RAFFLES INSTITUTION
2023 YEAR 6 TERM 3 COMMON TEST

Higher 2

CANDIDATE NAME

CLASS

INDEX NUMBER

CHEMISTRY 9729

26 June 2023

2 hours 45 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 21**. 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 (40 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 pages at the end of the booklet for Section B (pages 19 – 20). The question number must be clearly shown.

Section C (40 marks) consists of 4 free-response questions.

Answer both **C1** and **C2**, and only **one** of **C3 EITHER** or **C3 OR**.
Answers to this section are to be written 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 C (pages 36). The question number must be clearly shown.

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.

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.

Question	Marks
B1	/ 15
B2	/ 12
B3	/ 13

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 Which species is deflected to the greatest extent in an electric field?

A $^{0}_{-1}e$ **B** $^{1}_{1}H^{+}$ **C** $^{1}_{1}H^{-}$ **D** $^{4}_{2}He$

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

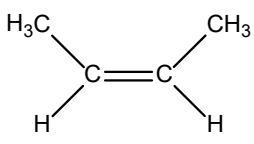
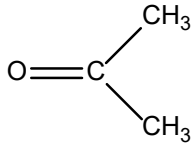
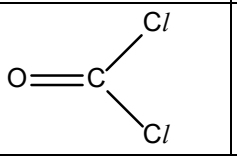
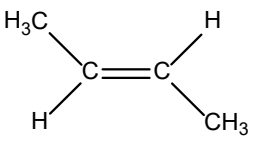
The table shows the fifth, sixth, seventh, eighth and ninth ionisation energies of an element in the third period.

	5th	6th	7th	8th	9th
ionisation energy / kJ mol^{-1}	6500	9400	11000	33600	38600

Which element has these ionisation energy values?

A P **B** S **C** C*l* **D** Ar

3 The table provides the structures of four compounds.

W	X	Y	Z
			

What is the correct order of increasing polarity?

A W → Z → X → Y

B W → Z → Y → X

C Z → W → X → Y

D Z → W → Y → X

4 In acidic solutions, BrO_3^- ions will slowly oxidise Br^- ions to Br_2.

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

The following results were obtained from investigations of this reaction.

experiment	$[BrO_3^-]$	$[Br^-]$	$[H^+]$	relative rate
1	0.10	0.10	0.30	2
2	0.10	0.20	0.15	1
3	0.10	0.20	0.30	4
4	0.20	0.20	0.30	8

What is the rate equation for this reaction?

A rate = $k[BrO_3^-][Br^-][H^+]^2$

B rate = $k[BrO_3^-][Br^-]^2[H^+]$

C rate = $k[BrO_3^-][Br^-]^2[H^+]^2$

D rate = $k[BrO_3^-]^2[Br^-][H^+]^2$

5 Hydrogen reacts with gaseous bromine to form hydrogen bromide.

$$H_2(g) + Br_2(g) \longrightarrow 2HBr(g)$$

The following mechanism involving free radicals has been proposed.

step 1 $Br_2 \longrightarrow 2Br\bullet$
step 2 $Br\bullet + H_2 \longrightarrow HBr + H\bullet$
step 3 $H\bullet + Br_2 \longrightarrow HBr + Br\bullet$
step 4 $HBr + H\bullet \longrightarrow H_2 + Br\bullet$
step 5 $2Br\bullet \longrightarrow Br_2$

The rate equation is

$$\text{rate} = \frac{k_1[H_2][Br_2]^{1.5}}{[Br_2] + k_2[HBr]}$$

Which statements about this reaction are correct?

1 The formation of HBr slows down the rate of the reaction.
2 Only steps 3 and 4 are propagation steps.
3 Doubling the concentration of Br_2 doubles the rate of reaction.

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

6 A 2 dm^3 buffer consisting of 2.0 mol dm^{-3} ethanoic acid and 1.0 mol dm^{-3} sodium ethanoate has a pH of 4.46.

What is the maximum mass of solid sodium hydroxide (in grams) that can be added if the pH is to be maintained below 4.60? [M_r of NaOH = 40.0]

A 9.0 **B** 18.0 **C** 48.1 **D** 96.2

7 Which statement is correct?

A K_a of water $\times$ K_b of water = K_w

B When an excess of a weak base is added to a strong acid, a buffer is formed.

C When an acidic buffer is diluted with a large volume of water, the pH does not change.

D When aqueous H_2SO_4 is titrated against aqueous NaOH, there are two regions of rapid pH change.

8 When dilute HC*l* is added to a solution of $AgNO_3$, a precipitate of AgC*l* is formed. When concentrated HC*l* is subsequently added, the white precipitate dissolves.

Which of the following statements best explains the observation?

A Ag^+ ions form a soluble complex with Cl^-.

B Ag^+ ions form a soluble complex with H^+.

C The precipitate dissolves due to the presence of the common ion Cl^-.

D AgC*l* is a Brønsted-Lowry base and reacts with H^+ in an acid-base reaction.

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9 Element R is in the third period (sodium to phosphorus) of the Periodic Table. The following four statements describe the properties of element R or its compounds.

Three statements are correct descriptions. One of the statements is not correct because it does not fit with the other three.

Which statement is **not** correct?

A Element R has the lowest first ionisation energy in the third period.

B The chloride of R reacts with water to give an acidic solution.

C The oxide of R is a solid at room temperature.

D The chloride of R reacts with excess water to form the oxide of R.

10 An octapeptide Q was obtained from the spike protein of SARS-CoV-2 virus. Partial hydrolysis yields the following dipeptide and tripeptide fragments.

Gly-Asn-Tyr Tyr-Leu-Tyr Tyr-Asn-Tyr Tyr-Arg

Which of the following is a possible sequence of Q?

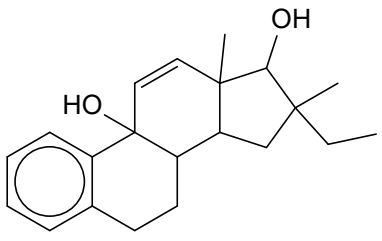
A Tyr-Asn-Tyr-Arg-Tyr-Leu-Gly-Asn

B Tyr-Leu-Tyr-Asn-Tyr-Arg-Gly-Asn

C Gly-Asn-Tyr-Arg-Tyr-Leu-Asn-Tyr

D Gly-Asn-Tyr-Asn-Tyr-Leu-Tyr-Arg

11 Compound A reacted with excess hot concentrated H_2SO_4 to give compound B.

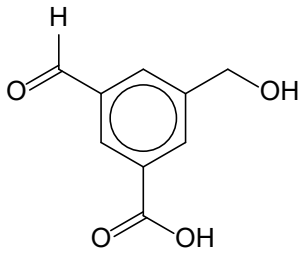


compound A

How many chiral centres does compound B have?

A 2 **B** 3 **C** 4 **D** 5

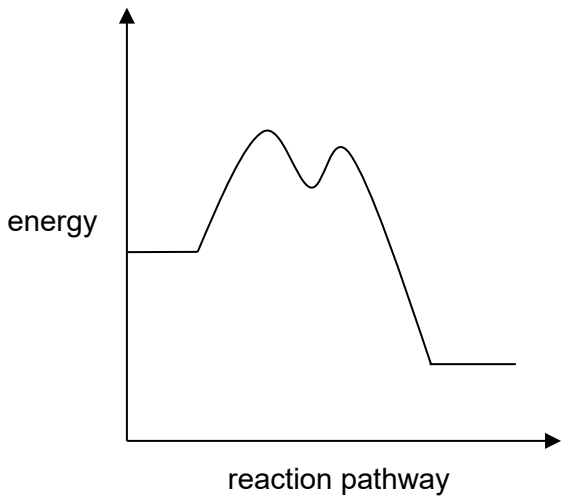
12 Which reagents and conditions will convert the compound below to a product containing three identical substituents on benzene?



1 $K_2Cr_2O_7$(aq), H_2SO_4(aq), heat
2 $LiAlH_4$ in dry ether
3 $NaBH_4$

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

13



Which reactions can be represented by the above diagram?

1 $(CH_3)_3CCl + KOH \longrightarrow (CH_3)_3COH + KCl$
2 $CH_3CH_2Cl + KOH \longrightarrow CH_3CH_2OH + KCl$
3 $CH_3CHO + HCN \longrightarrow CH_3CH(OH)CN$

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

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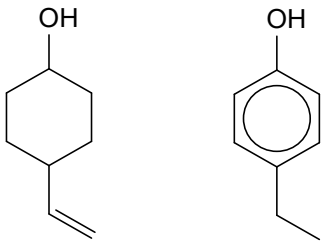
14 Which reagents give rise to a colour change with one of the compounds shown below, but not with the other?



1 $KMnO_4(aq)$, $H_2SO_4(aq)$, heat

2 $K_2Cr_2O_7(aq)$, $H_2SO_4(aq)$, heat

3 neutral $FeCl_3(aq)$

4 $Br_2(aq)$

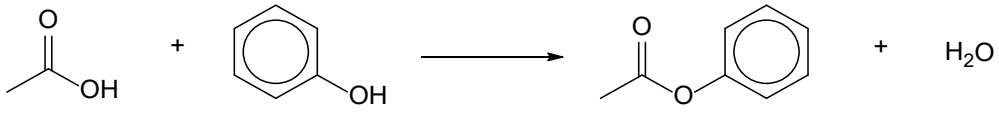
A 1, 2 and 3

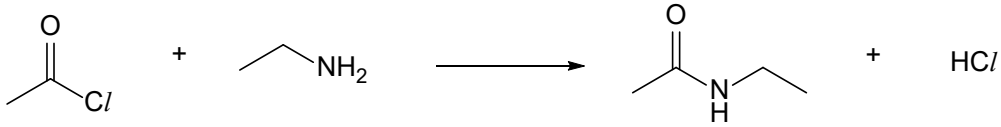
B 2, 3 and 4

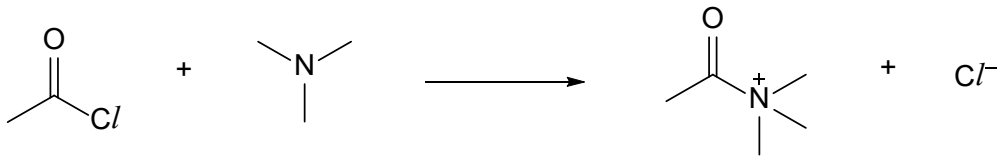
C 1 and 4 only

D 2 and 3 only

15 Which reactions are correct?

1 

2 

3 

A 1 and 3 only

B 2 only

C 1 and 2 only

D 1, 2 and 3

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Section B (40 marks)

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

1 **(a)** **X** is a gas which undergoes decomposition to form two products **Y** and **Z**.

0.010 mol of **X** was placed in a 1 dm^3 evacuated vessel at constant temperature and the concentrations of **X**, **Y** and **Z** were determined at regular time intervals. The results are shown in Fig. 1.1.

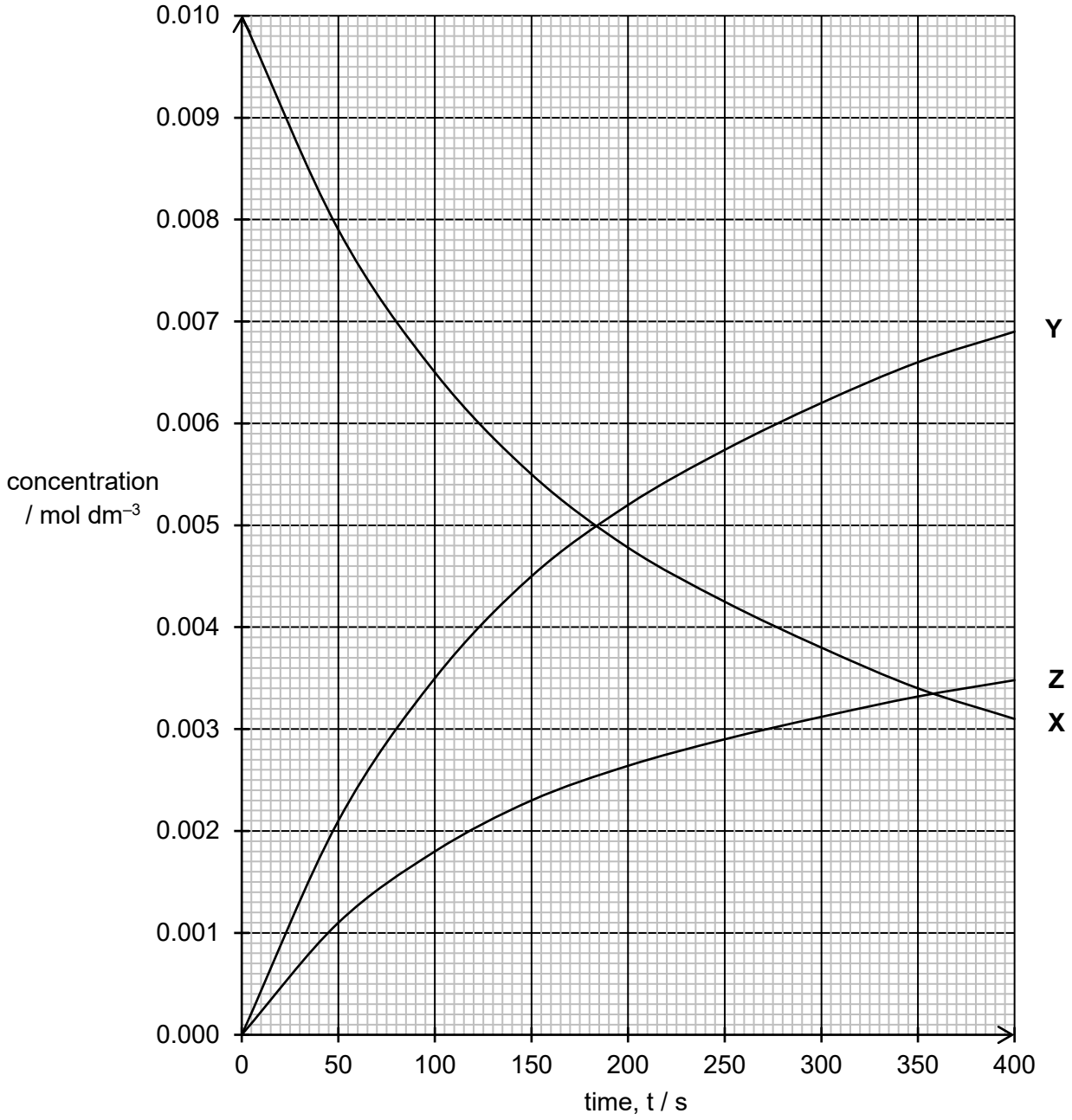

Fig. 1.1

(i) Explain what is meant by *half-life of a reaction*.

……

……[1]

(ii) By determining appropriate half-life values, deduce if the order of reaction with respect to **X** is one.

You should show all your working and draw any construction lines clearly on the graph.

[3]

The gradients at t = 150 s were determined for two of the graphs and their values are given in Table 1.1.

Table 1.1

graph	value of gradient
X	-1.7×10^{-5}
Z	7.8×10^{-6}

(iii) State the rate of decomposition of **X** at t = 150 s, including its units.

…….....[1]

(iv) By constructing a suitable tangent and using the information provided in Table 1.1, deduce the balanced equation for the decomposition of **X** to form **Y** and **Z**.

[2]

(b) The benzenediazonium cation decomposes according to the following equation.

$$C_6H_5N_2^+ + H_2O \longrightarrow C_6H_5OH + H^+ + N_2$$

The order of reaction with respect to $C_6H_5N_2^+$ can be determined by a series of experiments using the 'clock' method.

This is done by measuring the time taken for the **same** volume of nitrogen to be collected from different initial $C_6H_5N_2^+$ concentrations, followed by graphically analysing the results. A suitable volume of nitrogen needs to be collected for each experiment such that a good approximation of the initial rate of reaction can be achieved.

$C_6H_5N_2^+$ is generally stable at 5 °C and below, but decomposes above 10 °C.

In Experiment 1, when 20 cm^3 of a 0.20 mol dm^{-3} $C_6H_5N_2^+$ solution at around 5 °C was mixed with 10 cm^3 of distilled water at 50 °C, the temperature of the mixture rose to approximately 20 °C, allowing the decomposition of $C_6H_5N_2^+$ to occur.

(i) Calculate the volume of nitrogen, in cm^3, that would be produced at r.t.p. should the reaction in Experiment 1 be allowed to proceed to completion.

[1]

(ii) Plan a procedure to determine the order of reaction with respect to $C_6H_5N_2^+$ for its decomposition, including the volumes used in Experiment 1.

You may assume you are provided with:

- 100 cm^3 of 0.20 mol dm^{-3} $C_6H_5N_2^+$ solution, maintained at 0 to 5 °C,
- hot distilled water, maintained at 50 °C,
- cold distilled water, maintained at 5 °C,
- stopwatch,
- the equipment normally found in a school or college laboratory.

In your plan you should include brief details of:

- the apparatus you would use,
- the quantities you would use,
- the procedure you would follow,
- a fully labelled diagram of the set-up you would use,
- the volume of nitrogen you would collect for the experiments, with justification,
- how you would estimate the initial rate for each experiment,
- the graph you would plot and how you would use it to determine the order of reaction.

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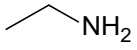
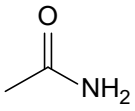
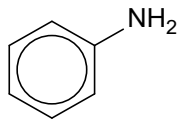
2 **(a)** Arrange the following compounds in increasing pK_b values. Explain your answer.



ethylamine



ethanamide



phenylamine

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……[3]

(b) When 1-bromopropane is heated with amines, a nucleophilic substitution reaction occurs.

(i) Suggest the rate equation for this reaction. You may use RNH_2 to represent the amine.

……[1]

Three amines were separately reacted with 1-bromopropane and the following data was obtained.

amine	relative rate
ethylamine	1
diethylamine	3
triethylamine	2

Explain the differences in the rates of reaction of 1-bromopropane with

(ii) ethylamine and diethylamine,

……

……

……

……[1]

(iii) diethylamine and triethylamine.

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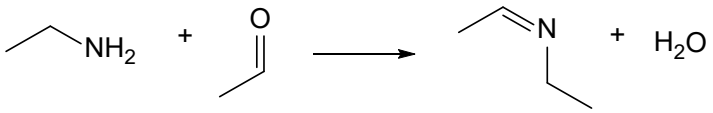
……[1]

(c) Ethylamine can react with ethanal to form an imine, an organic compound with a C=N double bond.



imine

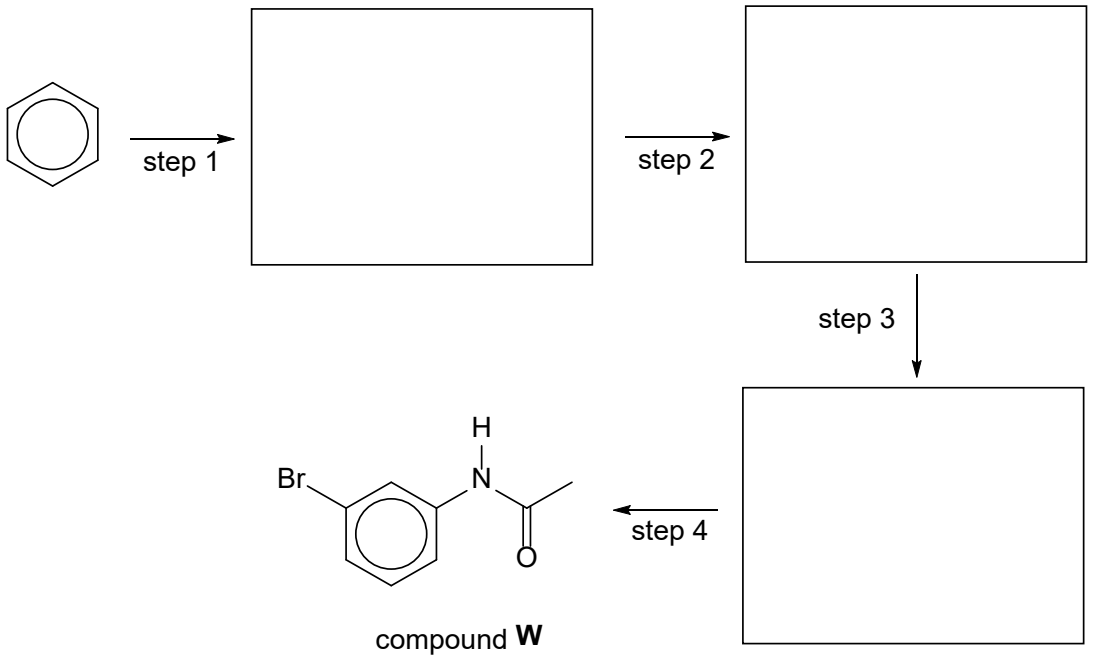
(i) State the type of reaction.

……[1]

(ii) The imine product exists as a pair of stereoisomers. Draw diagrams to illustrate the stereoisomerism.

[1]

(d) Propose a four-step synthesis of compound **W** from benzene. Show all reagents and conditions, and intermediate structures.



compound **W**

Reagents and conditions:

step 1: ……

step 2: ……

step 3: ……

step 4: ……

[4]

[Total: 12]

3 Electrochemistry is crucial for sustainable energy systems as it enables the creation of efficient energy storage, which reduces reliance on fossil fuels and integrates renewable energy sources.

(a) Fig. 3.1 shows a fuel cell comprising half-cells A and B being used to provide energy for an electrolysis reaction in cell C, under standard conditions.

Methanol is oxidised at the anode of the fuel cell. The half-equation of the oxidation of methanol is given below.

$$CH_3OH + 6OH^- \longrightarrow 5H_2O + 6e^- + CO_2$$

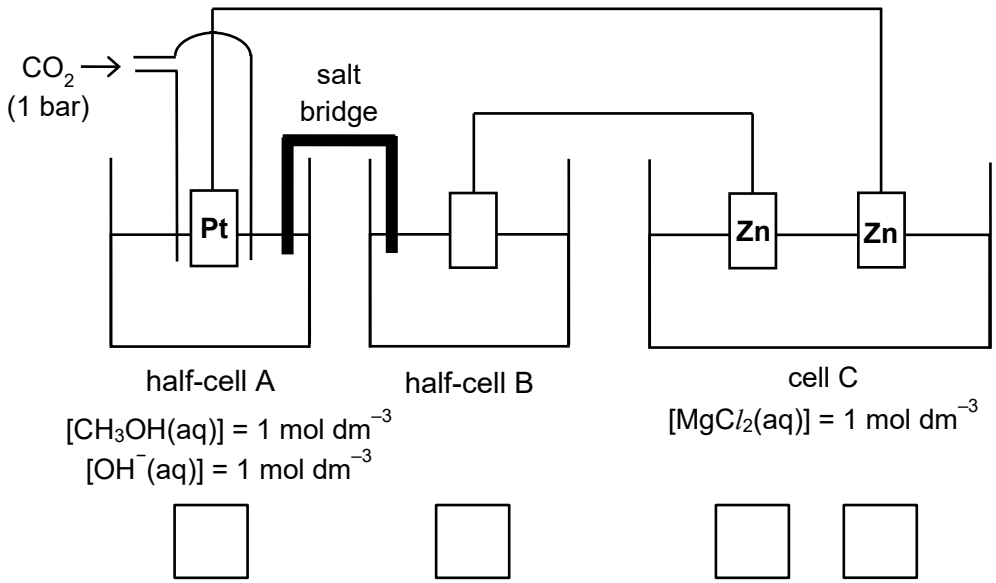


Fig. 3.1

(i) On Fig. 3.1, assign the polarity of the electrodes in the boxes provided and indicate the direction of electron flow. [2]

(ii) *Use of the Data Booklet is relevant to this question.*

Predict, with reasons, the product(s) formed at the anode of electrolytic cell C.

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……[2]

(iii) In electrolytic cell C, water is reduced at the cathode.

Describe the observations at the cathode.

……...

……[1]

For electrolysis to occur, the $E^{\ominus}_{cell}$ of the fuel cell must be greater than the magnitude of $E^{\ominus}_{cell}$ of the electrolytic cell.

The half-equation for the reaction involving methanol is given below.

equation 1 $5H_2O + 6e^- + CO_2 \rightleftharpoons CH_3OH + 6OH^-$ $E^{\ominus} = +0.03$ V

(iv) Determine the minimum standard electrode potential of the reaction in half-cell B for the electrolysis in cell C to occur.

[1]

(v) By considering half-cell A and using the concept of Le Chatelier's Principle, explain why the fuel cell is not able to provide energy for the electrolysis reaction after a period of time.

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……[2]

(vi) The charge required for the electrolysis reaction is 3×10^5 C. Calculate the theoretical minimum volume of methanol solution required.

[2]

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(b) Batteries play a crucial role in sustainability as they enable the widespread adoption of renewable energy sources and electric vehicles.

Table 3.1 contains information about different types of batteries. Energy density is a measure of the amount of energy that can be stored per unit mass, measured in watt-hour per kilogram (Wh kg^{-1}). The number of charge cycles is the number of times a battery can be charged until battery failure.

Table 3.1

type of battery	energy density / Wh kg^{-1}	cost of raw materials	toxicity of materials	number of charge cycles
lithium-ion	100-265	high	contains toxic electrolytes and heavy metals such as cobalt and nickel	300 to 500
lead-acid	25-35	low	contains toxic chemicals such as lead and sulfuric acid	500 to 1000
nickel-metal hydride	70-100	moderate	contains toxic electrolytes and heavy metals such as cobalt and nickel, but is less toxic than lithium-ion batteries	700 to 1000

A manufacturer would like to design an electric vehicle that is environmentally sustainable.

By considering at least two factors from Table 3.1, evaluate the best choice of battery for electric vehicles for the manufacturer.

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……[2]

(c) Al_2O_3 is commonly used in batteries as a coating for the separator material, which separates the anode and cathode.

However, Al_2O_3 is not a suitable separator material in highly acidic or alkaline solutions.

Write an equation for the reaction between Al_2O_3 and concentrated NaOH solution.

……..…… [1]

[Total: 13]

Additional answer space

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

RAFFLES INSTITUTION
2023 YEAR 6 TERM 3 COMMON TEST

Higher 2

C

CANDIDATE NAME

CLASS

INDEX NUMBER

For Examiner's Use Only

Section		Marks
A		**/ 15**
B	**B1**	**/ 15**
	B2	**/ 12**
	B3	**/ 13**
C Answer **both C1** and **C2**. **Circle the question (C3 EITHER or C3 OR)** you have answered.	**C1**	**/ 10**
	C2	**/ 20**
	C3 EITHER	**/ 10**
	C3 OR	**/ 10**
Total		**/ 95**
Percentage		**/ 100**
Penalty		
Overall		**/ 100**
Grade		

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Section C (40 marks)

Answer both C1 and C2, and only one of C3 EITHER or C3 OR in this section.
Answers to this section are to be written in the spaces provided in the question paper.

1 **(a)** Calcium hydroxide is a sparingly soluble ionic compound.

(i) Write an expression for the K_{sp} of calcium hydroxide. [1]

The K_{sp} of calcium hydroxide may be determined using a titrimetric method.

In a particular experiment, an excess of solid calcium hydroxide was shaken with 0.010 mol dm^{-3} aqueous sodium hydroxide and allowed to reach equilibrium at 298 K. The mixture was filtered. 25.0 cm^3 of the filtrate was completely neutralised by 20.0 cm^3 of 0.050 mol dm^{-3} hydrochloric acid.

(ii) Calculate the molar concentration of OH^- in the filtrate. [1]

(iii) Calculate the value of the K_{sp} of calcium hydroxide. [2]

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(b) Table 1.1 shows the pH and concentration of hydroxide ions in a saturated solution of calcium hydroxide at different temperatures.

Table 1.1

temperature / K	pH	$[OH^-]$ / mol dm^{-3}
298	12.3	2.00×10^{-2}
305	11.7	x

(i) Given that $K_w = 1.70 \times 10^{-14}$ mol^2 dm^{-6} at 305 K, calculate the value of x. [1]

(ii) Explain whether the dissolution of calcium hydroxide in water is exothermic or endothermic. [2]

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(c) The numerical values of the solubility products of some Group 2 fluorides, at 298 K, are given in the Table 1.2.

Table 1.2

	numerical values of K_{sp}
BaF_2	1.84×10^{-7}
CaF_2	3.45×10^{-11}

A student accidentally mixed 25.0 cm^3 of 0.100 mol dm^{-3} $CaCl_2$ solution with 25.0 cm^3 of 0.100 mol dm^{-3} $BaCl_2$ solution in the laboratory. To separate the two metal ions, he added just enough solid KF to precipitate the maximum amount of CaF_2 from the mixture, without precipitating BaF_2.

(i) Calculate the molar concentration of F^- in the solution at the end of the separation. [2]

(ii) Calculate the molar concentration of Ca^{2+} remaining in the solution. [1]

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2 **(a)** Describe and explain the relative acidities of ethanol, ethanoic acid and phenol. [3]

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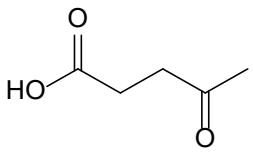
(b) Levulinic acid, $C_5H_8O_3$, is a weak acid with a pK_a of 4.65.



levulinic acid

(i) Explain why pentanoic acid is less acidic than levulinic acid. [1]

(ii) Write a chemical equation to explain why a solution of sodium levulinate, $C_5H_7O_3Na$, is basic. [1]

(iii) Calculate the pH of a 0.200 mol dm^{-3} solution of sodium levulinate, $C_5H_7O_3Na$. [2]

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(c) Carbonyl compounds can react with alcohols via a nucleophilic addition reaction, with the alcohol acting as a nucleophile.

Fig. 2.1 shows the reaction between propanone and ethanol.

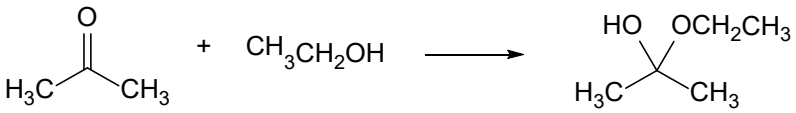
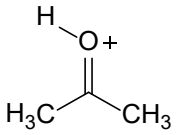


Fig. 2.1

- In the first step of the mechanism, a tetrahedral zwitterionic intermediate is formed.
- In the second step, an intramolecular proton transfer occurs to give the product.

(i) Draw the mechanism for the reaction in Fig. 2.1. Show all relevant charges, dipoles, lone pairs and curly arrows. [2]

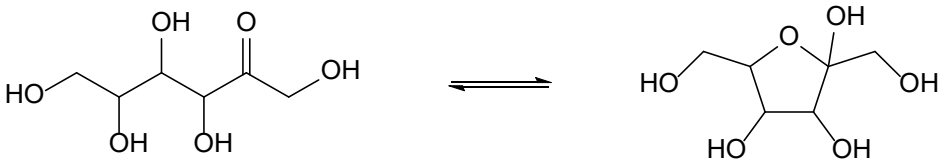
(ii) When the reaction is carried out under acidic conditions, propanone is first protonated to form the following structure.



By considering the structure above, explain why the reaction rate is higher in acidic conditions. [1]

Fructose equilibrates between the linear form and several cyclic forms. This occurs when one of the –OH groups attacks the carbonyl carbon through a nucleophilic addition reaction.

Fig. 2.2 shows the formation of the 5-membered cyclic form.



fructose (linear form) fructose (cyclic form)

Fig. 2.2

(iii) One enantiomer of linear fructose undergoes nucleophilic addition to produce two stereoisomers of cyclic fructose.

By considering the mechanism of the reaction, explain why. [1]

(iv) Fructose can also exist as a 6-membered cyclic form.

Draw the structure of the 6-membered cyclic form. [1]

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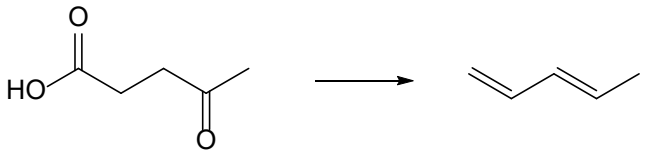
(d) Propose a two-step synthesis for the following transformation, stating the reagents and conditions required, and the structure of the intermediate formed.



[2]

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(e) Compound **A**, $C_5H_6O_2$, is neutral and contains a chiral centre.

When compound **A** is heated with dilute sulfuric acid, compound **B**, $C_5H_8O_3$, is formed.

When compound **B** is heated with acidified potassium manganate(VII), compound **C**, $C_3H_4O_3$, is formed as the only organic product. Compound **C** gives a yellow precipitate when warmed with alkaline aqueous iodine. Compound **C** also reacts with aqueous sodium carbonate with effervescence observed.

Deduce the structures of compounds **A**, **B** and **C**, explaining the reactions involved. [6]

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3 EITHER

(a) Describe and explain the trend in the thermal stabilities of the Group 2 carbonates. [3]

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(b) Gilman reagents, R_2CuLi, provide R^- nucleophiles in organic addition reactions.
(R = alkyl group)

In some circumstances, C=C can undergo nucleophilic addition reactions using Gilman reagents. An example is shown in Fig. 3.1.

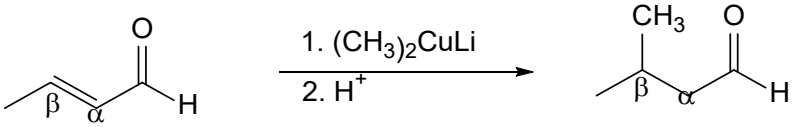

Fig. 3.1

- Step 1: nucleophilic attack by CH_3^- occurs on the β-carbon to produce an anion intermediate with a negative charge at the α-carbon.
- Step 2: the anion intermediate reacts with H^+ to give the final product.

(i) Define the term *nucleophile*. [1]

(ii) Using the concepts of electronegativity, electronic effects and delocalisation, suggest reasons why nucleophilic attack can occur at the β-carbon. [2]

(iii) Describe the mechanism for the reaction in Fig. 3.1, including all charges, lone pairs and curly arrows showing the movement of electrons. [2]

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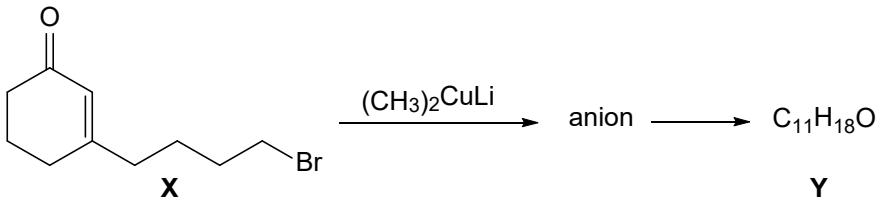
(iv) Compound **X** undergoes a two-step reaction to give **Y**. **Y** gives an orange precipitate with 2,4-dinitrophenylhydrazine and contains two chiral carbons.



X **Y**

Suggest structures for the anion and **Y**. [2]

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(a) Describe the thermal decomposition of the hydrogen halides HC*l*, HBr and HI and explain any variation in their thermal stabilities. [3]

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(b) When 1 mol of buta-1,3-diene undergoes electrophilic addition with 1 mol of HBr, a mixture of products is obtained in unequal proportions, as shown in Fig. 3.2.

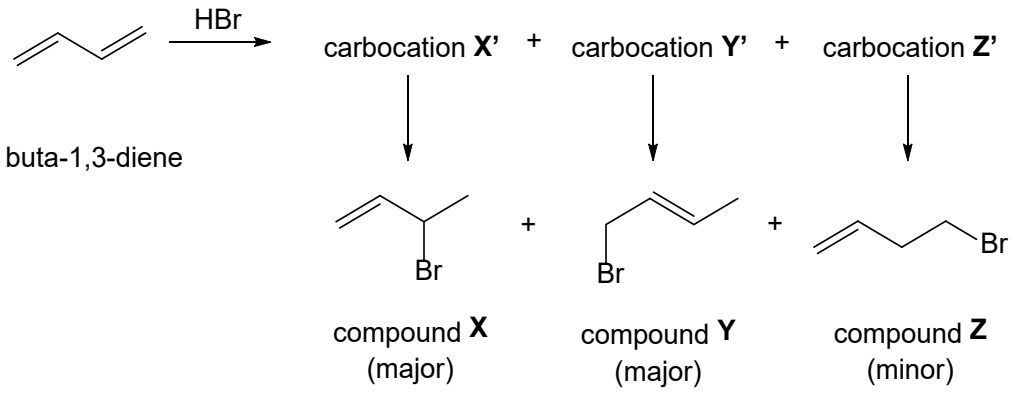

Fig. 3.2

(i) Define the term *electrophile*. [1]

(ii) Draw the structures of carbocations **X'** and **Y'**. [2]

(iii) By considering the structures of the carbocations **X'** and **Y'**, explain why compounds **X** and **Y** were obtained as major products. Support your answer with relevant diagrams. [2]

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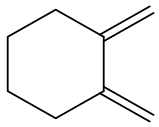
(iv) By considering the information provided above, draw the structures of the two **major** products, **S** and **T**, formed when equimolar amounts of compound **R** and HBr react.



R

HBr

S + **T**

[2]

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Additional answer space

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