H

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME			
CLASS		TUTOR'S NAME	

CHEMISTRY **9729/02**

Paper 2 Structured Questions **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.

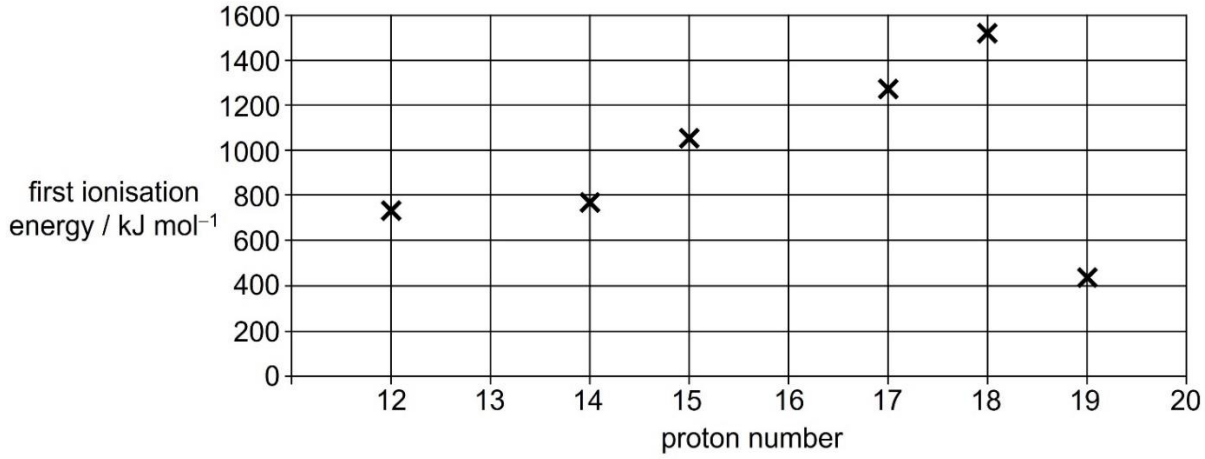

Fig. 1.1

(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.

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……...

……...[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}.

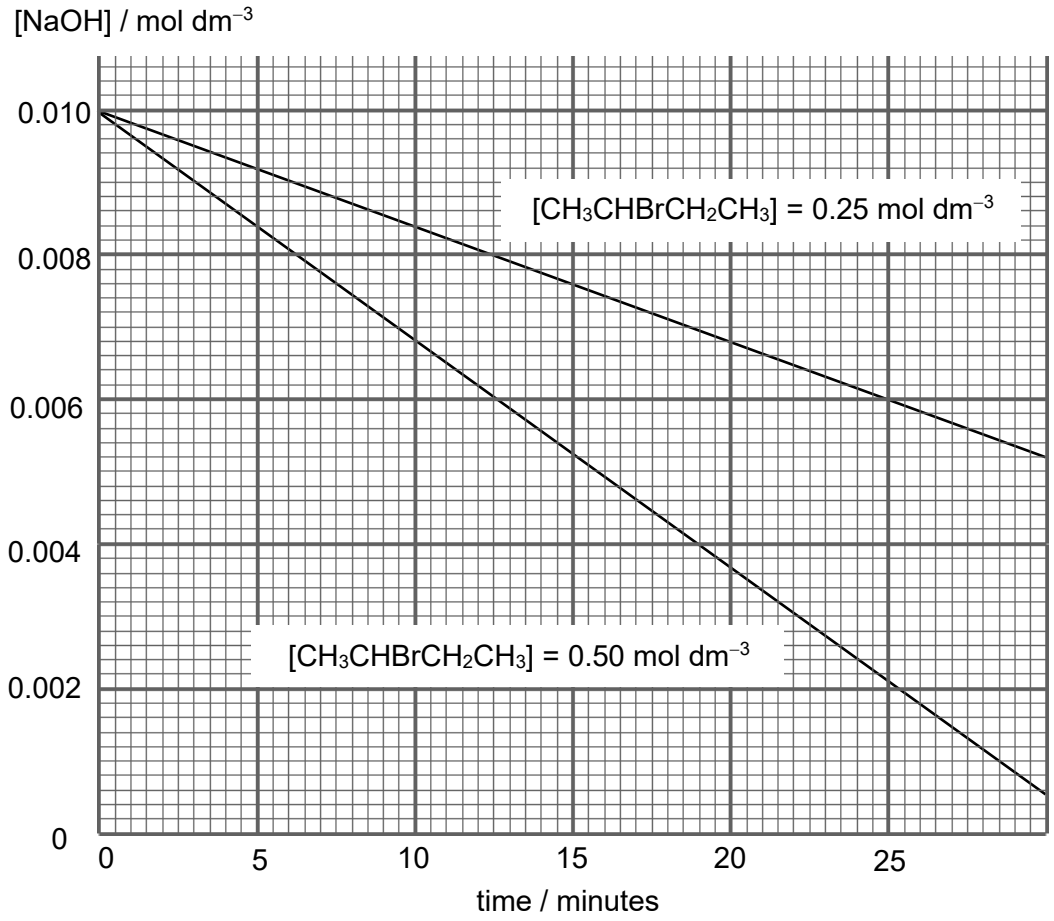

Fig. 2.1

(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.

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……...

……...

……..[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.

……

……

……

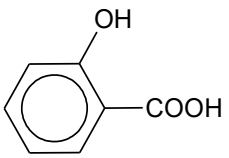
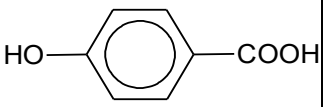
……[2]

[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).

……...

……...

……...

……...

……...

……...[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 cm³ 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]

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.

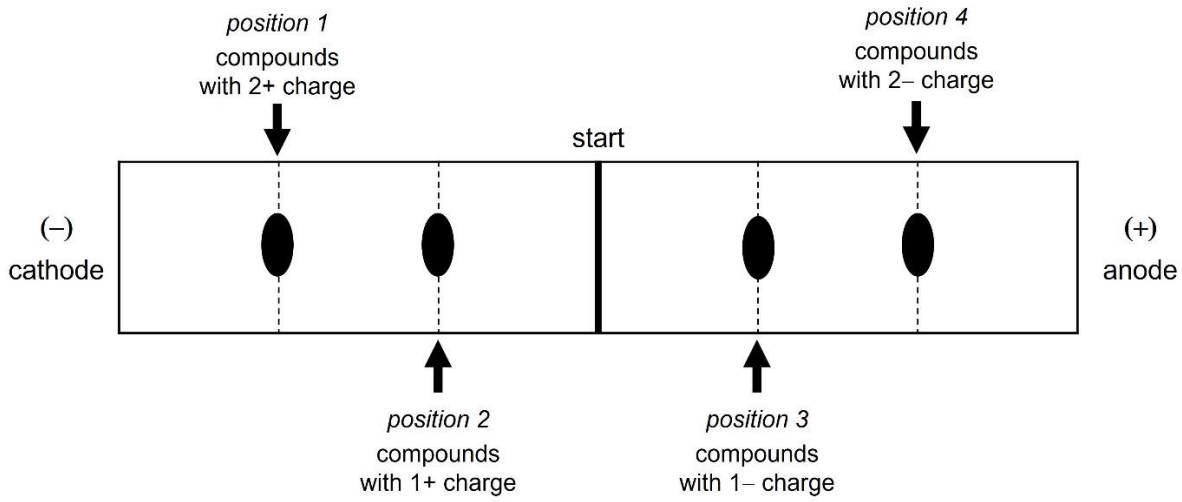


Fig. 4.1

(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.

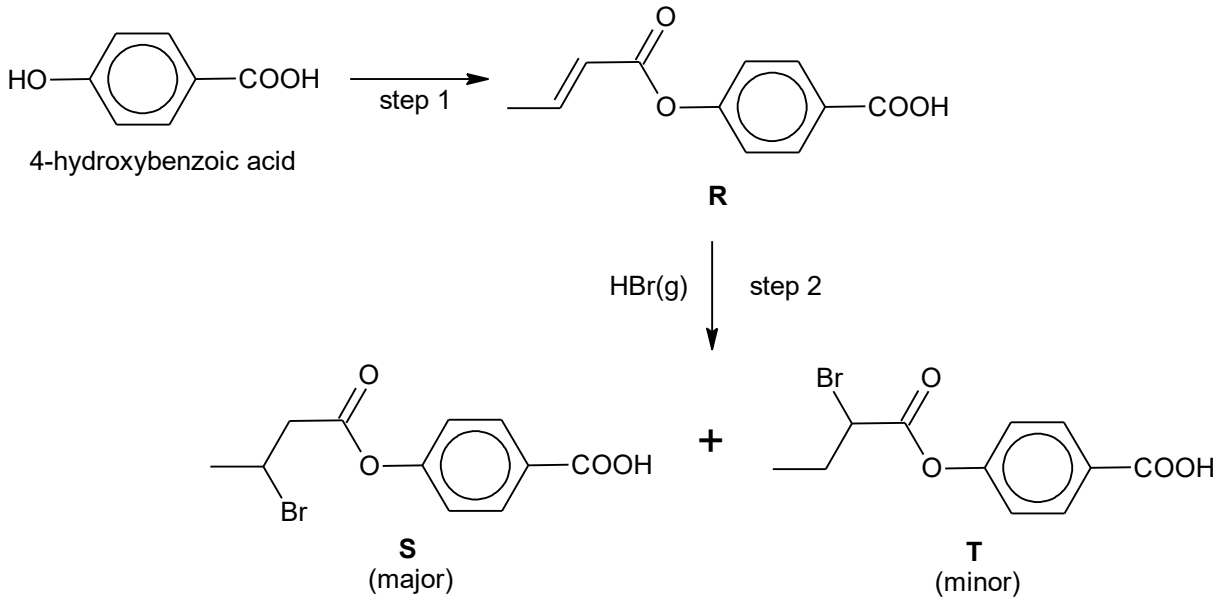


Fig. 4.2

(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.

……...

……...

……...[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.

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……...

……...[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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……...

……...

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……...[2]

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

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……...

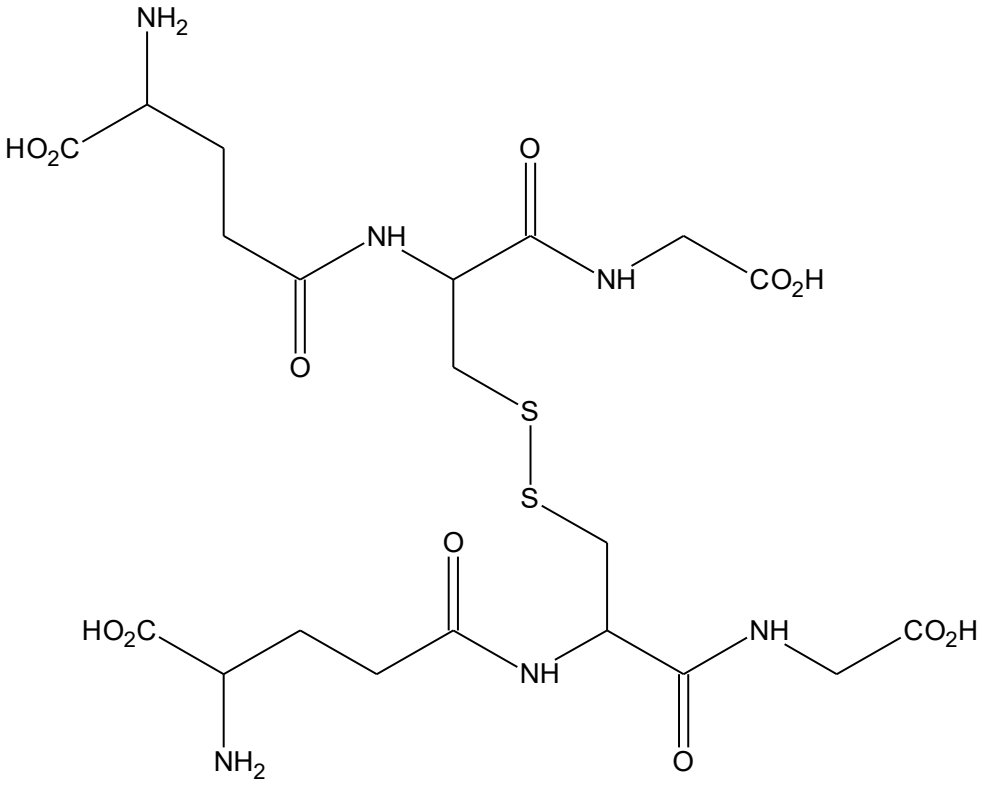
……...

……...

……...[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 $O_3 + ClO\bullet \rightarrow Cl\bullet + 2O_2$

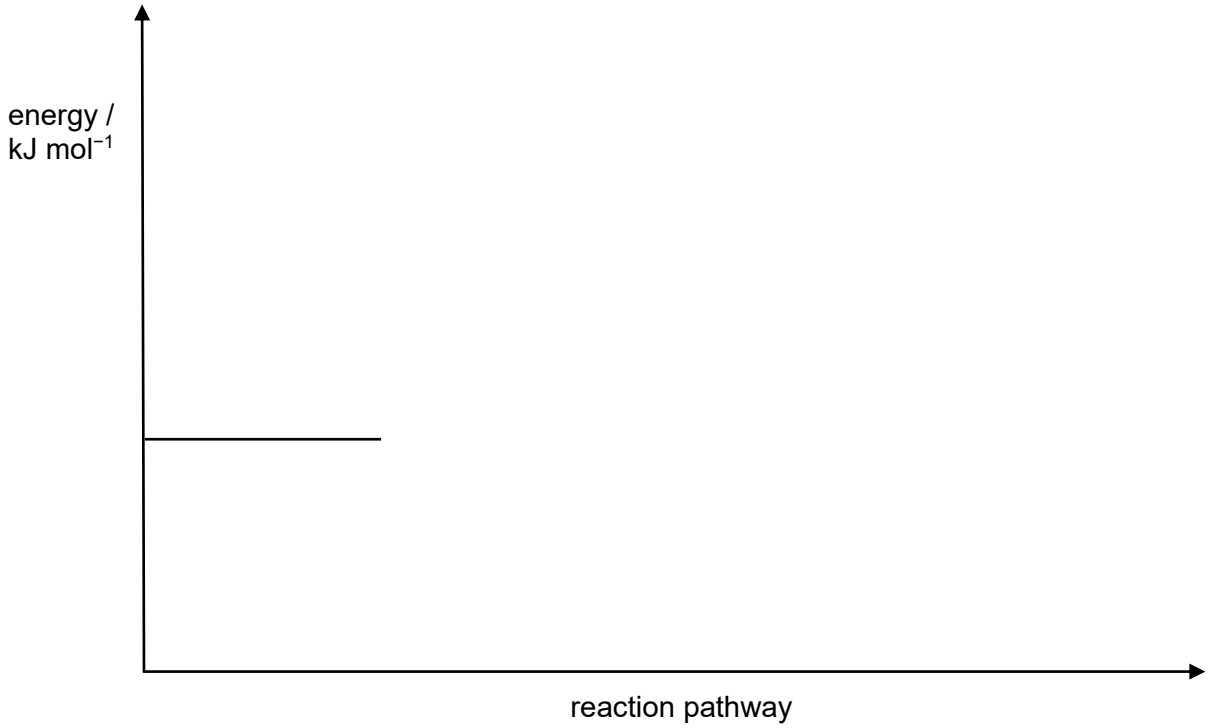
Use this mechanism to state and explain the role of $Cl\bullet$.

……...

……...

……...[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]