Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

9 May 2024

Zone A morning | **Zone B** morning | **Zone C** morning

Candidate session number

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]**.

2224 – 6208

24 pages

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]

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) A sample of the vapour of **A** at 200.0 °C, and 1.00×10^5 Pa, has a density of 2.544×10^3 g m^{-3}.

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

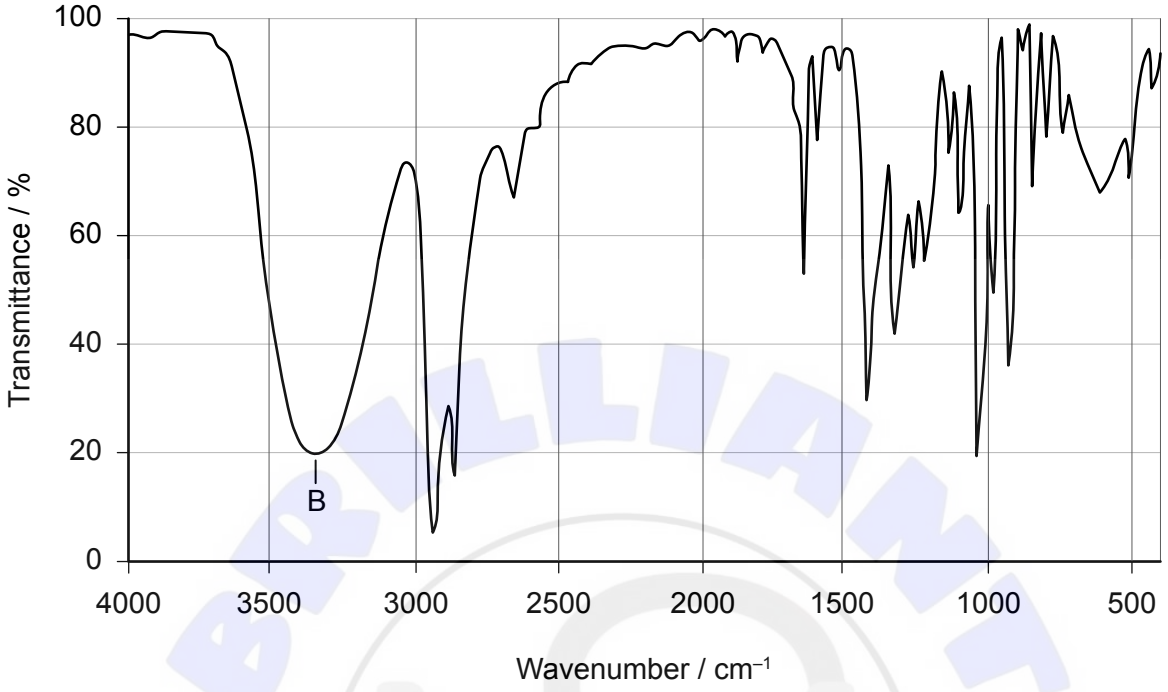
. . . . . .

. . . . . .

(This question continues on the following page)

(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]

. . . . . .

(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]

. . . . . .

. . . . . .

(This question continues on the following page)

(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.

$$O_3(g) \rightarrow O_2(g) + O(g)$$

(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]

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

(This question continues on the following page)

(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]

. . . . . .

. . . . . .

. . . . . .

(d) Explain the dependence of the dissociation of diatomic oxygen, O_2, and ozone, O_3, on the wavelength of UV radiation. [2]

. . . . . .

. . . . . .

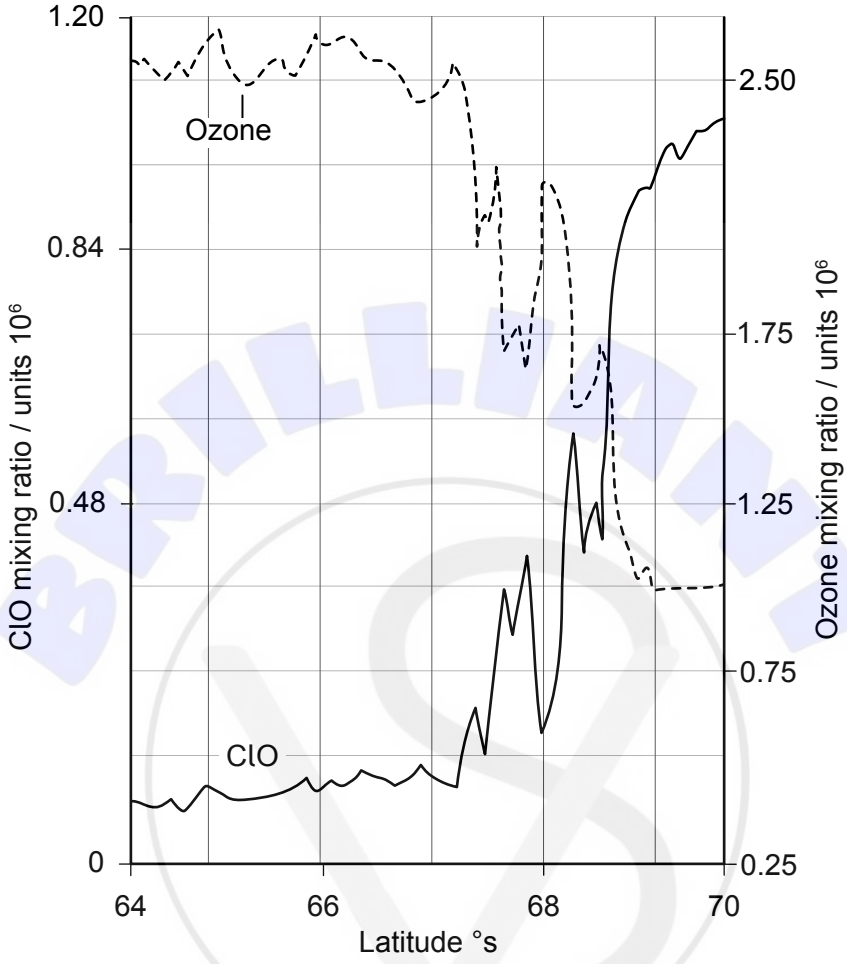
. . . . . .

. . . . . .

(This question continues on the following page)

(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]

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

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_2. [1]

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

(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^3.

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

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

(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 mol dm^{-3} aqueous solution of hydrocyanic acid. [3]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

4. The complex ion $[CuCl_4]^{2-}$ is formed when concentrated hydrochloric acid is added to an aqueous solution of hydrated copper(II) ions.

$$Cu^{2+}(aq) + 4Cl^{-}(aq) \rightleftharpoons [CuCl_4]^{2-}(aq)$$

Blue Yellow

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

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(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]

. . . . . .

. . . . . .

. . . . . .

(e) State, with a reason, the effect of adding aqueous silver nitrate, $AgNO_3(aq)$, on the position of this equilibrium. [1]

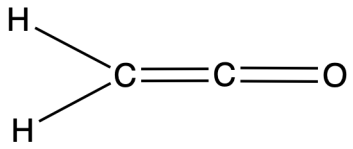
$$Ag^+(aq) + Cl^-(aq) \rightleftharpoons AgCl(s)$$

. . . . . .

. . . . . .

. . . . . .

5. Ethenone, CH_2CO, is used in the synthesis of pharmaceutical compounds.



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

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question 5 continued)

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

$$CH_3COCH_3\ (l) \rightarrow CH_2CO\ (g) + CH_4\ (g)$$

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

. . . . . .

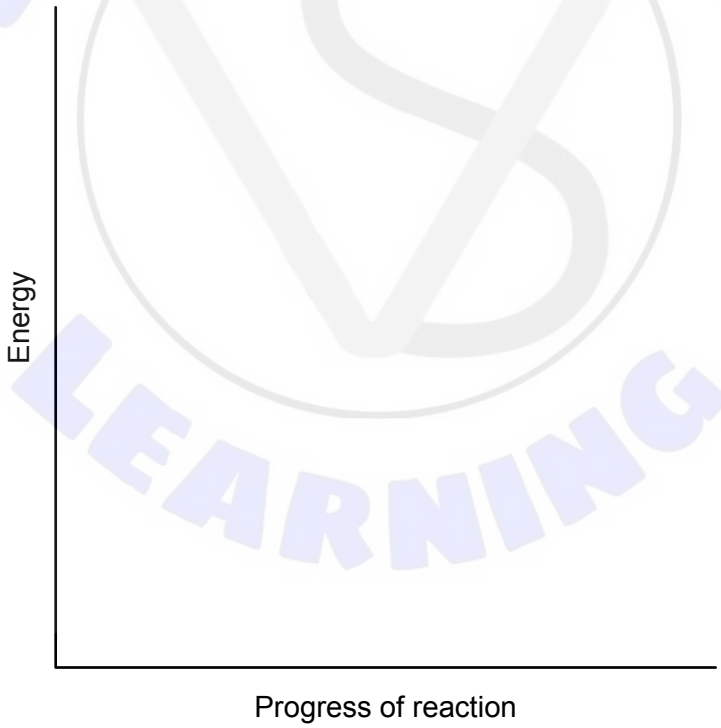
. . . . . .

. . . . . .

. . . . . .

. . . . . .

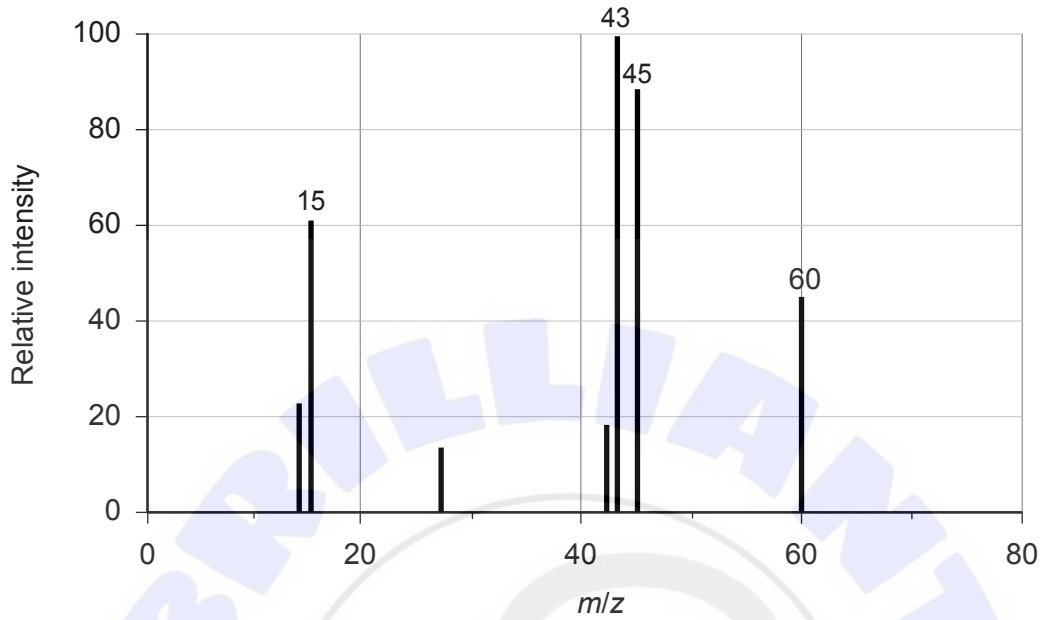
(ii) Sketch the potential energy diagram for the thermal decomposition of propanone from (c)(i). Use the axis given and indicate both the enthalpy of reaction and the activation energy. [2]



(This question continues on the following page)

(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.



[Source: Used with permission. © United States of America as represented by the Secretary of Commerce.]

Deduce the identity of **G** giving **two** reasons based on the spectrum. [3]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(e) 10.0 cm^3 of ethenone is mixed with 100 cm^3 of oxygen and burnt completely.

$$CH_2CO\ (g) + 2O_2\ (g) \rightarrow 2CO_2\ (g) + H_2O\ (l)$$

Determine the final volume of the gaseous mixture after the reaction mixture has returned to the original temperature and pressure. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question 5 continued)

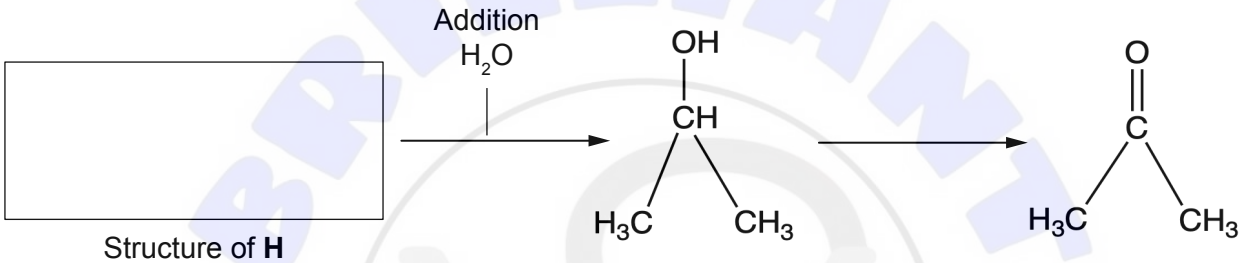
(f) Calculations often assume that real gases behave like ideal gases.

State **one** reason why gases such as carbon dioxide and ethenone become less ideal at higher pressures. [1]

. . . . . .

. . . . . .

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



Structure of **H**

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]

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

6. A student investigated the kinetics of the reaction between a dye, RCl, and aqueous sodium hydroxide. The dye has an intense blue colour that fades during the reaction.

The reaction can be represented by the following equation.

$$RCl\ (aq) + OH^-\ (aq) \rightarrow ROH\ (aq) + Cl^-\ (aq)$$

Blue Colourless

In a trial investigation the student mixed the solutions and measured the time for the colour to disappear in the reaction mixture shown in the table. The student calculated the rate of reaction using the following equation.

Calculated rate = [RCl] / time for colour to disappear

Initial concentration / mol dm^{-3}		**Time for colour to disappear / s**	**Calculated rate / mol dm^{-3} s^{-1}**
[RCl]	[OH^-]		
3.00×10^{-6}	2.00×10^{-2}	110	2.73×10^{-8}

(a) The student modified the procedure to measure the concentration of the dye using a spectrophotometer.

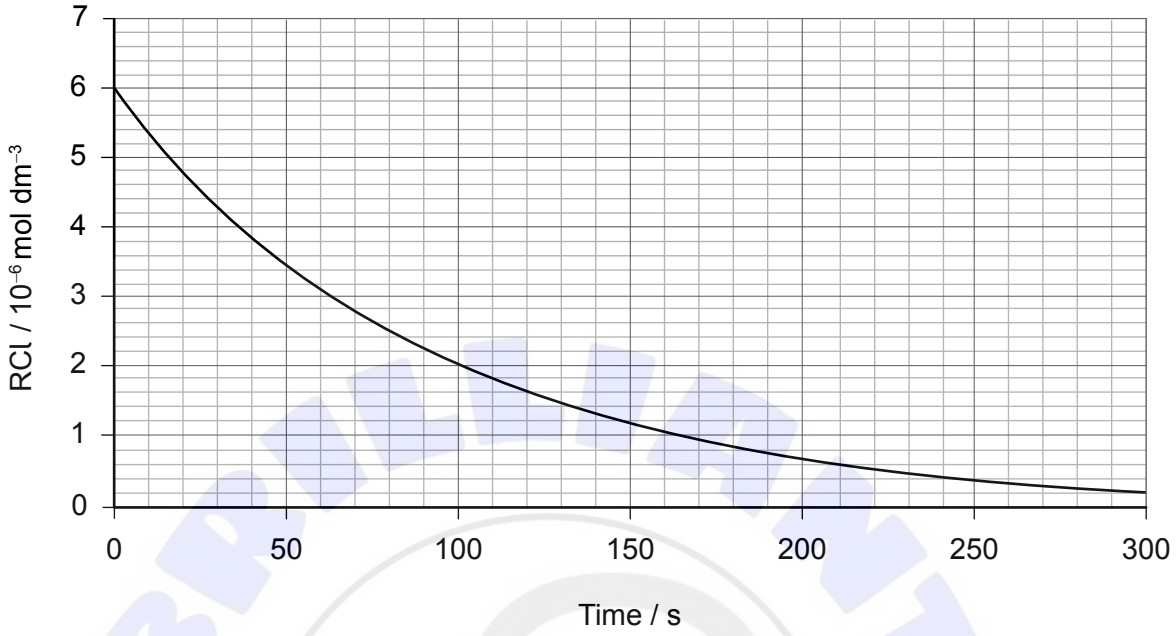
The concentration of the dye was measured continually by monitoring the light absorbed by the reaction mixture.

Experiment	**Initial concentration / mol dm^{-3}**		**Initial rate / mol dm^{-3} s^{-1}**
	[RCl]	**[OH^-]**	
1	3.00×10^{-6}	2.00×10^{-2}	3.20×10^{-8}
2	1.50×10^{-6}	1.00×10^{-2}	8.00×10^{-9}
3		2.00×10^{-2}	

(This question continues on the following page)

(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: . . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Deduce the order of the reaction with respect to each of the reactants. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question 6 continued)

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

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

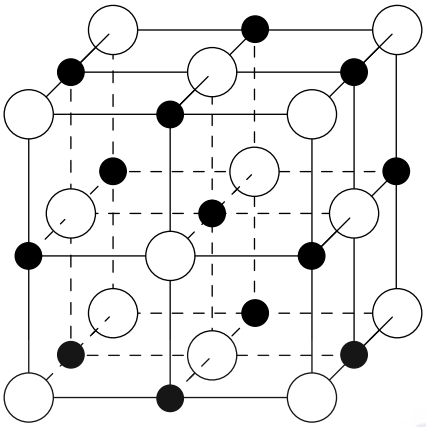
. . . . . .

. . . . . .

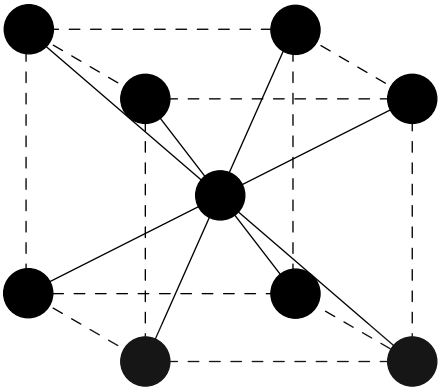
. . . . . .

. . . . . .

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]

. . . . . .

. . . . . .

(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): . . . . . .

. . . . . .

. . . . . .

. . . . . .

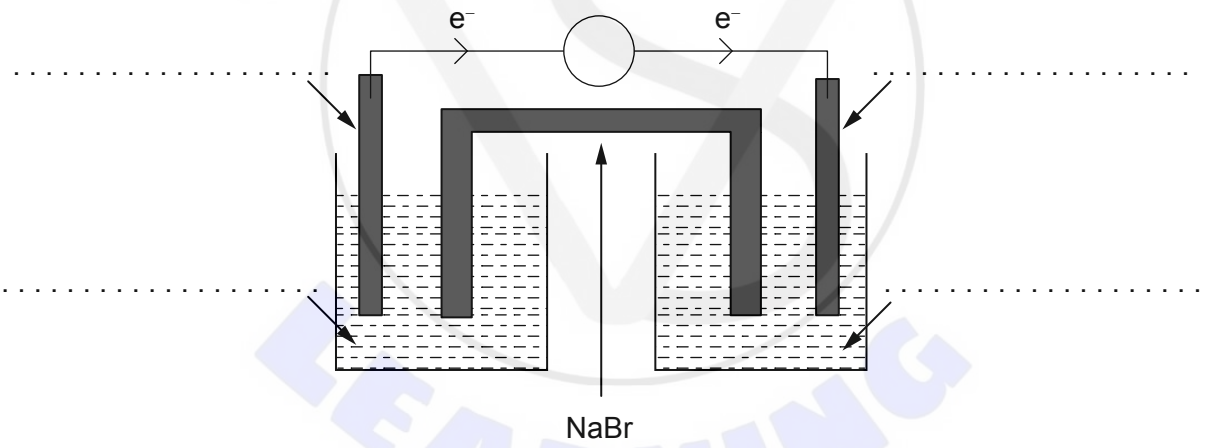
Negative electrode (cathode): . . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]



(This question continues on the following page)

(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]

$Na(s) \rightarrow Na(g)$ $\quad \Delta H = +107 \text{ kJ mol}^{-1}$

$Br_2(l) \rightarrow Br_2(g)$ $\quad \Delta H = +30 \text{ kJ mol}^{-1}$

$Na(s) + \frac{1}{2}Br_2(l) \rightarrow NaBr(s)$ $\quad \Delta H = -361.5 \text{ kJ mol}^{-1}$

. . . . . .
. . . . . .
. . . . . .
. . . . . .
. . . . . .
. . . . . .

(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 kJ mol^{-1}, although this is not the correct answer). [2]

. . . . . .
. . . . . .
. . . . . .
. . . . . .
. . . . . .

(h) Predict, giving a reason, the result of reacting aqueous sodium bromide separately with iodine and chlorine. [2]

Iodine: . . . . . .
. . . . . .
Chlorine: . . . . . .
. . . . . .

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.

5.(d) Used with permission. © United States of America as represented by the Secretary of Commerce.

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

Answers written on this page
will not be marked.

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

Answers written on this page
will not be marked.

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

Answers written on this page
will not be marked.