RAFFLES INSTITUTION
2024 YEAR 6 TERM 3 TIMED PRACTICE

Higher 2

CANDIDATE NAME

CLASS | INDEX NUMBER

CHEMISTRY 9729

26 Jun 2024

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 page at the end of the booklet for Section B (page 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 pages at the end of the booklet for Section C (pages 37 – 38). 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	/ 7
B2	/ 14
B3	/ 19

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

0.523 mol of an iron oxide, Fe_xO_y, was reacted with excess carbon monoxide in an enclosed vessel to produce carbon dioxide and 146 g of molten iron. The resultant gas mixture was passed through aqueous sodium hydroxide. The volume of the gas was reduced by 75.4 dm^3 (measured at r.t.p.).

What are the values of *x* and *y*?

	x	*y*
A	1	1
B	2	3
C	5	6
D	5	7

2 5 moles of halide ion, X^-, can react with 1 mole of XO_n^- to form a single halogen-containing product.

Which row shows the value of n and the identity of the halogen-containing product?

	n	halogen-containing product
A	1	X_2
B	2	XO^-
C	3	X_2
D	4	XO^-

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

What is the electronic configuration of Fe^{3+}?

A [Ar] $3d^5$

B [Ar] $3d^6$

C [Ar] $3d^44s^1$

D [Ar] $3d^34s^2$

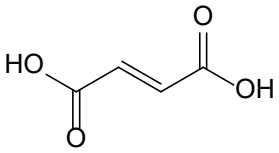
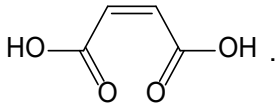
[Turn Over

4 Which statements are the result of hydrogen bonding?

1 $CH_3CH_2CONH_2$ is neutral.

2 The M_r of CH_3CO_2H in the vapour state is 120.

3 Gaseous $(CH_3)_3N$ is more basic than gaseous $(CH_3)_2NH$.

4 The K_{a1} of  is smaller than that of  .

A 1, 2 and 3

B 1, 3 and 4

C 2 and 3 only

D 2 and 4 only

5 The mechanism for a given reaction is shown below.

$2E \rightleftharpoons G$	fast
$G + F \rightarrow H$	slow
$H + F \rightarrow E_2F_2$	fast

Which statements are correct?

1 The rate equation is rate = $k[E]^2[F]$.

2 The overall equation is $2E + 2F \rightarrow E_2F_2$.

3 The mechanism involves two transition states.

A 1, 2 and 3

B 1 and 2 only

C 2 and 3 only

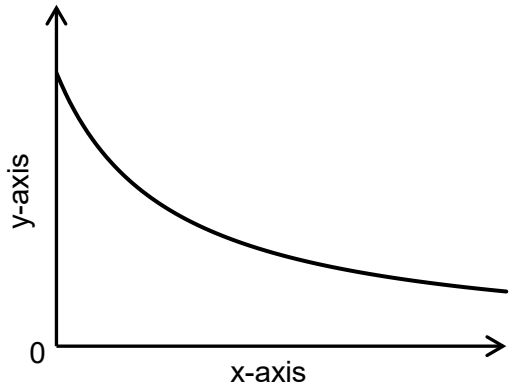
D 1 only

6 The rate of the reaction between Br_2 and HCOOH was investigated by using a spectrophotometer to measure the absorbance of the solution. The absorbance of the solution is directly proportional to the concentration of $Br_2(aq)$.

$Br_2(aq) + HCOOH(aq) \rightarrow 2HBr(aq) + CO_2(g)$

The table shows pairs of quantities that were plotted as graphs.

Which pairs could have given the following graph?



	y-axis	x-axis
1	absorbance	time
2	$[Br_2(aq)]$	time
3	pressure	time
4	rate	$[Br_2(aq)]$

A 1, 2 and 3

B 1 and 3 only

C 1 and 2 only

D 1, 2 and 4

7 In which reaction is ammonia acting as an acid?

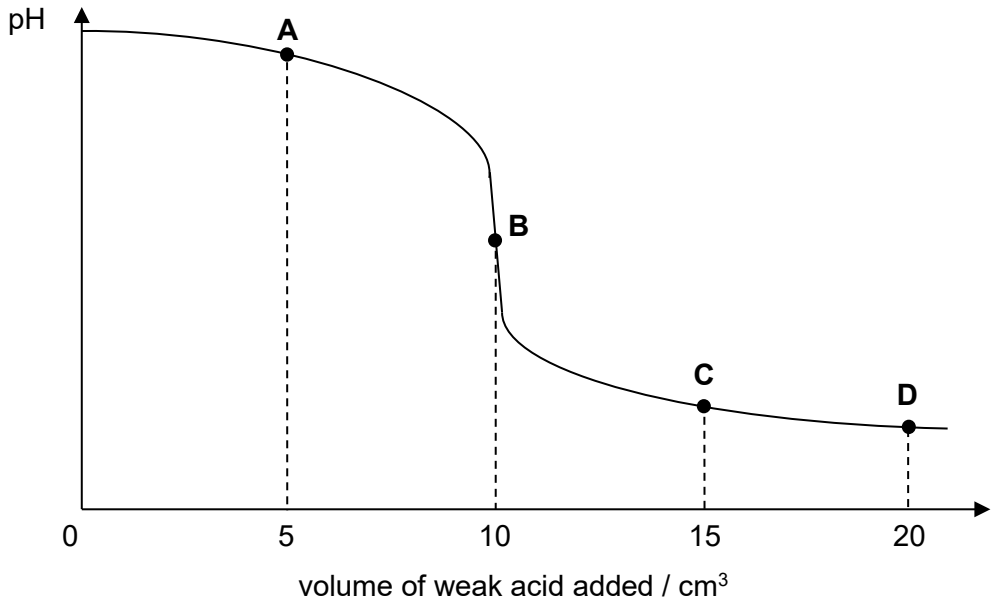
A $2NH_3(l) + 2Na(s) \longrightarrow 2NaNH_2(s) + H_2(g)$

B $NH_3(g) + H_2O(l) \longrightarrow NH_4^+(aq) + OH^-(aq)$

C $4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(g)$

D $4NH_3(aq) + Cu^{2+}(aq) \longrightarrow [Cu(NH_3)_4]^{2+}(aq)$

8 The pH change when 0.100 mol dm^{-3} of a weak acid is added dropwise to 10.0 cm^3 of 0.100 mol dm^{-3} NaOH is shown below.



Which statements are correct?

1 The weak acid is a monobasic acid.
2 pH of the solution at point **B** is above 7.
3 A buffer solution with maximum buffering capacity is formed at point **A**.

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

9 The following are pK_a values for phosphoric acid, H_3PO_4, at 25 °C.

species	pK_a values
H_3PO_4	2.15
$H_2PO_4^-$	7.20
HPO_4^{2-}	12.38

Which substances, in aqueous solution, would be the most suitable to prepare a buffer of pH 7.4?

A K_2HPO_4 and NaOH
B H_3PO_4 and NaH_2PO_4
C NaH_2PO_4 and HC*l*
D NaH_2PO_4 and K_2HPO_4

10 The values of two solubility products are given.

K_{sp} $[Ca(IO_3)_2]$ = 6.47 x 10^{-6} mol^3 dm^{-9}
K_{sp} $[Pb(IO_3)_2]$ = 3.69 x 10^{-13} mol^3 dm^{-9}

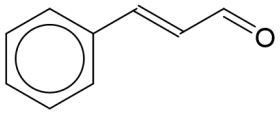
Solid calcium iodate is shaken with water and the remaining solid is filtered off, leaving a saturated solution **Z**.

Drops of aqueous lead(II) nitrate are added to **Z** until lead(II) iodate just precipitates.

Which row is correct?

	$[IO_3^-(aq)]$ in **Z** after filtration / mol dm^{-3}	$[Pb^{2+}(aq)]$ when $Pb(IO_3)_2$ just precipitates / mol dm^{-3}
A	0.0117	3.15 x 10^{-11}
B	0.0117	2.70 x 10^{-9}
C	0.0235	1.58 x 10^{-11}
D	0.0235	6.68 x 10^{-10}

11 Cinnamaldehyde gives cinnamon its flavour and aroma.



cinnamaldehyde

Which statement about cinnamaldehyde is correct?

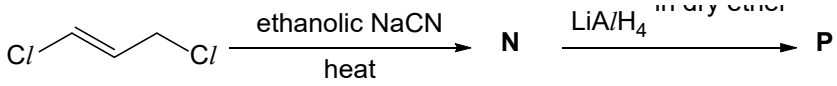
A It contains three sp^2 hybridised carbon atoms.

B It gives a positive test with Fehling's solution, but not Tollens' reagent.

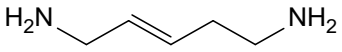
C 1 mole of cinnamaldehyde reacts with 1 mole of Br_2 dissolved in CCl_4.

D 1 mole of cinnamaldehyde reacts with hot acidified $K_2Cr_2O_7$ to give 2 moles of carbon dioxide gas.

12 The diagram below shows a reaction sequence.



What could be the identity of **P**?

A


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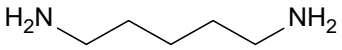
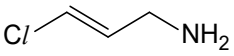
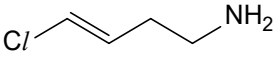
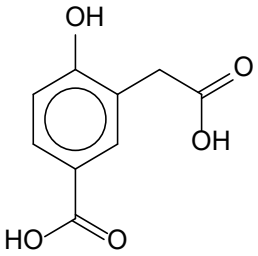


C


D


13 Which compound produces the smallest volume of gas when 1 mole of each compound is reacted with excess $Na_2CO_3(aq)$ at room temperature?

A


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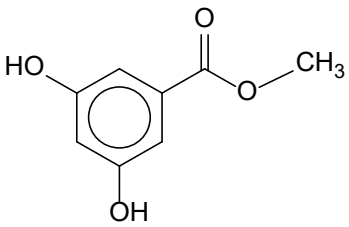
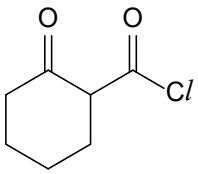
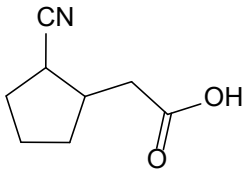
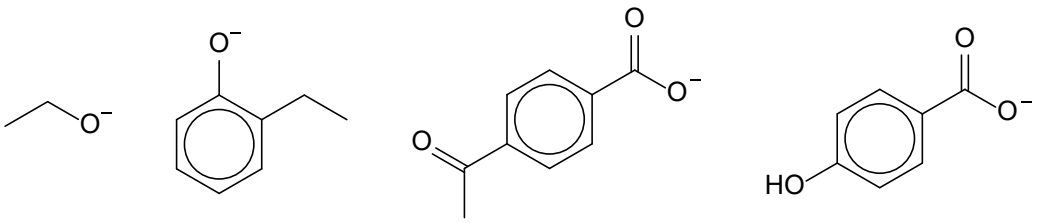


C


D


14 Consider the following four compounds.



E **F** **G** **H**

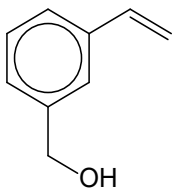
What is the relative order, in decreasing basicity, of these compounds?

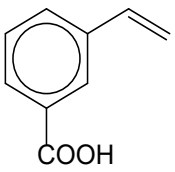
A **E** > **F** > **H** > **G**
B **G** > **H** > **F** > **E**
C **E** > **F** > **G** > **H**
D **H** > **G** > **F** > **E**

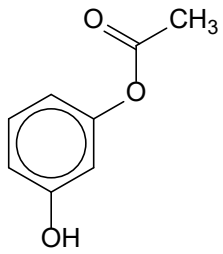
15 Compound **H** has the following properties.

- When reacted with Na, effervescence occurs, and the gas produced extinguishes a lighted splint with a “pop” sound.
- It decolourises orange aqueous Br_2.
- It turns hot acidified $K_2Cr_2O_7$(aq) from orange to green.

What could be the identity of compound **H**?

1 

2 

3 

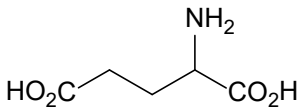
A 1 only
B 1 and 3
C 1 and 2
D 2 and 3

[Turn Over

Section B (40 marks)

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

1 **(a)** Glutamic acid is an amino acid with three pK_a values: 2.1, 4.1 and 9.5.



glutamic acid

By considering the given pK_a values, suggest the structure of the major species present in a solution of glutamic acid at pH 3.

[1]

(b) The enzyme chymotrypsin digests polypeptides at the carboxylic acid end of the amino acid phenylalanine (phe). The following three peptides were identified after digestion of the polypeptide **P** with chymotrypsin, and subsequent separation.

asp-lys-gly-phe, lys-val-arg and val-phe

Another enzyme trypsin digests polypeptides at the carboxylic acid end of lysine (lys). The following three peptides were identified after digestion of the same polypeptide **P** with trypsin, and subsequent separation.

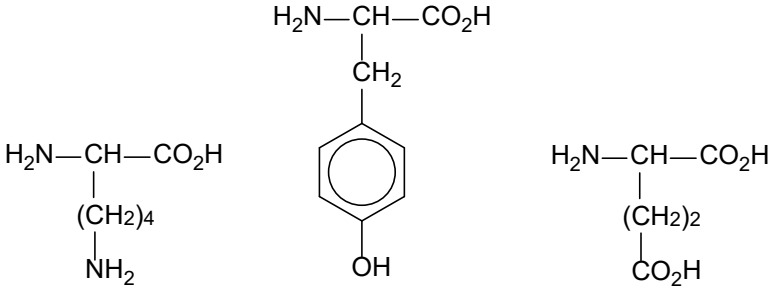
gly-phe-lys, val-arg and val-phe-asp-lys

State the amino acid sequence of polypeptide **P**.

……..……..[1]

[Turn Over

(c) On hydrolysis, a tripeptide produced the following amino acids in equimolar amounts.



B **C** **D**

(i) Given that each tripeptide contains three different amino acid residues, state the number of ways these three amino acids can be coupled by peptide bonds to form a tripeptide.

……[1]

(ii) Draw the structural formula of the **BCD** tripeptide.

[1]

(iii) Draw the structural formula of the product formed when the **BCD** tripeptide in **(ii)** is dissolved in aqueous sodium hydroxide at room temperature.

[1]

(iv) Explain what is meant by the term *zwitterion* and draw the zwitterionic form of **B** to illustrate your answer.

……

……

……[2]

[Total: 7]

2 (a) Major concerns about global warming have led scientists to seek ways to reduce greenhouse gases such as carbon dioxide, CO_2.

One method to reduce CO_2 levels in the atmosphere is to convert CO_2 to methanoic acid, HCOOH, as shown in equation 1.

equation 1 $\quad 2CO_2 + 2H_2O \longrightarrow 2HCOOH + O_2$

(i) State the type of reaction involving carbon dioxide in equation 1. Describe the change in oxidation state of carbon which occurs during this reaction.

……

……

……[2]

(ii) The standard electrode potentials of the two half-equations involved are shown below.

$CO_2 + 2H^+ + 2e^- \rightleftharpoons HCOOH \qquad E^\ominus = -0.61$ V

$O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O \qquad E^\ominus = +1.23$ V

Calculate $E^\ominus_{cell}$ and $\Delta G^\ominus$ of the reaction in equation 1 to show that the reaction is not spontaneous and a power supply is required for the reaction to occur.

[2]

(iii) With reference to the half-equations in **(a)(ii)**, explain why a lower pressure of CO_2 will require a higher power supply.

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……[2]

(b) The standard electrode potential of the CO_2/HCOOH half-cell in **(a)(ii)** can be determined using the standard hydrogen electrode.

Draw a fully labelled diagram for the setup and indicate the direction of electron flow.

[3]

(c) The Biomimetic Electrolytic Cell (BEC) shown in Fig. 2.1 can be used to convert CO_2 to useful HCOOH. The BEC contains porous gas diffusion electrodes which allow CO_2 gas to be transported to the catalyst layer and O_2 gas to depart from the anode directly without passing through the electrolyte solution. The anode is also covered with a membrane to prevent contact with the HCOOH formed.

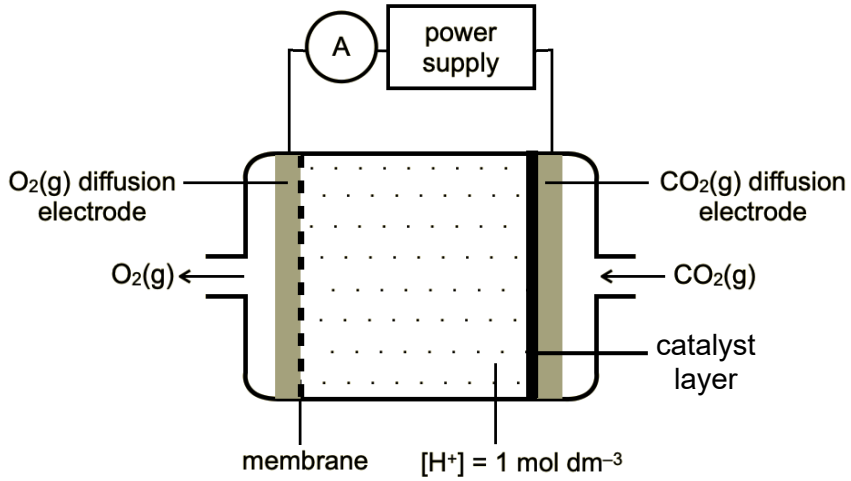

Fig. 2.1

(i) Using the information provided, suggest why HCOOH should not be allowed to come into contact with the anode.

……

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……[1]

(ii) Suggest a disadvantage of using dissolved $CO_2(aq)$ in the BEC instead of $CO_2(g)$.

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……[1]

(d) A 30.0 cm^3 sample of solution containing $HCOO^-$ is reacted with excess $KMnO_4$ under alkaline conditions. The resultant mixture contains CO_3^{2-} ions and a brown-black precipitate of MnO_2.

The half-equation for the reduction of MnO_4^- is shown below.

$$MnO_4^- + 2H_2O + 3e^- \longrightarrow MnO_2 + 4OH^-$$

(i) Construct a balanced ionic equation for the reaction between $HCOO^-$ and MnO_4^- under alkaline conditions.

……[1]

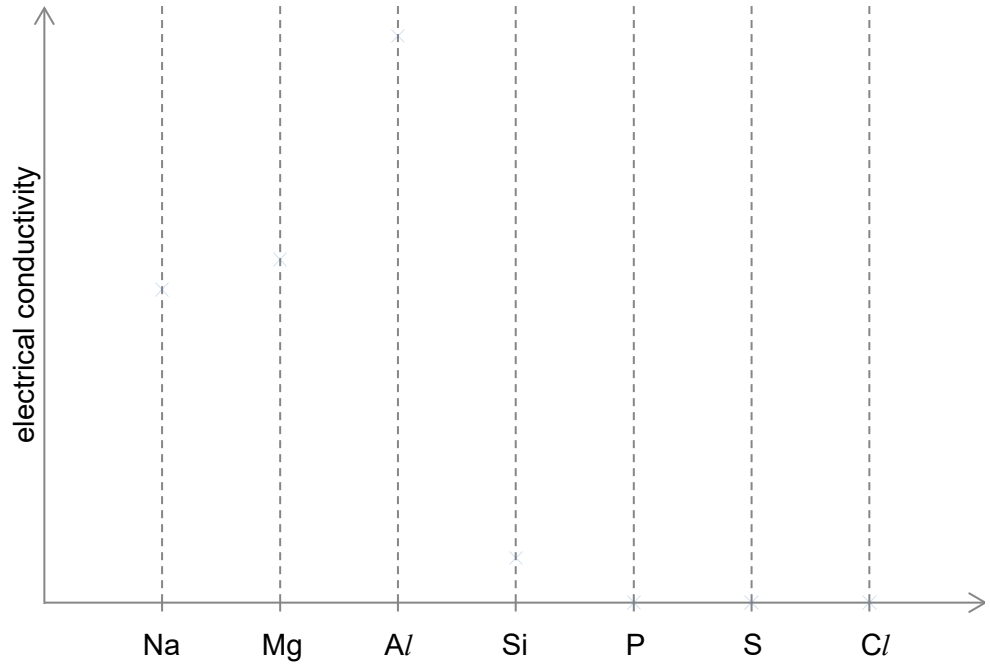
(ii) 0.450 g of MnO_2 is formed in the resultant mixture.

Calculate the concentration of $HCOO^-$ in the sample.
[M_r of MnO_2 = 86.9]

[2]

[Total: 14]

3 (a) Sketch a graph showing the variation of electrical conductivity across the third period of the Periodic Table, and explain qualitatively its shape.



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……[3]

(b) Describe the reactions, if any, of the chlorides $MgCl_2$ and PCl_5 with water.
Write equations for all reactions that occur, and suggest the pH of the resulting solutions.

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……[4]

(c) A 1.0 mol dm^{-3} solution of $AlCl_3$ has a pH of 3.0.

By using data from the *Data Booklet*, suggest whether a 1.0 mol dm^{-3} solution of $CrCl_3$ has a higher or lower pH. Explain your answer.

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……[3]

[Turn Over

Struvite, $MgNH_4PO_4$, is a naturally occurring mineral that causes problems for wastewater treatment plants as it is sparingly soluble in water.

$$MgNH_4PO_4(s) \rightleftharpoons Mg^{2+}(aq) + NH_4^+(aq) + PO_4^{3-}(aq)$$

(d) (i) Write an expression for the solubility product, K_{sp}, for struvite giving its units.

……[1]

(ii) The numerical value of the K_{sp} for struvite is 4.37×10^{-14} at 298 K.

Calculate the solubility of struvite in water at 298 K.

[1]

(iii) Calculate the solubility of struvite in 0.100 mol dm^{-3} of $(NH_4)_2SO_4$ at 298 K.

[2]

(iv) In modern water treatment, a chemical sedimentation step is necessary to remove struvite from wastewater. $MgCl_2$ is added to precipitate struvite which is then removed. This reduces blockages in pipes.

With the aid of relevant equation, explain the removal of struvite by treating wastewater with $MgCl_2$.

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……[1]

(v) When struvite is heated with excess reagent **X**, ammonia gas is produced. Suggest the identity of reagent **X**.

……[1]

(vi) State the types of chemical bonds present in struvite.

……[1]

(e) Struvite can be used as a fertiliser as it contains magnesium, nitrogen and phosphorus. An impure sample of struvite contains only two impurities listed in Table 3.1.

Table 3.1

compound	M_r	% impurity by mass
$MgCO_3$	84.3	10
$Ca_3(PO_4)_2$	310.3	5

(i) Calculate the total phosphorus content, in grams, of a 100 g sample of impure struvite fertiliser.
[M_r of struvite = 137.3]

[1]

(ii) Hence, calculate the mass of impure struvite fertiliser needed to achieve a total phosphorus content of 50 kg.

[1]

[Total: 19]

[Turn Over

Additional answer space

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

RAFFLES INSTITUTION
2024 YEAR 6 TERM 3 TIMED PRACTICE

Higher 2

C

CANDIDATE NAME

CLASS

INDEX NUMBER

For Examiner's Use Only

Section		Marks
A		**/ 15**
B	**B1**	**/ 7**
	B2	**/ 14**
	B3	**/ 19**
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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[Turn Over

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) A halogenoalkane can react with a hydroxide ion to form an alcohol and a halide ion. The rate of this reaction depends on various factors, one of which is the strength of the carbon−halogen bond.

Explain, by providing two reasons, why the carbon-halogen bond strength decreases down Group 17. [2]

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(b) To investigate the rates of substitution, 1–chlorobutane, 1–bromobutane and 1–iodobutane were reacted with aqueous hydroxide ions separately.

$$CH_3CH_2CH_2CH_2X + OH^- \longrightarrow CH_3CH_2CH_2CH_2OH + X^- \qquad (X = Cl, Br, I)$$

Individual samples of these halogenoalkanes were mixed with excess sodium hydroxide at 50 °C. At 2 min, the reaction mixture was acidified with dilute nitric acid. Subsequent addition of aqueous silver nitrate caused the formation of a silver halide precipitate. The amount of precipitate that formed was then determined via gravimetry.

$$Ag^+(aq) + X^-(aq) \longrightarrow AgX(s) \qquad (X = Cl, Br, I)$$

(i) Suggest the role of nitric acid in this experiment. [1]

(ii) Plan an investigation to determine the **amount** of silver halide precipitate obtained when **0.05 mol** of each halogenoalkane is reacted with excess sodium hydroxide for 2 minutes at 50 °C.

The reactions between the halogenoalkanes and hydroxide ions are incomplete at t = 2 min.

You may assume that you are provided with:

- **FA1**, 2.00 mol dm^{-3} aqueous sodium hydroxide, NaOH,
- **FA2**, 2.00 mol dm^{-3} dilute nitric acid, HNO_3,
- **FA3**, 2.00 mol dm^{-3} aqueous silver nitrate, $AgNO_3$,
- three 250 cm^3 conical flasks with 50 cm^3 solutions containing 0.05 mol 1–chlorobutane, 1–bromobutane and 1–iodobutane respectively,
- water bath,
- thermometers,
- stopwatch,
- the equipment normally found in a school or college laboratory.

In your plan you should include brief details of:

- the quantities you would use, so that there is an excess of sodium hydroxide, nitric acid, and silver nitrate,
- the apparatus you would use,
- the procedure you would follow,
- the measurements you would make,
- how you would determine the amount of precipitate obtained. [7]

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[Total: 10]

2 Acid anhydrides are useful reactants in organic synthesis as they are highly reactive towards nucleophiles. Fig. 2.1 shows the general structure of an acid anhydride, where R_1 and R_2 represent alkyl groups.

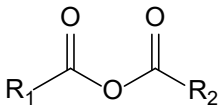
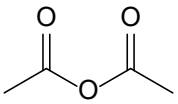


Fig. 2.1

(a) Acetic anhydride, **A**, is a useful precursor in the synthesis of different painkillers.



A

Paracetamol can be synthesised from phenol in three steps as shown in Fig. 2.2.

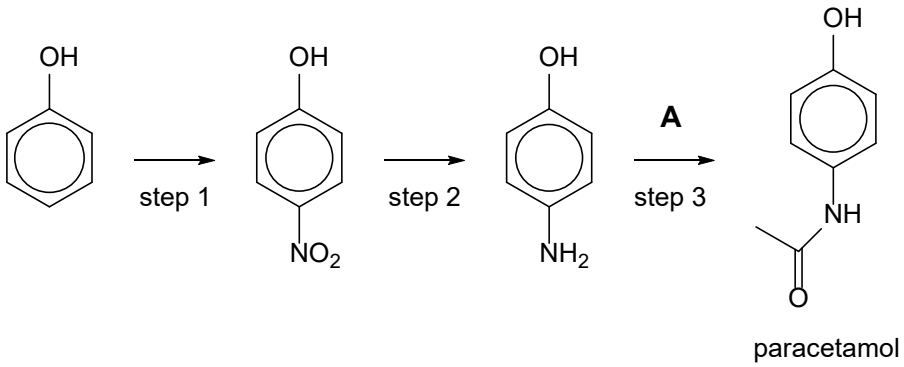


Fig. 2.2

(i) State the reagents and conditions for steps 1 and 2. [2]

(ii) State the type of reaction for step 3. [1]

(iii) Arrange 4-nitrophenol, ethanol and phenol in order of increasing pK_a. Explain your answer. [3]

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(b) Fig. 2.3 shows the chemical equation for the reaction between salicylic acid and acetic anhydride, in the presence of an acid catalyst, to form Aspirin and compound **B**.

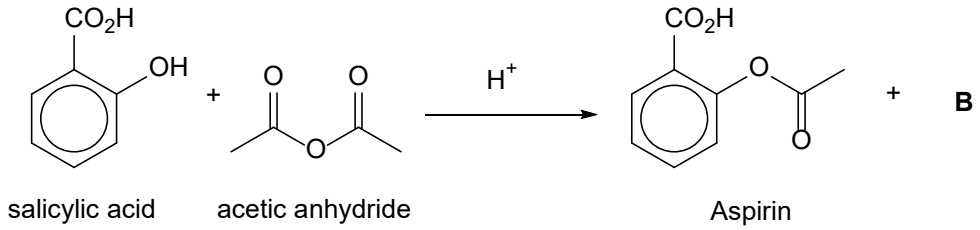


Fig. 2.3

(i) The first two steps of the mechanism for the reaction between salicylic acid and acetic anhydride are described below.

Step 1: Protonation of the oxygen in C=O of acetic anhydride by an acid catalyst, H^+.

Step 2: Nucleophilic attack by salicylic acid to the protonated acetic anhydride.

Complete the mechanism on Fig. 2.4 by adding lone pairs and curly arrows.

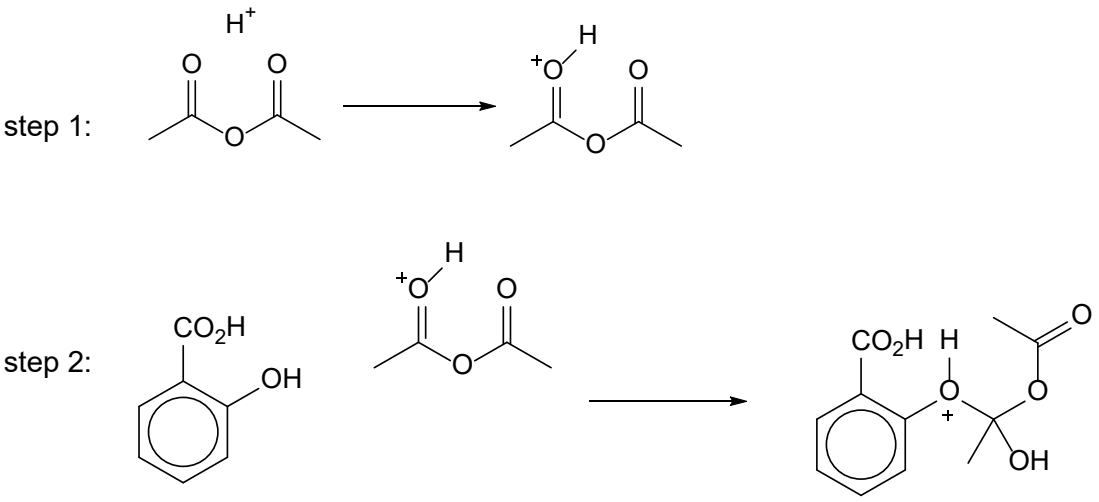


Fig. 2.4

[2]

(ii) With reference to the structure of the protonated acetic anhydride intermediate, suggest a reason why the reaction occurs quickly when an acid catalyst is used. [1]

(iii) With reference to Fig. 2.3, draw the displayed formula of **B.** [1]

Acid anhydride readily undergoes hydrolysis, as shown in Fig. 2.5.

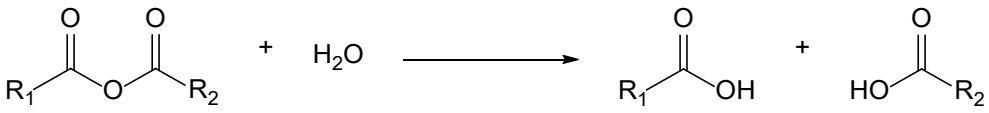
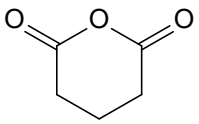


Fig. 2.5

(iv) Draw the structure of the product obtained when glutaric anhydride undergoes hydrolysis. [1]



glutaric anhydride

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(c) Compound **P**, $C_9H_{10}O_2$, can rotate plane-polarised light. **P** reacts with lithium aluminium hydride to form **Q**, $C_9H_{12}O$.

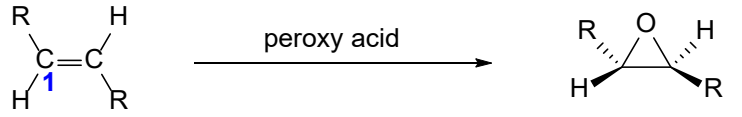
P reacts with $(CH_3)_2CHCH_2Cl$ in the presence of anhydrous $AlCl_3$ to form **R**, $C_{13}H_{18}O_2$. **R** reacts with hot acidified potassium manganate(VII) to form **S**, $C_8H_6O_4$. Only one mono-brominated product is formed when **S** undergoes bromination.

Deduce the structures of compounds **P**, **Q**, **R** and **S**, explaining the reactions described. [9]

[Total: 20]

3 EITHER

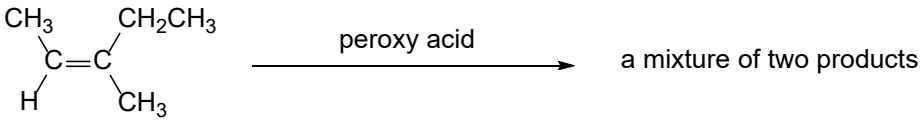
Epoxides are cyclic ethers with a 3-membered ring system. They can be prepared by reacting alkenes with peroxy acids. In this process, the substituents that are *trans* to each other in the alkene remain *trans* to each other in the epoxide. The reaction can be considered as an addition of an O atom across the C=C bond. An example is shown below.



trans-alkene *trans*-epoxide

(a) State the shape around carbon-1 of the alkene molecule. [1]

(b) When the following *trans*-alkene undergoes reaction with a peroxy acid, a mixture of two epoxide products is formed. This mixture does **not** rotate plane-polarised light.



(i) State the type of isomerism present in the products. [1]

(ii) Draw the three-dimensional structures of the two products, showing clearly the stereochemistry of the molecules with the use of wedged and hashed bonds. [2]

(iii) By considering your answer in **(a),** explain why the mixture does **not** exhibit any optical activity. [2]

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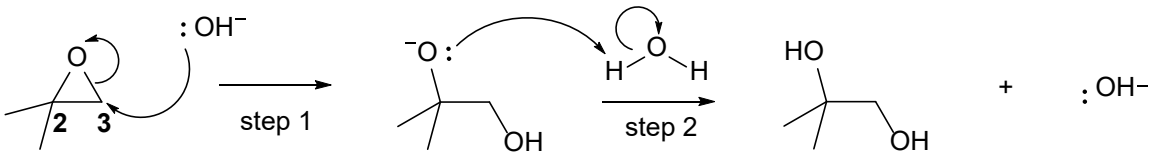
(c) Epoxides are highly reactive due to ring strain and hence undergo ring-opening reactions readily. NaOH(aq) can be used to carry out this reaction. The mechanism of one such reaction is shown below.

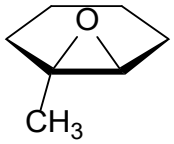


- Step 1 proceeds via an S_N2 mechanism.
- Step 2 is an acid-base reaction whereby the alkoxide intermediate is protonated by water.

(i) By considering the structure of the above epoxide, explain why the epoxide is susceptible to nucleophilic attack. [1]

(ii) Give two reasons why the nucleophilic attack in step 1 occurs at carbon-3 instead of carbon-2. [2]

(iii) The following epoxide undergoes ring-opening reaction with the use of NaOH(aq).



side-view of epoxide

Draw the three-dimensional structure of the product, showing clearly the stereochemistry of the product. [1]

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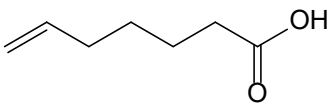
[Total: 10]

3 OR

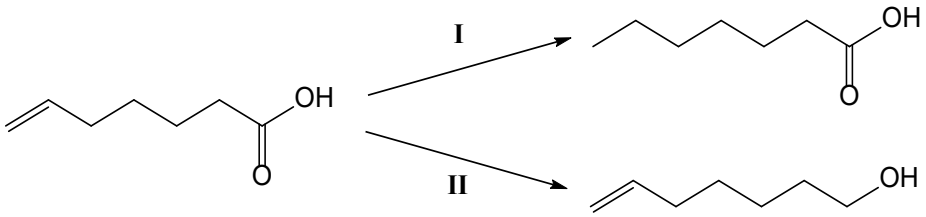
(a) 6-Heptenoic acid, $C_7H_{12}O_2$, is one of the carboxylic acids found in tobacco.



6-heptenoic acid

(i) Under suitable conditions, **U**, $C_7H_{13}O_2Br$, reacts to produce 6-heptenoic acid as the **only** product. Identify **U** and state the reagents and conditions required for the reaction. [2]

(ii) 6-Heptenoic acid can undergo selective reduction to give different products.



State the reagents and conditions for reactions **I** and **II**. [2]

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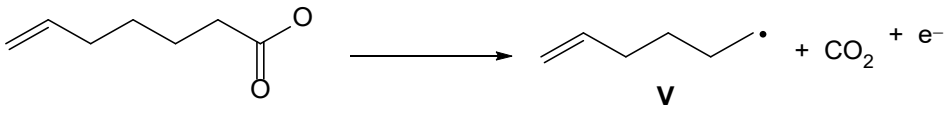
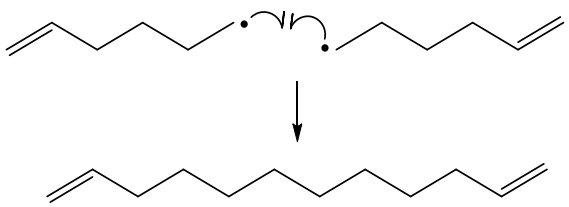
(b) The Kolbe reaction involves the electrochemical oxidation of carboxylate anions resulting in the formation of dimeric products.

During the electrolysis of sodium 6-heptenoate, the anion loses an electron and forms the intermediate radical **V** and carbon dioxide.



V

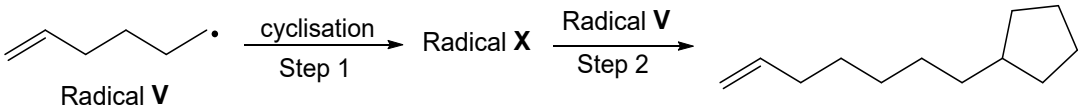
V dimerises to form **W** as the major product.



W

(M_r = 166.0)

The intermediate radical **V** is also able to cyclise to form radical **X**, which reacts with another radical **V** to form a minor product **Y**.



Radical **V**

Y

(M_r = 166.0)

(i) Suggest a structure for **X**. [1]

(ii) Hence propose a two-step mechanism for the formation of **Y**, starting from the cyclisation of **V** to form **X**. Use curly arrows to indicate the movement of single electrons and indicate any unpaired electrons by a dot (•). [2]

(iii) In the electrolysis of sodium 6-heptenoate, a current of 3.0 A was passed for 30 minutes.

Calculate the mass of **W** obtained given the information below. [3]

compound	% mass of product obtained
W	63
Y	37

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[Total: 10]

Additional answer space

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