pH of 1.0 mol dm^{-3} solution
$BeCl_2$	x
$NaCl$	7.0
$AlCl_3$	3.0
PCl_5	1.0

(i) Explain the difference in pH values of solutions of $NaCl$, $AlCl_3$ and PCl_5, in terms of the structures of the chlorides. Include appropriate equation(s) in your answer. [4]

(ii) Using the *Data Booklet*, suggest how the pH value of 1.0 mol dm^{-3} solution of $BeCl_2$ compares to 1.0 mol dm^{-3} solution of $AlCl_3$. Explain your answer. [2]

(iii) At certain temperatures, aluminum chloride exists as Al_2Cl_6 molecules. Draw the structure of Al_2Cl_6. Label the co-ordinate bonds on your structure. [1]

(b) Beryllium, in Period 2, is the only element in Group 2 that shares very similar chemical properties with aluminium which is in Period 3.

Describe the similarities in their acid-base behaviour and explain why beryllium oxide reacts similarly like aluminium oxide. Illustrate the reactions of beryllium oxide with equations. [2]

(c) BrCl reacts with benzene in the presence of $AlCl_3$ in an electrophilic substitution reaction to produce bromobenzene.

(i) Explain why bromobenzene is made in preference to chlorobenzene during the reaction. [1]

(ii) Hence, draw the electrophilic substitution mechanism of the reaction. [2]

(iii) The position of substitution in the electrophilic substitution of mono-substituted arene depends on the nature of the group, **Z**, already attached to the ring. This selectivity can be explained based on the stability of the intermediate formed in the first step. Fig. 1.1 shows three possible first steps in the mono-bromination of a mono-substituted arene and the products obtained.

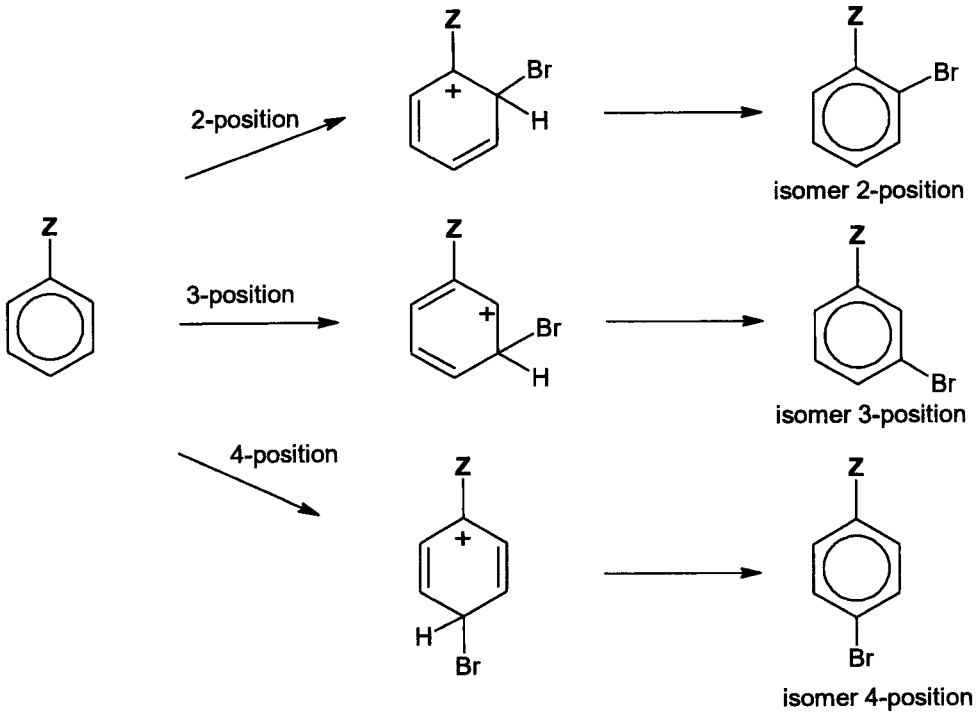
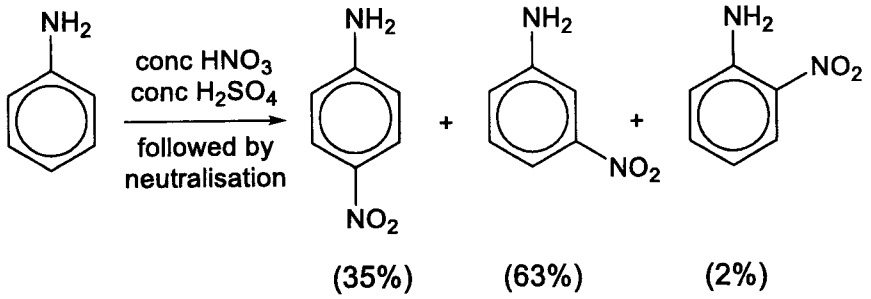


Fig. 1.1

Use this information to predict which substituted isomers in Fig. 1.1 will be formed the least and the most when **Z** is a $-C(CH_3)_3$ group. Explain your reasoning. [2]

(iv) When **Z** is a $-NH_2$ group and was reacted with concentrated HNO_3 and concentrated H_2SO_4, the proportion of 3-nitrophenylamine was found to be unexpectedly high.



Explain why 3-nitrophenylamine was the major product. [1]

(d) Three organohalogeno compounds are shown.

$C_6H_5CH_2Cl$	C_6H_5Cl	C_6H_5COCl
A	**B**	**C**

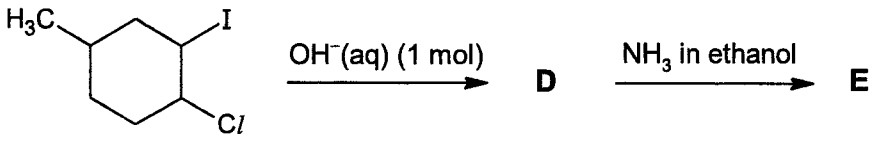
Arrange **A**, **B** and **C** in order of increasing relative rate of hydrolysis. Explain your answer. [3]

(e) The different reactivities of organic halogeno compounds, and of amines and alcohols, can be exploited in successive reactions of dihalogeno compounds.

Suggest the structures of the intermediates **D** and **F** and the products **E** and **G**.

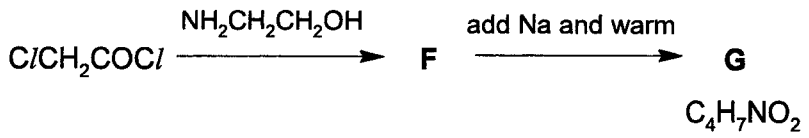
E and **G** are cyclic compounds.

(i)



[2]

(ii)



[2]

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[Total: 22]

2 **(a)** A calorimeter containing 300 cm^3 of water at 25 °C was calibrated. 10 kJ of heat energy from a heating coil was used to increase the temperature of water by 7.5 °C. Calculate the heat capacity of the empty calorimeter. [2]

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(b) Ag_2CO_3 is a sparingly soluble salt. A 100 cm^3 saturated solution of Ag_2CO_3 in water was found to contain 2.57×10^{-4} mol dm^{-3} of Ag^+ ions.

(i) Calculate the K_{sp} of Ag_2CO_3 and state its units. [2]

(ii) Hence, calculate the solubility of Ag_2CO_3 when 2.50 g of Na_2CO_3 solid was added to the solution above. [2]

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(c) The term 'tri-iodide' refers to molecules that contain three iodine atoms in their molecular formula, such as nitrogen tri-iodide, NI_3, and aluminium tri-iodide, AlI_3.

AlI_3 has a simple molecular structure. In the gas phase, it dimerises readily to form the dimer Al_2I_6. The two species are related by the equilibrium shown below.

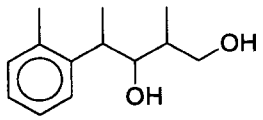
$$Al_2I_6(g) \rightleftharpoons 2AlI_3(g) \qquad \Delta H > 0$$

(i) A 10.0 g sample of Al_2I_6 was allowed to vapourise in a 2 dm^3 vessel at 400 °C. Calculate the initial pressure of Al_2I_6. [1]

(ii) Given that the degree of dissociation of Al_2I_6 was 0.35, calculate the value of K_p for the equilibrium at 400 °C. State its units. [3]

(iii) Explain the effect on the degree of dissociation of Al_2I_6 if the reaction was carried out at 300 °C. [2]

(d) Alcohols are very useful in organic synthesis and can be used to produce a wide variety of compounds. The structural formula of one such alcohol is shown below.



compound **A** ($C_{13}H_{20}O_2$)

(i) When compound **A** is heated with an excess of concentrated sulfuric acid, a mixture of two isomeric hydrocarbons, **P** and **Q** are produced. Draw the structures of **P** and **Q**. [2]

Compound **D** can be formed from compound **A** via a five-step synthesis as shown in Fig. 2.1.

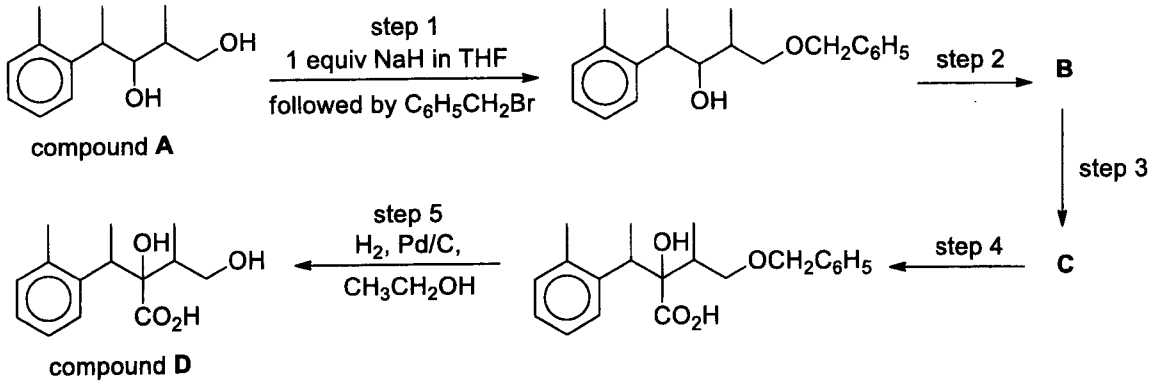


Fig. 2.1

(ii) Suggest the type of reaction in step 1. [1]

(iii) State the reagents and conditions required for steps 2 to 4 and draw the structures of **B** and **C**. [5]

[Total: 20]

3 There are over 20 different binary compounds containing only the elements nitrogen and hydrogen. The most common of these is ammonia, but others include tetrazene and hydrogen azide in Table 3.1.

Table 3.1

Compound	Molecular formula
Ammonia	NH_3
Tetrazene	N_4H_4
Hydrogen azide	HN_3

(a) N_4H_4 contains a N=N bond. Draw the structure of N_4H_4. [1]

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(b) Hydrogen azide has a boiling point of 37 °C and tetrazene has a boiling point of 135 °C. Suggest a reason for the higher boiling point of tetrazene compared to hydrogen azide. [1]

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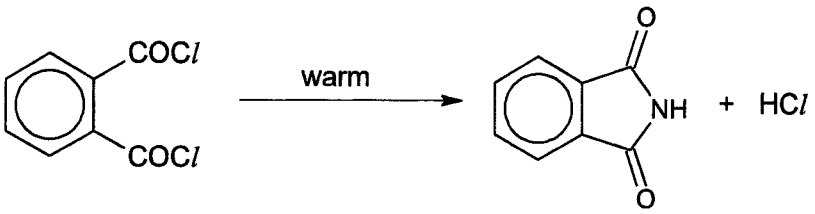
(c) Ammonia can react in various ways: as an acid, as a base, as a nucleophile, as an oxidising agent and as a reducing agent. Study the following reactions and decide how ammonia is reacting in each case. Explain your answers fully. [4]

(i) $NH_3 + Na^+CH_2{=}CH^- \longrightarrow CH_2{=}CH_2 + NaNH_2$

(ii) $NH_3 + BH_3 \longrightarrow NH_3BH_3$

(iii) $2NH_3 + NaOCl \xrightarrow{\text{room temperature}} N_2H_4 + NaCl + H_2O$

(iv) $NH_3 +$  $+ HCl$

(d) State the type of reaction in **(c)(iv)**. Fig. 3.1 shows the mechanism for the reaction in **(c)(iv)**. Complete the mechanism for steps 1 to 3 on Fig. 3.1. Show all charges and relevant lone pairs and show the movement of electron pairs by using curly arrows. [3]

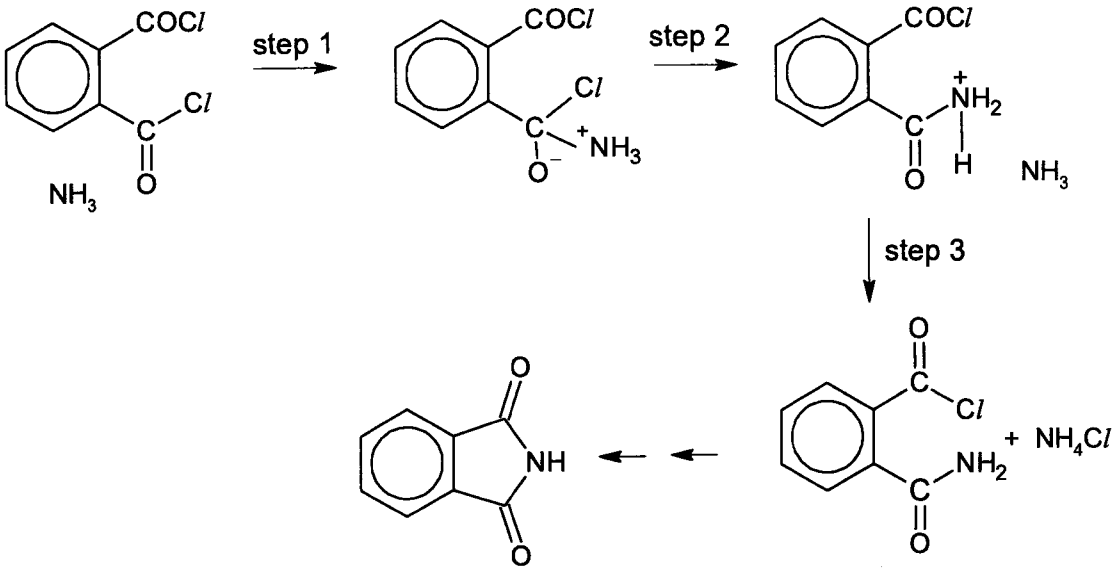


Fig. 3.1

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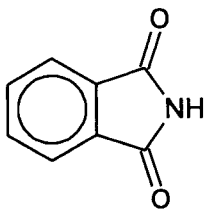
(e) Phthalimide is a white solid that is slightly soluble in water. The stability of this compound is attributed to the presence of the benzene ring and C=O groups, which allows for resonance to take place. The nitrogen atom in phthalimide is sp^2 hybridised.



phthalimide

(i) By reference to the hybridisation of the N atom and orbital overlap, suggest how the electrons are arranged in the second shell of the sp^2 nitrogen atom in phthalimide. [2]

(ii) Suggest and explain how the basicity of 4-methylphenylamine might compare to that of phthalimide. [2]

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(f) Amino acids are critical to life, and they serve as building blocks of proteins.

Lysine is an alpha amino acid which shows both acidic and basic properties. The R group of lysine is $-(CH_2)_4NH_2$. In acidic solution, lysine is completely protonated.

10.0 cm^3 of completely protonated lysine is titrated with 1.00 mol dm^{-3} sodium hydroxide solution. Its titration curve is shown in Fig. 3.2.

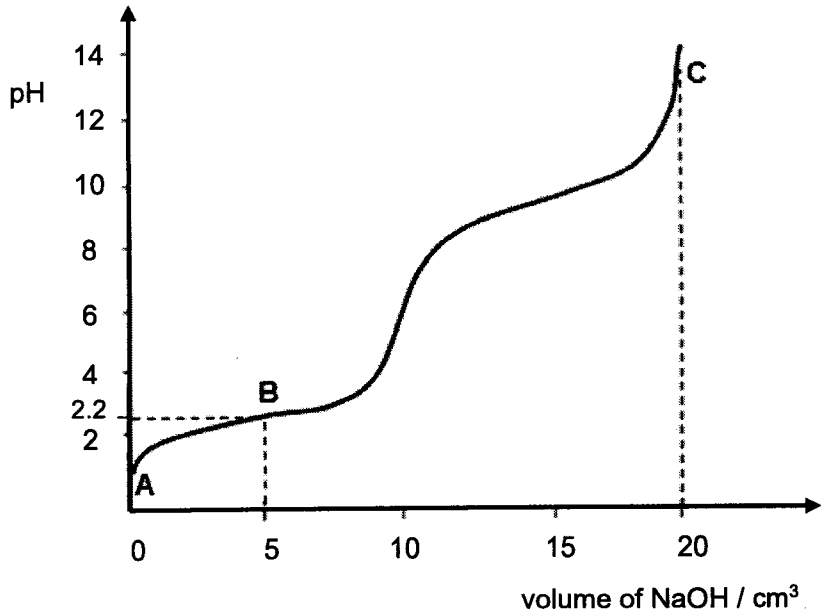

Fig. 3.2

(i) Calculate the first dissociation constant K_{a1} of fully protonated lysine. [1]

(ii) With the aid of an equation, explain how the species present at point **B** can resist changes in pH when a small amount of base is added. [2]

(iii) Calculate the pH when 10.0 cm^3 of 0.0200 mol dm^{-3} sodium hydroxide is added to the solution at point **B**. (You may represent the fully protonated lysine as HA.) [2]

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[Total: 18]

Section B

Answer **one** question from this section.

4 **(a)** Lead(II) carbonate decomposes on heating in the same way as magnesium carbonate. By using relevant data from the *Data Booklet*, predict and explain which of the two carbonates, lead(II) carbonate or magnesium carbonate, would have a higher decomposition temperature. [2]

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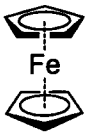
(b) Ferrocene, $Fe(C_5H_5)_2$, is an orange solid. In this complex, $C_5H_5^-$ is the ligand and it donates π electrons from the ring to the vacant 3d orbital of Fe.



ferrocene

Ferrocene can undergo a series of different reactions and some are analogues of organic reactions. Two reactions of ferrocene are shown in Fig. 4.1.

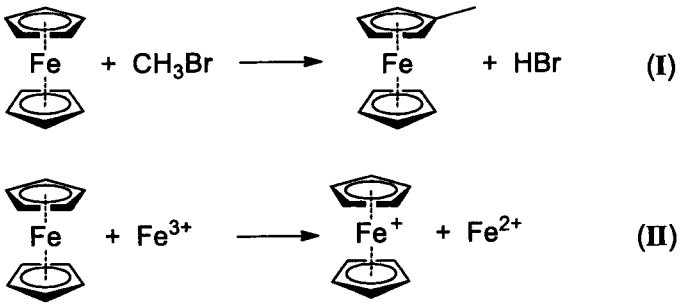


Fig. 4.1

(i) State the type of reaction for reaction (I). [1]

(ii) State the oxidation number of Fe in ferrocene and write its electronic configuration. [1]

(iii) Explain why ferrocene is a coloured complex. [2]

(iv) The complementary colours are illustrated with the colour wheel in Fig. 4.2.

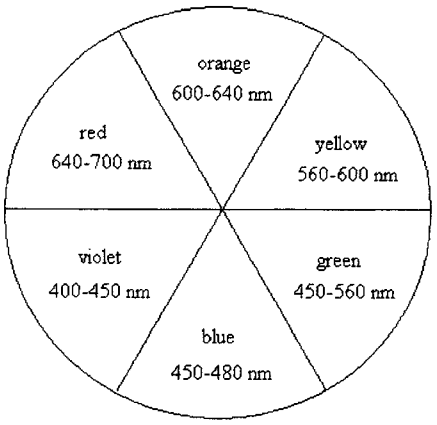


Fig. 4.2

Aqueous Fe^{2+} ion is green in colour. Suggest and explain if water causes a larger d-d splitting as compared to $C_5H_5^-$. [2]

(v) By considering reaction (II), suggest if $E^{\ominus}(Fe(C_5H_5)_2^+|Fe(C_5H_5)_2)$ is more or less positive than $E^{\ominus}(Fe^{3+}|Fe^{2+})$. Explain your answer. [1]

(vi) The reaction between $S_2O_8^{2-}$ and I^- is slow in the absence of catalyst. Ferrocene can be a suitable catalyst for this reaction between $S_2O_8^{2-}$ and I^-.

Explain with the aid of equations how it works. You may use $Fe(C_5H_5)_2$ to represent ferrocene. [3]

(vii) By considering your answers for **(v)** and **(vi)**, suggest a value for $E^{\ominus}(Fe(C_5H_5)_2^+|Fe(C_5H_5)_2)$. [1]

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(c) Compound **G** has a sweet smell. When heated with an excess of acidified concentrated manganate(VII) ions, it forms initially three products **H**, **J** and ethanedioic acid. Ethanedioic acid will be further oxidised to give $CO_2(g)$.

$$\underset{C_{13}H_{20}O_2}{\mathbf{G}} \xrightarrow{MnO_4^- / H^+} \underset{C_6H_8O_3}{\mathbf{H}} + \underset{C_5H_{10}O_2}{\mathbf{J}} + \text{ethanedioic acid } (C_2H_2O_4)$$

When compound **G** was mixed with liquid bromine at room temperature, $C_{13}H_{20}O_2Br_4$ was obtained.

Compound **J** evolves CO_2 with $NaHCO_3$. **J** also reacts with $LiAlH_4$ to give a compound which does not undergo elimination reaction with concentrated sulfuric acid.

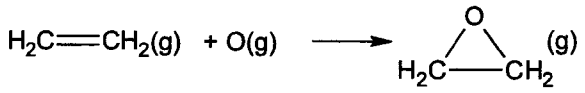
Compound **H** gives an orange precipitate with 2,4-dinitrophenylhydrazine reagent. **H** has no reaction with Tollens' reagent. When one mole of **H** reacts with an excess of alkaline aqueous iodine, two moles of yellow precipitate are produced.

Use the information above to deduce the structures for compounds **G**, **H** and **J**. [7]

[Total: 20]

5 **(a)** Like all compounds containing a 3-membered ring, the bonds in epoxyethane are strained. This can be illustrated by the following calculations, in which we assume that the C–H bond energy is the same in ethene and epoxyethane.

The reaction between the ethene molecules and oxygen atoms is shown below.



$\Delta H^{\ominus} = -354$ kJ mol^{-1}

epoxyethane

(i) Use the *Data Booklet* to calculate a theoretical value for the sum of the C–C and 2 × C–O bond energies in epoxyethane. [1]

(ii) Use the $\Delta H^{\ominus}$ value for the reaction between ethene molecules and oxygen atoms given above to calculate the actual value for the sum of the C–C and 2 × C–O bond energies in epoxyethane. Suggest an explanation for the difference between the theoretical and actual values. [2]

(iii) Predict, with a reason, the entropy change for the above reaction. [2]

(iv) Hence, explain if the reaction is feasible at high, low or all temperatures. [1]

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(b) Dinitrogen pentoxide, N_2O_5, exist as colourless crystals that sublime slightly above room temperature. It exists as covalent molecules $O_2N–O–NO_2$ in the gas phase, but as ionic $[NO_2^+ NO_3^-]$ in the solid or in solution.

When heated in CCl_4 solvent, N_2O_5 decomposes on heating to give NO_2 and O_2. The mechanism for the thermal decomposition of N_2O_5 is thought to involve three steps.

- There is an initial homolytic breaking of an N–O bond to give NO_2• and NO_3• radicals.
- This is followed by the dimerisation of the NO_3• radical to give N_2O_6, which contains a –O–O– peroxide bond.
- The third step involves the dissociation of this dimer via further N–O bond cleavage to form the products.

Use the information to draw out the mechanism for the thermal decomposition of N_2O_5. You are advised to use structural formulae for all species so that it is clear which bonds are broken and which are formed. Indicate any unpaired electrons by a dot (•). [3]

(c) $Mg(NO_3)_2$ is widely used as a fertiliser due to its high solubility and ability to provide both magnesium and nitrate nutrients to plants. Magnesium is an essential plant nutrient involved in chlorophyll production and enzyme activation, while nitrate is a significant source of nitrogen.

Use the data in Table 5.1, together with data from the *Data Booklet*, to construct an energy level diagram to calculate the lattice energy of magnesium nitrate.

You may assume the three N–O bonds in NO_3 have the same strength.

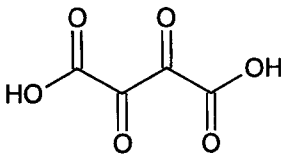
Show your working. [4]

Table 5.1

	ΔH / kJ mol^{-1}
1st electron affinity of NO_3(g)	–317
bond energy of N–O bonds in NO_3(g)	+400
standard enthalpy change of atomisation of Mg(s)	+148
standard enthalpy change of formation of $Mg(NO_3)_2$(s)	–791

(d) Compound **J**, $C_7H_{10}O_2$, decolourises bromine water. One mole of **J** reacts with sodium metal to produce 22.7 dm^3 of hydrogen gas at s.t.p. On heating with acidified $KMnO_4$, **K**, $C_5H_4O_5$, is the only organic product formed.

K reacts with sodium carbonate and 2,4-dintrophenylhydrazine reagent. When **K** reacts with alkaline aqueous iodine, **L** is formed upon acidification.



L

(i) Give the systematic name for compound **L**. [1]

(ii) Suggest structures for **J** and **K** and explain the reactions described. [6]

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[Total: 20]

Additional page

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