Name: ( )	Class: 24S0_____

RAFFLES INSTITUTION
2023 YEAR 5 PROMOTION EXAMINATION

Higher 2

CHEMISTRY 9729

28 September 2023

2 hours 30 minutes

Additional Materials: Multiple Choice Answer (OMR) Sheet
Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, 6-digit exam index number and civics tutorial group in the spaces provided on the OMR sheet and the cover sheets on **pages 1 and 19**. Shade your 6-digit exam index number on the OMR sheet.

This paper consists of three sections, **A**, **B** and **C**.

Section A (15 marks) consists of 15 multiple-choice questions.

Answer this section first. The OMR sheet will be collected after the **first 30 minutes**.
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 OMR sheet. Each correct answer will score one mark. A mark will not be deducted for a wrong answer. Any rough working should be done in the question paper.

Section B (35 marks) consists of 3 structured questions.

Answer **all** questions in the spaces provided in the question paper. If additional space is required, you should use the page at the end of the booklet for Section B (page 18). The question number must be clearly shown.

Section C (40 marks) consists of 3 free-response questions.

Answer **all** questions in the spaces provided in the question paper. If additional space is required, you should use the pages at the end of the booklet for Section C (pages 31 – 32). The question number must be clearly shown.

Write in dark blue or black pen. You may use a HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use Only	
B1	**/ 10**
B2	**/ 11**
B3	**/ 14**

Section A (15 marks)

For each question, there are four possible answers, **A**, **B**, **C**, and **D**. Choose the **one** you consider to be correct.

1 Methylamine, CH_3NH_2, is a colourless gas at room temperature.

The following equation shows the complete combustion of CH_3NH_2.

$$4CH_3NH_2 + 9O_2 \longrightarrow 4CO_2 + 2N_2 + 10H_2O$$

In an experiment, 20 cm^3 of CH_3NH_2 is mixed with 60 cm^3 of O_2 at room temperature and pressure. The mixture is sparked, resulting in the complete combustion of CH_3NH_2. The mixture is then cooled back to room temperature and pressure.

What is the final volume of the mixture?

A 30 cm^3
B 45 cm^3
C 90 cm^3
D 95 cm^3

2 Under alkaline conditions, manganate(VI) ions, MnO_4^{2-}, undergo disproportionation to form manganate(VII) ions, MnO_4^-, and one other manganese-containing product.

2 moles of MnO_4^- is formed when 3 moles of MnO_4^{2-} undergoes disproportionation.

What is the other manganese-containing product?

A $Mn(OH)_2$
B $Mn(OH)_3$
C MnO_2
D MnO_4^{3-}

3 *Tumbaga* is an alloy of copper and gold found in the pre-Columbian Mesoamerica civilisations. The information in the table was obtained by analysis of a sample of *tumbaga*.

mass number	63	65	197
% abundance	62	32	6

Which A_r value for copper is given by these figures?

A 59.9
B 63.5
C 63.7
D 71.7

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

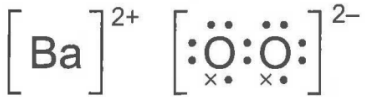
What do the ions $^{36}S^{2-}$ and $^{37}Cl^{-}$ have in common?

1 Both ions have the same nucleon number.
2 Both ions have an outer electronic configuration of $3s^2\ 3p^6$.
3 Both ions have more electrons than neutrons.

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

5 The peroxide ion contains two oxygen atoms joined by a single covalent bond. In this question, × represents an electron from Ba and • represents an electron from O.

Which dot-and-cross diagram shows the bonding present in barium peroxide?

A 

B 

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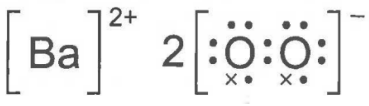
D 

6 Under which set of conditions is a gas least likely to show ideal gas behaviour?

	temperature / K	pressure / Pa
A	300	1.0×10^5
B	300	1.0×10^6
C	1000	1.0×10^5
D	1000	1.0×10^6

7 Hot air balloons have openings to allow for air flow in and out of the balloons. The pressure in the balloon is therefore the same as that of the surrounding atmosphere.

A partially inflated hot air balloon contains air with a volume of 5000 m^3 at 25 °C and 1 atm. The air in the balloon is then heated to 65 °C, causing the balloon to expand to a volume of 5500 m^3.

What is the ratio of the number of moles of air in the heated balloon to the initial number of moles of air in the balloon?

A 0.42 **B** 0.97 **C** 1.03 **D** 2.36

8 Phosgene, $COCl_2$, decomposes to form carbon monoxide, CO, and chlorine, Cl_2.

$$COCl_2(g) \rightleftharpoons CO(g) + Cl_2(g) \qquad K_c = a$$

Which expression, in terms of a, gives the equilibrium constant for the reaction below?

$$2CO(g) + 2Cl_2(g) \rightleftharpoons 2COCl_2(g)$$

A $\frac{1}{2a}$ **B** $-2a$ **C** a^2 **D** $\frac{1}{a^2}$

9 Methanoic acid, HCO_2H, is reacted with methanol, CH_3OH, which is contaminated with a small amount of ethanol, C_2H_5OH.

The following equilibria are established.

$HCO_2H(l) + CH_3OH(l) \rightleftharpoons HCO_2CH_3(l) + H_2O(l) \qquad K_c = K_1$

$HCO_2H(l) + C_2H_5OH(l) \rightleftharpoons HCO_2C_2H_5(l) + H_2O(l) \qquad K_c = K_2$

Which statements are correct?

1 The expression for K_1 is $\frac{[HCO_2CH_3][H_2O]}{[HCO_2H][CH_3OH]}$.

2 K_1 is much larger than K_2 because there is much more CH_3OH present than C_2H_5OH.

3 Adding $HCO_2C_2H_5$ to the equilibrium mixture will increase the amount of HCO_2CH_3.

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

10 The enthalpy changes of formation, $\Delta H_f^{\ominus}$, of both $PCl_3(l)$ and $PCl_5(l)$ are exothermic.

PCl_3 reacts with Cl_2 as shown below.

$$PCl_3(l) + Cl_2(g) \longrightarrow PCl_5(l) \qquad \Delta H_r^{\ominus} = -124 \text{ kJ mol}^{-1}$$

Which pair of statements is correct?

	statement 1	statement 2
A	$\Delta H_r^{\ominus}$ is more negative than $\Delta H_f^{\ominus}$ [$PCl_5(l)$].	$\Delta H_f^{\ominus}$ [$Cl_2(g)$] is zero.
B	$\Delta H_r^{\ominus}$ is more negative than $\Delta H_f^{\ominus}$ [$PCl_5(l)$].	$\Delta H_f^{\ominus}$ [$Cl_2(g)$] is positive.
C	$\Delta H_r^{\ominus}$ is less negative than $\Delta H_f^{\ominus}$ [$PCl_5(l)$].	$\Delta H_f^{\ominus}$ [$Cl_2(g)$] is zero.
D	$\Delta H_r^{\ominus}$ is less negative than $\Delta H_f^{\ominus}$ [$PCl_5(l)$].	$\Delta H_f^{\ominus}$ [$Cl_2(g)$] is negative.

11 Separate samples of 30 cm^3 of 0.10 mol dm^{-3} NaOH(aq) were added to each of the different acid solutions. The initial temperature of each solution was 25 °C before mixing.

experiment	acid	concentration / mol dm^{-3}	volume / cm^3
1	H_2SO_4	0.10	20
2	HCl	0.10	20
3	CH_3COOH	0.10	20

Which statement describes the increase in temperature that occurs on mixing each of these three acids separately with NaOH?

A The temperature rise in experiment 1 is 1.5 times of that in experiment 2.

B The temperature rise in experiment 1 is 1.5 times of that in experiment 3.

C The temperature rise in experiment 2 is 1.5 times of that in experiment 1.

D The temperature rise in experiment 3 is 1.5 times of that in experiment 2.

12 Radioactive decay is a first-order reaction. The rate of decay of a radioactive isotope decreases from 200 counts per minute to 25 counts per minute after 24 hours.

What is the half-life of the radioactive isotope?

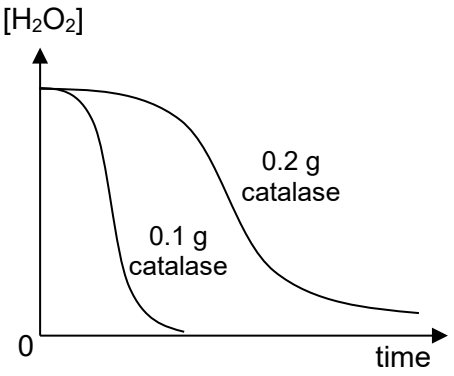
A 3 hours
B 6 hours
C 8 hours
D 12 hours

13 Catalase is an enzyme which catalyses the decomposition of H_2O_2. The decomposition is first order with respect to H_2O_2.

$$2H_2O_2(l) \longrightarrow 2H_2O(l) + O_2(g)$$

Which graphs are correct?

1



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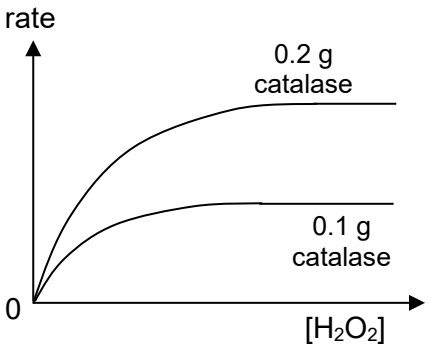

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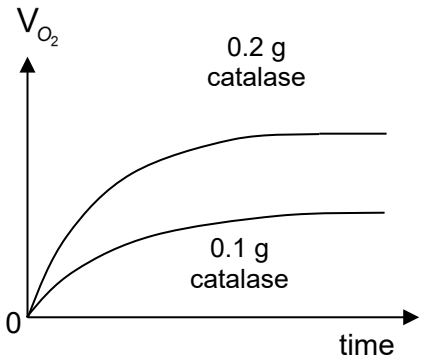

A 1 and 2 **B** 2 and 3 **C** 2 only **D** 3 only

14 Which statement is correct?

A A meso compound is optically active.

B Enantiomers interact in the same way with other chiral molecules.

C A racemic mixture consists of compounds with no plane of symmetry.

D A molecule with only one chiral centre does not rotate plane-polarised light.

15 The *cis-trans* isomers of hex-3-ene have different boiling points and standard enthalpy changes of combustion, $\Delta H_c^{\ominus}$.

Which row is correct?

	isomer with higher boiling point	isomer with more negative $\Delta H_c^{\ominus}$
A	*cis*-hex-3-ene	*cis*-hex-3-ene
B	*cis*-hex-3-ene	*trans*-hex-3-ene
C	*trans*-hex-3-ene	*cis*-hex-3-ene
D	*trans*-hex-3-ene	*trans*-hex-3-ene

[Turn Over

Section B (35 marks)

This section consists of **3** questions.
Answer **all** the questions in this section in the spaces provided.

1 **(a)** Draw a labelled diagram to show how the orbitals overlap to form the C=C bond in ethene. State the hybridisation of the carbon atom.

[2]

(b) Table 1.1 shows the boiling points of two compounds.

Table 1.1

compound	boiling point / °C
CH_3CH_3	−89
CH_2O	−19

Explain the difference in the boiling points of the compounds.

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……[2]

(c) State and explain, with reference to the Valence Shell Electron Pair Repulsion theory, the shape and bond angle around the nitrogen atom in CH_3NH_2.

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[Turn Over

(d) State and explain the general trend in first ionisation energy across Period 3 elements. Explain why aluminium does not follow this general trend.

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(e) **(i)** Draw a labelled diagram to show the significant force of attraction between two water molecules.

[1]

(ii) With reference to the structure of ice, explain why ice is less dense than water.

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……[1]

[Total: 10]

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2 (a) Sulfur trioxide can undergo thermal decomposition to form sulfur dioxide and oxygen.

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$$

An 8.01 g sample of SO_3 was placed in an evacuated container with a movable piston. As SO_3 began to decompose, the piston moved until the reaction reached equilibrium. The temperature and pressure were kept constant at 600 °C and 1.80 atm respectively throughout the experiment. The density of the gaseous mixture at equilibrium was 1.60 g dm^{-3}.

You may assume that the gases behave ideally under the given conditions.

(i) Write the expression for the equilibrium constant, K_p, for this reaction, and state its units.

[1]

(ii) Show, by calculation, that the volume of the gaseous mixture at equilibrium was 5.01 dm^3.

[1]

(iii) Determine the total amount of gas in the gaseous mixture at equilibrium.

[1]

(iv) Hence, or otherwise, calculate the percentage decomposition of SO_3 at 600 °C.

[2]

(b) The oxidation of SO_2 to SO_3 is a key step in sulfuric acid production.

equation 2.1 $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta H < 0$

Table 2.1 shows the equilibrium partial pressures for three experiments involving the above reaction. For experiments 2 and 3, the results were obtained after separate changes were made to the equilibrium mixture in experiment 1.

Table 2.1

	equilibrium partial pressure / atm		
experiment	SO_2	O_2	SO_3
1	0.38	0.44	0.12
2	0.28	2.72	0.22
3	0.28	0.39	0.22

Suggest, with reasoning, **<u>one</u>** change that was made to the equilibrium mixture in experiment 1 to result in the new equilibrium partial pressures in

(i) experiment 2,

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……[2]

(ii) experiment 3.

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……[2]

(iii) In the industrial manufacturing of sulfuric acid, the oxidation of SO_2 to SO_3 is conducted at 400 °C and 2 atm in the presence of V_2O_5 catalyst.

By considering the information given in equation 2.1, explain the industrial conditions used.

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……[2]

[Total: 11]

3 Hydrogen peroxide is available commercially for cleaning and disinfecting purposes.

FA 1 is a solution of hydrogen peroxide and **FA 2** is a standard solution of potassium manganate(VII). A student was asked to find the concentration of hydrogen peroxide in **FA 1** by titrating against **FA 2**.

She found that 10 drops of **FA 1**, when suitably acidified, required 82 drops of **FA 2** for complete reaction. She correctly decided that the concentration of hydrogen peroxide in **FA 1** was too high and needed to be diluted before titration against **FA 2**.

(a) Construct a balanced equation for the reaction between MnO_4^- ions and H_2O_2 under acidic conditions.

……..……..[1]

(b) Explain, with calculations, why the **FA 1** provided would have been unsuitable for use in the titration against **FA 2** in the burette. Assume that 25.0 cm^3 of **FA 1** is used for the titration.

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(c) Using the information given above, you are required to write a plan to determine the concentration of hydrogen peroxide in **FA 1**.

You may assume that you are provided with

- **FA 1**, hydrogen peroxide solution
- **FA 2**, potassium manganate(VII) solution of concentration 0.0200 mol dm^{-3}
- 1.0 mol dm^{-3} sulfuric acid
- the apparatus and chemicals normally found in a school or college laboratory.

In your plan you should give:

- details, including quantities, for the preparation of **FA 3**, the diluted hydrogen peroxide solution from **FA 1**
- the essential details of the titration procedure.

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....[6]

For examiner's use only

(d) In the student's titration, **v** cm^3 of **FA 1** was diluted to **w** cm^3 of **FA 3**. She found that 25.0 cm^3 of **FA 3** reacted with exactly **y** cm^3 of **FA 2** of concentration 0.0200 mol dm^{-3}. Show how her results may be used to determine the concentration of H_2O_2 in **FA 1**.

[2]

(e) The volume strength of a solution of hydrogen peroxide is the volume of O_2 (in dm^3) produced at standard temperature and pressure from 1 dm^3 of the solution.

The volume strength of a brand of commercial hydrogen peroxide is labelled as 13.4. Calculate the concentration of hydrogen peroxide in mol dm^{-3}.

[1]

(f) In the presence of the catalyst manganese(IV) oxide, MnO_2, hydrogen peroxide decomposes to oxygen gas.

$$2H_2O_2(aq) \longrightarrow 2H_2O(l) + O_2(g)$$

Another student suggested using a gas collection method to determine the concentration of hydrogen peroxide in **FA 1**, as shown in Fig. 3.1.

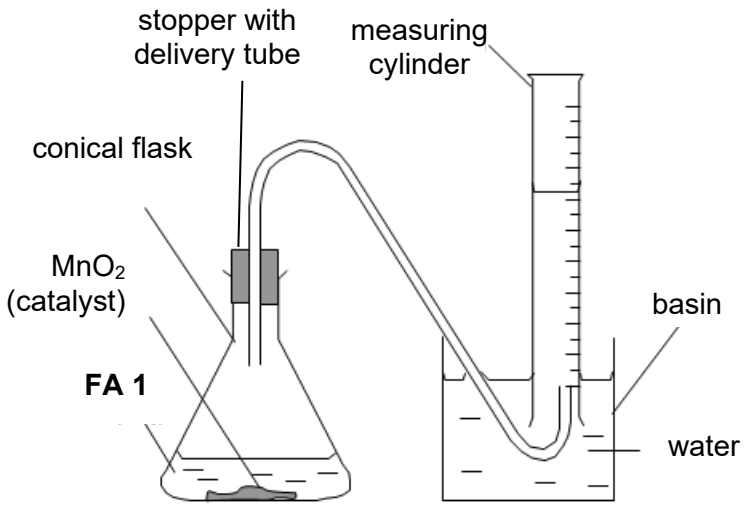

Fig. 3.1

Suggest a reason and explain why the concentration of hydrogen peroxide determined by this gas collection method would be lower than the actual concentration of hydrogen peroxide in **FA 1**.

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[Total: 14]

Additional answer space

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

RAFFLES INSTITUTION
2023 YEAR 5 PROMOTION EXAMINATION

Higher 2

CANDIDATE NAME

CLASS

INDEX NUMBER

CHEMISTRY 9729

28 September 2023

Section		Marks
A		**/ 15**
B	**B1**	**/ 10**
	B2	**/ 11**
	B3	**/ 14**
C	**C1**	**/ 11**
	C2	**/ 13**
	C3	**/ 16**
Total		**/ 90**
Percentage		**/100**
Penalty		
Overall		**/100**

[Turn Over

Section C (40 marks)

This section consists of **3** questions.
Answer **all** the questions in this section.

1 (a) Copper forms two types of oxides, copper(I) oxide, Cu_2O, and copper(II) oxide, CuO.

(i) Using the information in Table 1.1 and the *Data Booklet*, construct an energy level diagram and calculate the lattice energy of copper(I) oxide, Cu_2O.

Table 1.1

	$\Delta H^{\ominus}$ / kJ mol^{-1}
standard enthalpy change of atomisation of Cu(s)	+339
1st electron affinity of O(g)	−141
2nd electron affinity of O(g)	+791
standard enthalpy change of formation of Cu_2O(s)	−166

[4]

(ii) The lattice energies of Cu_2O and CuO are provided in Table 1.2.

Table 1.2

	experimental lattice energy / kJ mol^{-1}	theoretical lattice energy / kJ mol^{-1}
Cu_2O	from **(a)(i)**	−3190
CuO	x	−4050

Predict if the experimental lattice energy of CuO, x, will deviate more from its theoretical value, compared to Cu_2O. Explain your answer. [2]

(iii) Consider the following reaction:

$$Cu_2O(s) + H_2SO_4(aq) \longrightarrow CuSO_4(aq) + Cu(s) + H_2O(l)$$

When 2.86 g of solid Cu_2O was added to 60.0 cm^3 of dilute sulfuric acid of approximately 2 mol dm^{-3}, the temperature of the solution was raised by 8.9 K. Calculate the enthalpy change for the above reaction.

Assume that the specific heat capacity and density of the solution are 4.18 J g^{-1} K^{-1} and 1.00 g cm^{-3} respectively. [2]

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(b) When 2,3,4-trimethylpentane, C_8H_{18}, is combusted, it can form either CO_2 or CO, according to the following equations.

reaction 1 $\quad C_8H_{18}(l) + \frac{25}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$

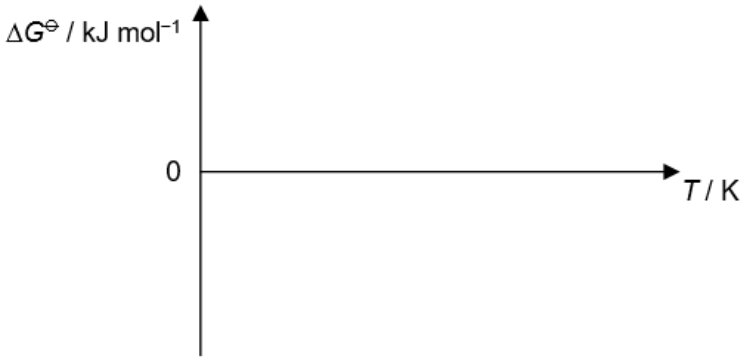
reaction 2 $\quad C_8H_{18}(l) + \frac{17}{2}O_2(g) \rightarrow 8CO(g) + 9H_2O(l)$

Table 1.3

reaction	$\Delta H^{\ominus}$ / kJ mol^{-1}	$\Delta S^{\ominus}$ / J mol^{-1} K^{-1}	$\Delta G^{\ominus}$ / kJ mol^{-1}
1	−5465	−553	−5300
2	−3261	+138	*y*

(i) Use the data in **Table 1.3** to calculate the value of *y*. [1]

(ii) On the axes provided below, sketch how $\Delta G^{\ominus}$ for each reaction 1 and 2 will vary with temperature. Label your sketches appropriately. Assume $\Delta H^{\ominus}$ and $\Delta S^{\ominus}$ remain constant in the temperature range of the sketch.



[2]

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[Total: 11]

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2 In the presence of an acid, BrO_3^- oxidises Br^- to Br_2.

$$BrO_3^- + 5Br^- + 6H^+ \longrightarrow 3Br_2 + 3H_2O$$

(a) Four experiments were conducted at 25 °C to determine the orders of reaction with respect to H^+ and Br^-.

The initial rate of this reaction is defined as the decrease in $[BrO_3^-]$ with respect to time at $t = 0$ s.

The results of experiments 1 and 2 were recorded in Table 2.1.

Table 2.1

experiment	$[BrO_3^-]$ / mol dm^{-3}	$[Br^-]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	initial rate of reaction / $\times 10^{-9}$ mol dm^{-3} s^{-1}
1	0.00100	0.100	0.00500	4.67
2	0.00100	0.100	0.0100	18.4

(i) Calculate the amount of Br_2 produced in experiment 1 in 5 s in a 1 dm^3 reaction mixture.

State one assumption that you have made. [2]

(ii) Determine the order of reaction with respect to H^+. [1]

The results of experiments 3 and 4 were recorded in Table 2.2.

Table 2.2

experiment	$[BrO_3^-]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	$[Br^-]$ / mol dm^{-3}	half-life of BrO_3^- / s
3	0.00100	0.240	0.400	16.1
4	0.00100	0.110	0.200	154.2

The order of reaction with respect to BrO_3^- is 1.

(iii) Show that the order of reaction with respect to Br^- is 1. [1]

(iv) Hence, write the rate equation for this reaction and state the units for the rate constant. [2]

(v) Calculate the initial rate of reaction of experiment 3. [1]

(vi) Calculate the final concentration of Br_2 produced in experiment 3.

Hence, sketch a graph of $[Br_2]$ against time. Label two half-lives on your graph. [3]

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(b) Explain, with the aid of a labelled Boltzmann Distribution curve, how an increase in temperature causes the rate of reaction to increase. [3]

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[Total: 13]

3 (a) (i) Suggest two reasons for the general unreactivity of alkanes. [2]

(ii) Outline the mechanism of the reaction between ethane and chlorine to form chloroethane. [3]

(iii) Hence, in terms of collision of particles, explain why using an excess of ethane relative to chlorine will minimise the formation of polychlorinated products. [1]

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(b) The use of excess ethane affects the purity of chloroethane formed and results in wastage of the unreacted ethane.

Fig. 3.1 shows the design of a chemical plant to produce pure chloroethane, C_2H_5Cl, and to recycle the excess ethane, C_2H_6.

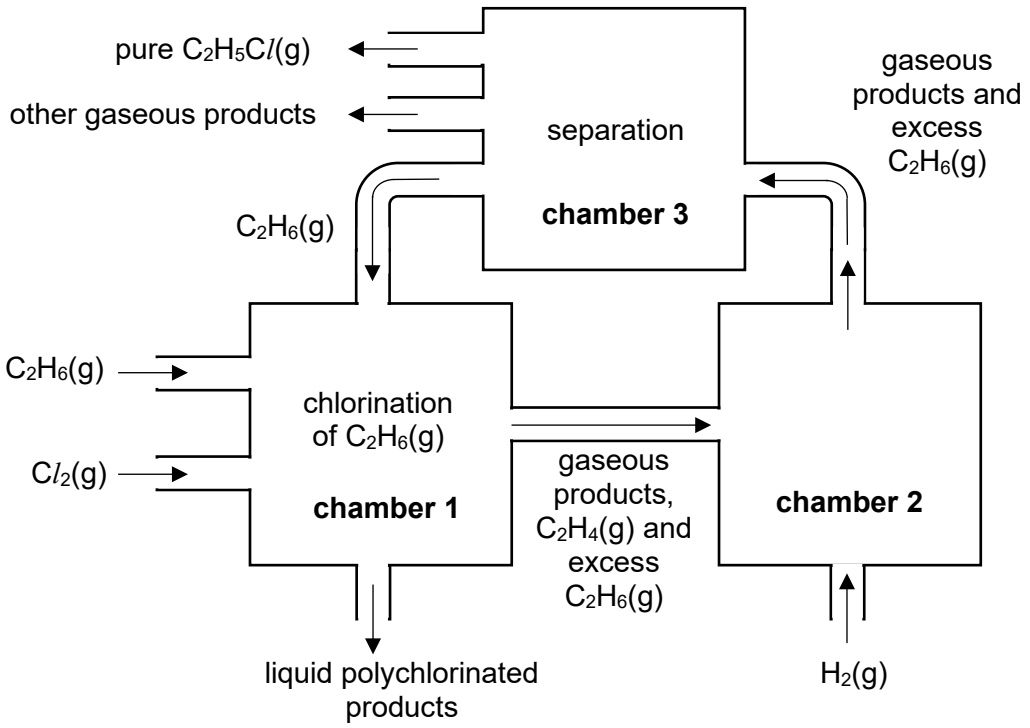
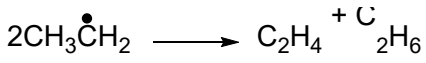


Fig. 3.1

During the chlorination of C_2H_6, some ethene, C_2H_4, is formed as a by-product, as shown in equation 1.

equation 1



C_2H_4 formed in chamber 1 is converted to C_2H_6 in chamber 2. The mixture is then separated in chamber 3 to give pure C_2H_5Cl. Excess C_2H_6 is recycled to produce more C_2H_5Cl in chamber 1.

(i) State the type of reaction in equation 1. [1]

(ii) On Fig. 3.2, draw curly arrows to show the mechanism for the reaction in equation 1.

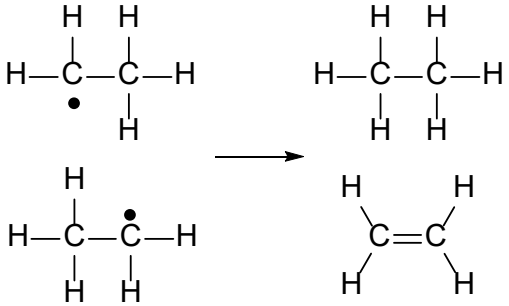


Fig. 3.2

[1]

(iii) State the reagents and conditions for the reaction in chamber 2. [1]

(iv) Suggest a suitable separation technique used in chamber 3 to obtain pure C_2H_5Cl and C_2H_6. [1]

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(c) Excess C_2H_5Cl reacts with bromine in the presence of ultraviolet (UV) light to form C_2H_4BrCl. One of the isomers of C_2H_4BrCl exhibits enantiomerism.

(i) Draw three-dimensional structures of the two enantiomers. [1]

(ii) Give the systematic name for the structure in **(c)(i)**. [1]

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(d) In this question, R can be H or any alkyl group.

An alkene can dimerise in the presence of UV light to form a cycloalkane, as shown in Fig. 3.3.

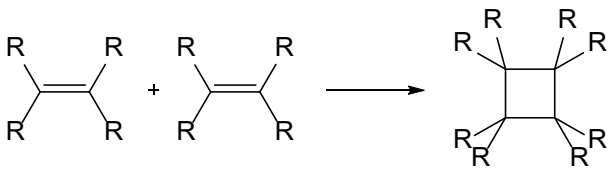

Fig. 3.3

Alkene **A** dimerises in the presence of UV light to form a mixture of compounds **B** and **C**, as shown in Fig. 3.4.

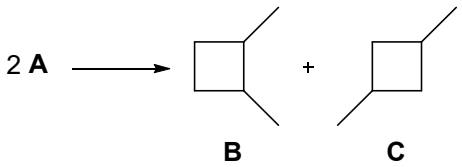

Fig. 3.4

(i) State the relationship between compounds **B** and **C**. [1]

(ii) Draw the displayed formula of alkene **A**. [1]

(iii) Draw the skeletal formulae of a pair of *cis-trans* isomers of compound **C**. [1]

(iv) Suggest the total number of stereoisomers that exist for compound **B**. [1]

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[Total: 16]

Additional answer space

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