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# Chemistry Higher level Paper 2

9 May 2024

Zone A morning | Zone B morning | Zone C morning

Candidate session number

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2 hours 15 minutes

## Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.



Please **do not** write on this page.

Answers written on this page  
will not be marked.



Answer **all** questions. Answers must be written within the answer boxes provided.

1. An organic compound, **A**, has the following composition by mass when its only combustion products, carbon dioxide and water, are analysed.

C / %	H / %
71.93	12.10

- (a) Outline why this compound is **not** a hydrocarbon. [1]

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- (b) Determine the empirical formula of **A**. [2]

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- (c) A sample of the vapour of **A** at 200.0 °C, and  $1.00 \times 10^5$  Pa, has a density of  $2.544 \times 10^3$  g m<sup>-3</sup>.

Determine the molar mass and the molecular formula of **A**. [2]

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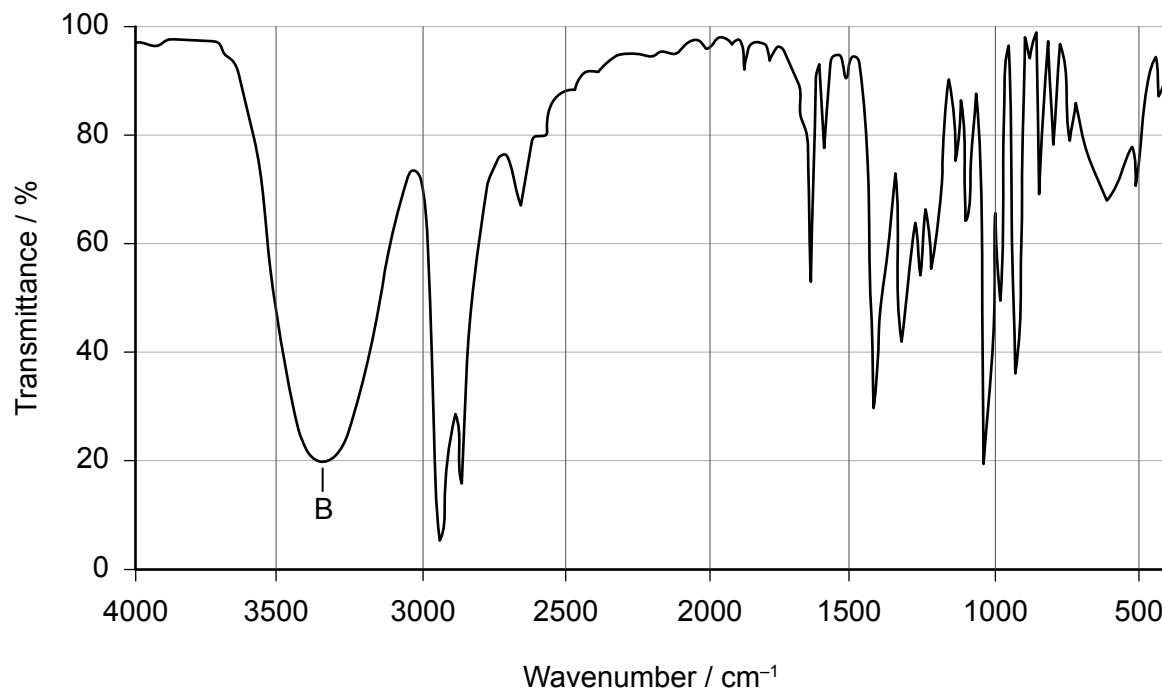
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**(Question 1 continued)**

- (d) The infrared (IR) spectrum of **A** is shown below.



Identify the bond responsible for the absorption labelled **B** in the IR spectrum. Use section 26 of the data booklet.

[1]

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- (e) **A** can be converted to compound **E**, which has a higher molecular mass, by heating it under reflux with acidified potassium dichromate(VI),  $K_2Cr_2O_7$ .

Identify **one** functional group present in **E** based on this information only.

[1]

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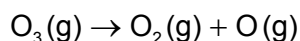


**(Question 1 continued)**

- (f) Deduce a possible structural formula for **A** consistent with the evidence presented. [1]



2. In the stratosphere, ozone is decomposed by ultraviolet radiation.



(a) State the full electron configuration of an oxygen atom and the number of unpaired electrons in that atom. [2]

Electron configuration: .....

Unpaired electrons: .....

(b) (i) Draw a Lewis (electron dot) structure for the ozone molecule. [1]

.....

(ii) Deduce the formal charge on each of the three oxygen atoms by adding them to your Lewis (electron dot) structure in (b)(i). [2]

(iii) Predict the shape and bond angle of the ozone molecule. [2]

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(iv) State the hybridization state of the central oxygen atom in ozone. [1]

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**(Question 2 continued)**

- (c) Suggest a value, in pm, for the bond lengths in the ozone molecule and explain your answer. Use section 10 of the data booklet. [2]

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- (d) Explain the dependence of the dissociation of diatomic oxygen, O<sub>2</sub>, and ozone, O<sub>3</sub>, on the wavelength of UV radiation. [2]

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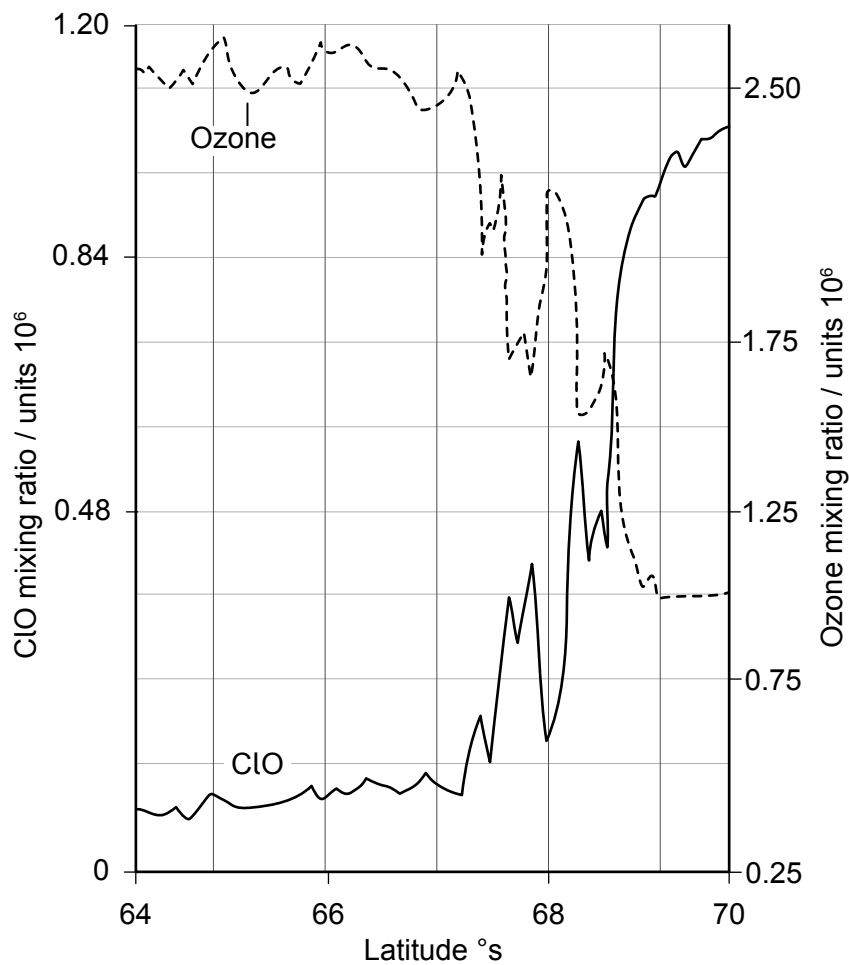
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(Question 2 continued)

- (e) The concentrations of ozone molecules and chlorine monoxide, ClO, free radicals were measured.



(This question continues on the following page)



**(Question 2 continued)**

(i) Outline the relationship between the concentrations of ozone and ClO, free radicals. [1]

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(ii) Comment, based on this graph, on the conclusion that the hole in the ozone layer is caused by ClO free radicals. [2]

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(iii) When a chlorine emission spectrum is produced, there is a strong line at 453 nm. Determine the energy of the photon of light emitted in J, using sections 1 and 2 of the data booklet. [2]

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3. The acid-base character of the oxides of elements depends on their position in the periodic table.

(a) (i) State **one** environmental problem caused by sulfur dioxide, SO<sub>2</sub>. [1]

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(ii) Write an equation to show how sulfur dioxide reacts in the atmosphere to produce a secondary pollutant. [1]

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(b) A solution was prepared by dissolving 0.100 mol of sodium oxide in distilled water and making the total volume up to 1.00 dm<sup>3</sup>.

(i) Write the equation for the reaction between sodium oxide and water. [1]

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

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(This question continues on the following page)



**(Question 3 continued)**

(c) Hydrocyanic acid, HCN(aq), has  $K_a = 6.17 \times 10^{-10}$ .

(i) Determine the pH of a  $0.202 \text{ mol dm}^{-3}$  aqueous solution of hydrocyanic acid. [3]

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(ii) State **one** assumption made for your calculation in (c)(i). [1]

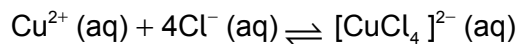
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(iii) State the composition of a buffer solution containing hydrocyanic acid. [1]

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4. The complex ion  $[\text{CuCl}_4]^{2-}$  is formed when concentrated hydrochloric acid is added to an aqueous solution of hydrated copper(II) ions.



Blue

Yellow

- (a) State an expression for the equilibrium constant,  $K_c$ , corresponding to this equation. [1]

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- (b) The numerical value of  $K_c$  under standard conditions is  $4.2 \times 10^5$ . Calculate the ratio when the chloride ion concentration is  $0.210 \text{ mol dm}^{-3}$ . [2]

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- (c) Explain why  $\text{Cu}^{2+}(\text{aq})$  is coloured, with reference to its electronic structure and section 17 of the data booklet. [3]

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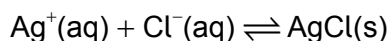


**(Question 4 continued)**

(d) State, with a reason, the effect of an increase in temperature on the value of  $K_c$ .  $\Delta H^\ominus > 0$  [1]

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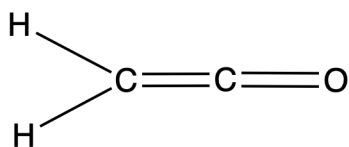
(e) State, with a reason, the effect of adding aqueous silver nitrate,  $\text{AgNO}_3(\text{aq})$ , on the position of this equilibrium. [1]



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5. Ethenone,  $\text{CH}_2\text{CO}$ , is used in the synthesis of pharmaceutical compounds.



(a) Suggest why the compound is given this IUPAC name. [2]

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(b) Compare and contrast the intermolecular forces that result in ethenone being less volatile than carbon dioxide. [2]

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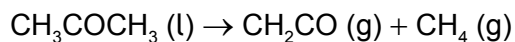
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**(Question 5 continued)**

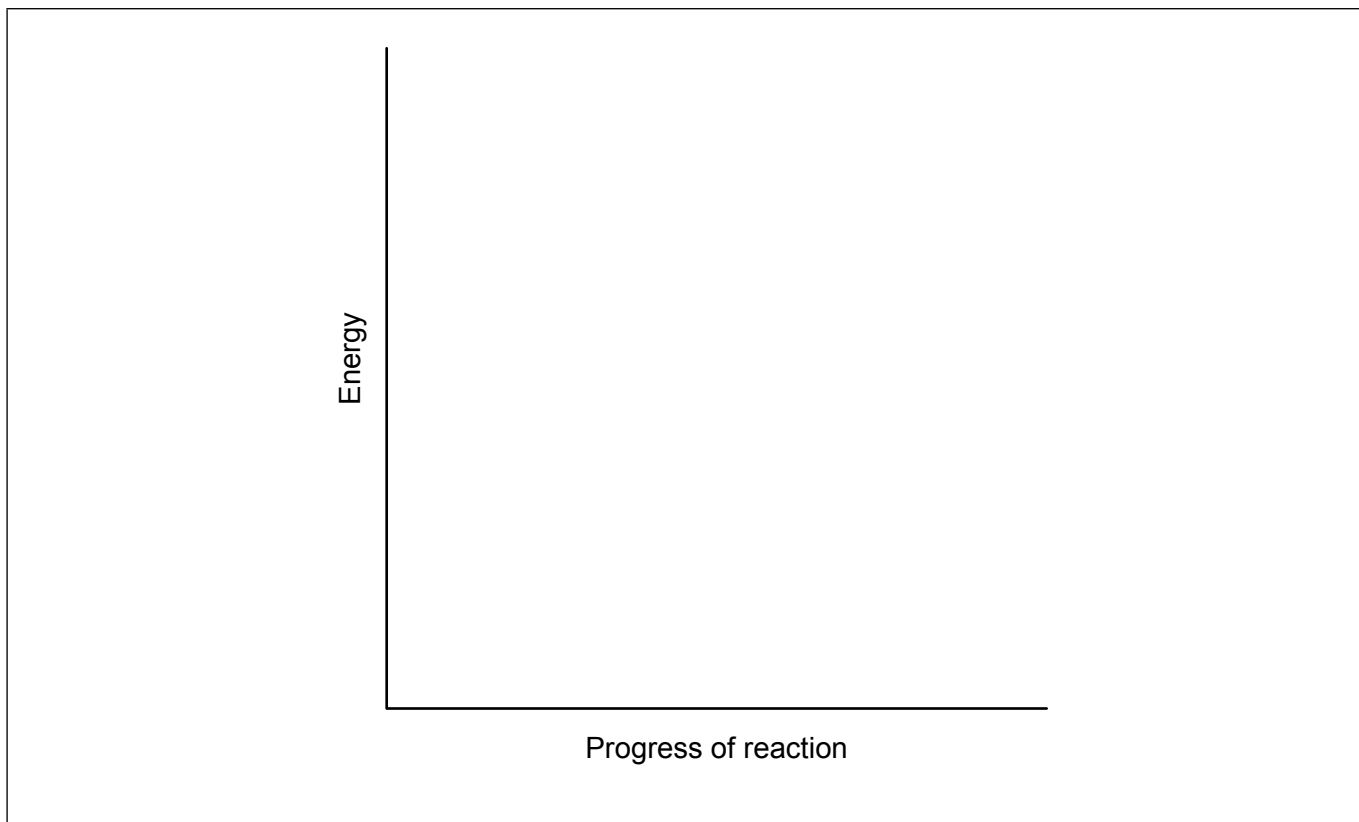
(c) Ethenone can be made by the thermal decomposition of propanone.



- (i) Calculate the standard enthalpy change for this reaction.  
Use  $\Delta H_f^\ominus$  ethenone =  $-87.2 \text{ kJ mol}^{-1}$  and section 12 of the data booklet. [2]

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- (ii) Sketch the potential energy diagram for the thermal decomposition of propanone from (c)(i). Use the axis given and indicate both the enthalpy of reaction and the activation energy. [2]



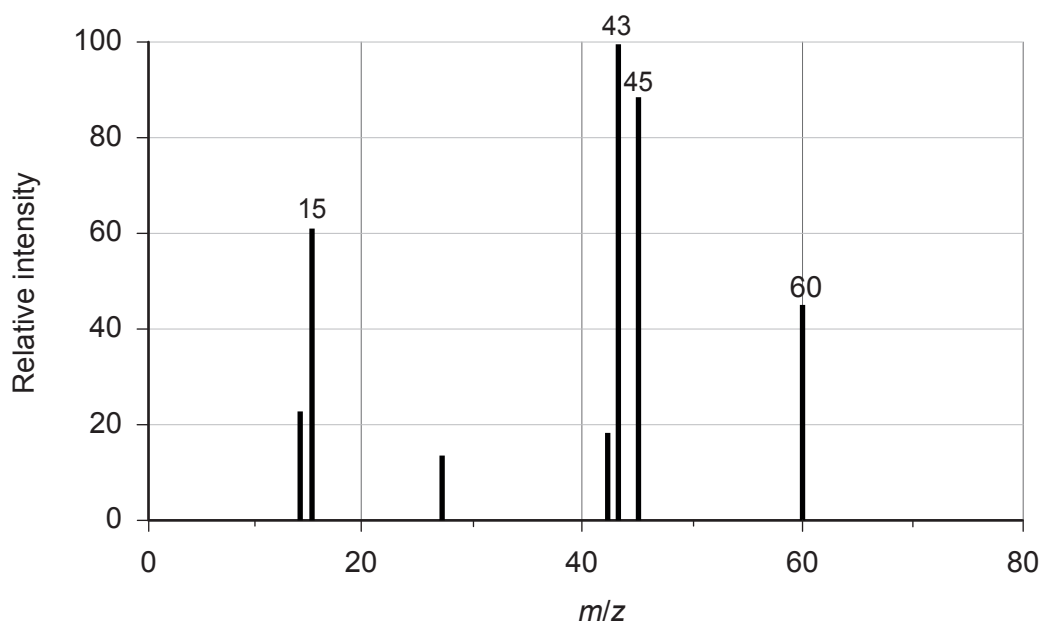
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**(Question 5 continued)**

- (d) Ethenone can be converted to compound **G**, which reacts slowly with metal oxides when in aqueous solution. The mass spectrum of **G** is shown.



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Deduce the identity of **G** giving **two** reasons based on the spectrum.

[3]

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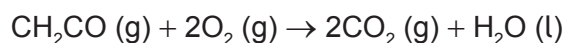
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- (e) 10.0 cm<sup>3</sup> of ethenone is mixed with 100 cm<sup>3</sup> of oxygen and burnt completely.



Determine the final volume of the gaseous mixture after the reaction mixture has returned to the original temperature and pressure.

[2]

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**(Question 5 continued)**

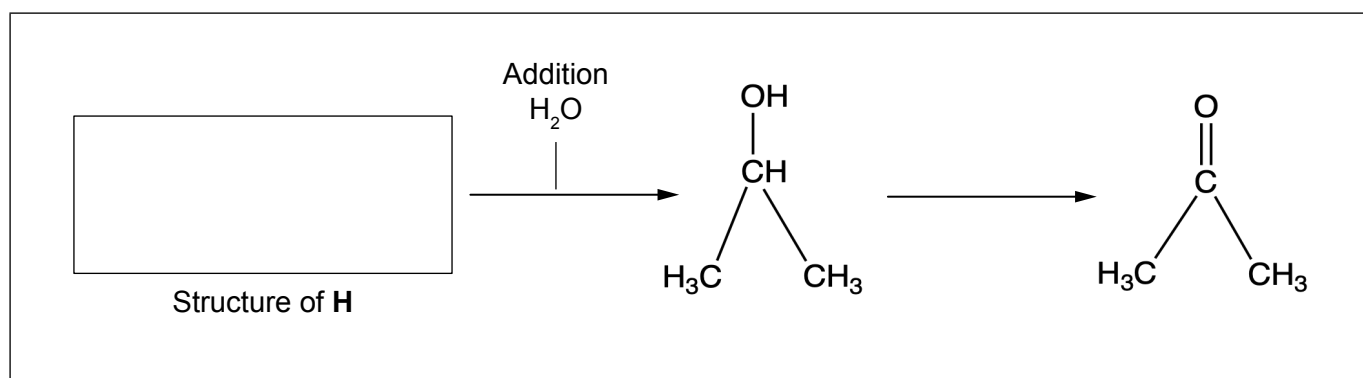
- (f) Calculations often assume that real gases behave like ideal gases.

State **one** reason why gases such as carbon dioxide and ethenone become less ideal at higher pressures.

[1]

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- (g) Propanone can be synthesised by the oxidation of propan-2-ol. Propan-2-ol can be synthesised from **H** by addition of water.



Draw the structure of **H**.

[1]

**(This question continues on the following page)**



**(Question 5 continued)**

(h) Butan-1-ol can be produced from 1-chlorobutane and sodium hydroxide.

(i) Identify the type of mechanism of this reaction. [1]

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(ii) Explain the mechanism of the reaction using curly arrows to represent the movement of electron pairs. [3]

(i) (i) Draw the stereoisomers of 2-chlorobutane using wedge-dash type representations. [1]

(ii) Outline how **two** enantiomers can be distinguished. [2]

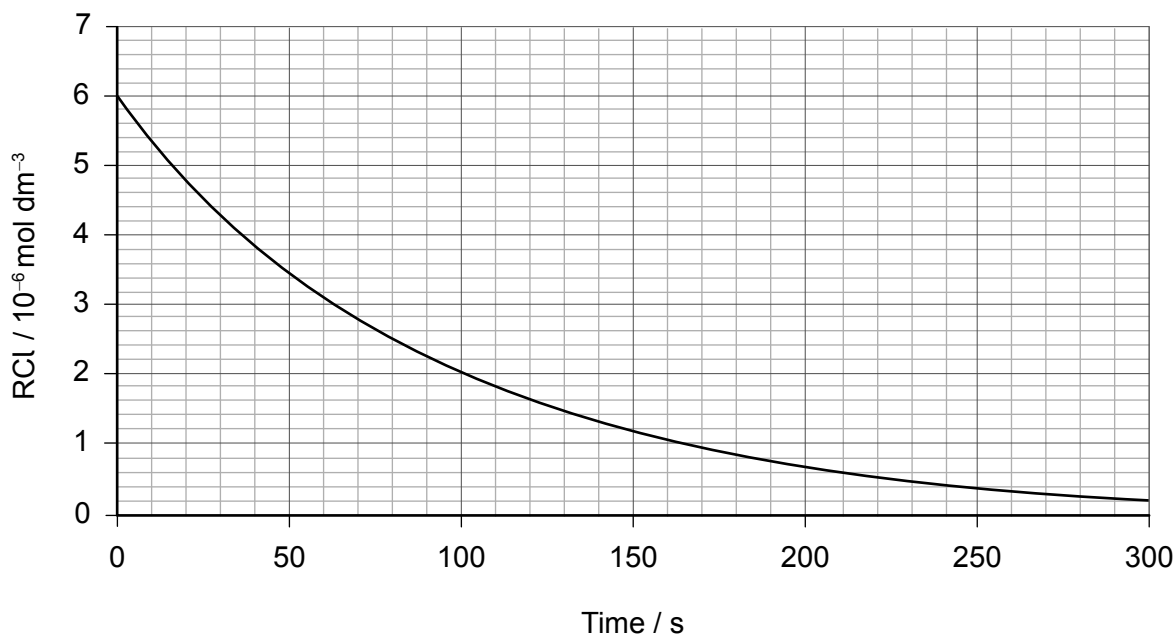
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**(Question 6 continued)**

A graph of [RCl] versus time for experiment 3 is shown.



- (i) Using the graph, determine the missing values from the table for **experiment 3**. Justify your answer.

[3]

Initial [RCl]: .....

.....

Initial rate: .....

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- (ii) Deduce the order of the reaction with respect to each of the reactants.

[2]

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**(Question 6 continued)**

(iii) Calculate the rate constant with units at this temperature, using the data from **experiment 1** in (a). [2]

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(b) Explain why increasing the temperature increases the rate of a chemical reaction. [2]

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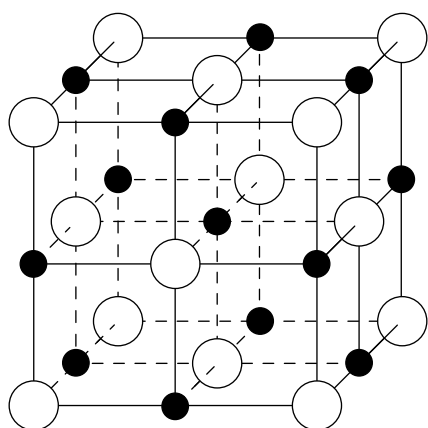
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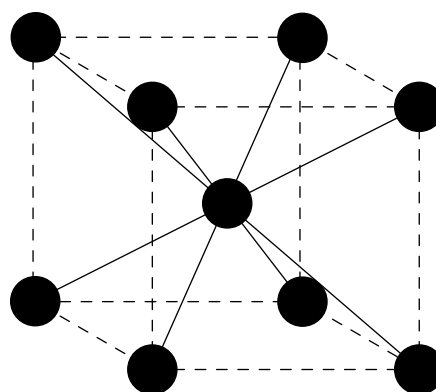
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7. The structures of sodium bromide and sodium metal are shown below.



Sodium bromide



Sodium metal

(a) Suggest a technique that could be used to determine these structures. [1]

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.....

(b) State and describe the bonding present in the two solid structures. [2]

NaBr: .....

Na: .....

(c) Write the half-equations for the formation of the products at the positive electrode (anode) and negative electrode (cathode) when molten sodium bromide is electrolysed. [2]

Positive electrode (anode): .....

Negative electrode (cathode): .....

(This question continues on the following page)



**(Question 7 continued)**

- (d) Determine the products formed at each electrode during the electrolysis of an aqueous solution of sodium bromide. Use section 24 in the data booklet. [2]

Positive electrode (anode): .....

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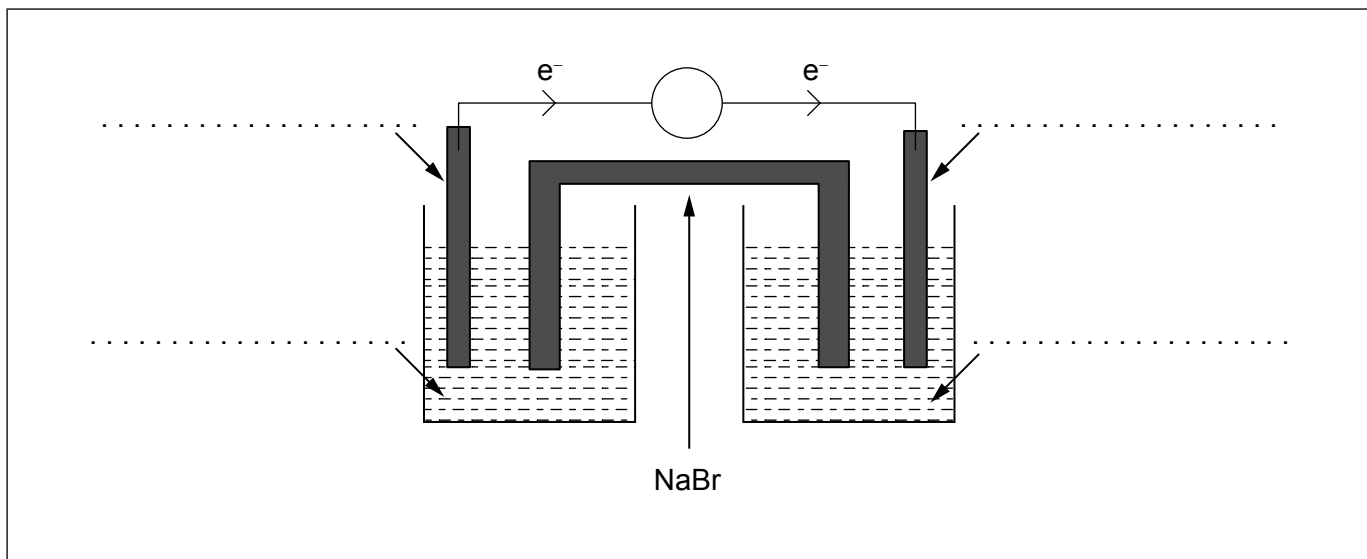
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Negative electrode (cathode): .....

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- (e) A sodium bromide solution can be used for a salt bridge in a voltaic cell. Annotate the diagram of the magnesium, Mg, and zinc, Zn, voltaic cell shown. Use section 24 of the data booklet. [2]



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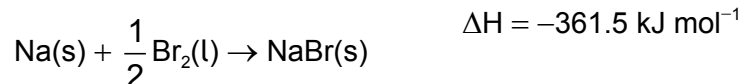




**(Question 7 continued)**

- (f) Determine the lattice enthalpy of sodium bromide using the data given below and sections 8 and 11 of the data booklet.

[3]



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- (g) Calculate the enthalpy of solution of sodium bromide. Use your answer from (f) and section 20 of the data booklet. (If you did not obtain an answer to (f), use a value of  $754 \text{ kJ mol}^{-1}$ , although this is not the correct answer).

[2]

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- (h) Predict, giving a reason, the result of reacting aqueous sodium bromide separately with iodine and chlorine.

[2]

Iodine: .....

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Chlorine: .....

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**References:**

- 1.(d) Irina Doroshenko et al. Infrared Absorption Spectra of Monohydric Alcohols. Open access article distributed under the Creative Commons Attribution License <https://creativecommons.org/licenses/by/4.0/>. Image adapted.
- 2.(e) Rowland, F.S., 2006. Stratospheric ozone depletion. *Philos Trans R Soc Lond B Biol Sci* 361(1469), pp. 769–790. [e-journal] Available at: <https://pubmed.ncbi.nlm.nih.gov/16627294/> [Accessed 12 April 2023]. Source adapted.
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