Please write clearly in block capitals.

Centre number | | | | | | Candidate number | | | | |

Surname _____

Forename(s) _____

Candidate signature _____

I declare this is my own work.

A-level CHEMISTRY

Paper 2 Organic and Physical Chemistry

Monday 19 June 2023 Afternoon Time allowed: 2 hours

Materials

For this paper you must have:
- the Periodic Table/Data Booklet, provided as an insert (enclosed)
- a ruler with millimetre measurements
- a scientific calculator, which you are expected to use where appropriate.

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do **not** write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- All working must be shown.
- Do all rough work in this book. Cross through any work you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 105.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
8	
9	
TOTAL	

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Answer **all** questions in the spaces provided.

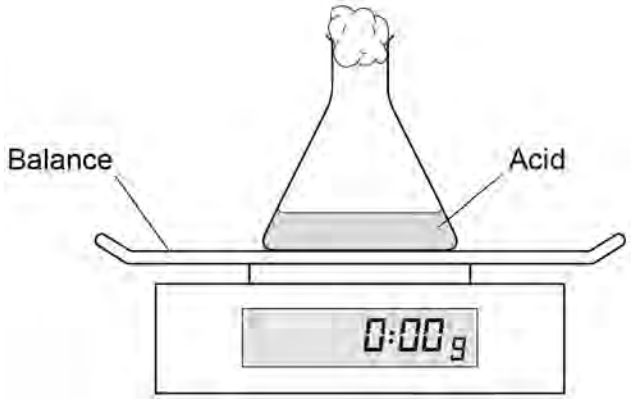
0 1 This question is about rates of reaction.

Figure 1 shows apparatus used to measure the rate of reaction when an acid reacts with an excess of solid sodium hydrogencarbonate, $NaHCO_3$

When different monoprotic organic acids are used, the rates at which gas escapes can be used to compare the strengths of the acids.

A timer is started when the $NaHCO_3$ is added to the acid and the mass of CO_2 gas lost is recorded at regular intervals.
(It is assumed that any change in mass is due to the loss of CO_2)

Figure 1



0 1 . 1 Suggest a reason why using a conical flask instead of a beaker would give more accurate results in this experiment.

[1 mark]

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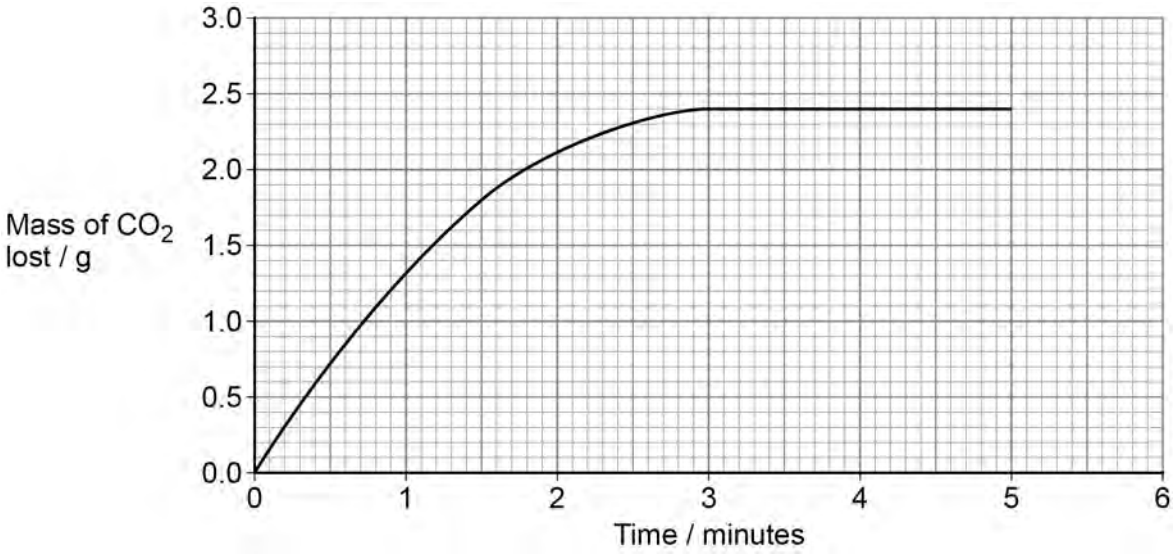
Figure 2 shows the results of this experiment when 25.0 cm^3 of a 2.23 mol dm^{-3} solution of ethanoic acid reacts with an excess of $NaHCO_3$

Figure 2



0 1 . 2 Use **Figure 2** to calculate the rate of reaction at 2 minutes.

Deduce the units of your calculated rate.

[3 marks]

Rate _____ Units _____

0 1 . 3 Chloroethanoic acid is a stronger acid than ethanoic acid.

Sketch, on **Figure 2**, the curve you would expect when 25.0 cm^3 of a 2.23 mol dm^{-3} solution of chloroethanoic acid reacts with an excess of $NaHCO_3$

Suggest why chloroethanoic acid is a stronger acid than ethanoic acid.

[3 marks]

_____

_____

_____

_____

7

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0 2 A and B react together in the presence of an acid catalyst.

$$A(aq) + 2B(aq) \rightarrow C(aq) + D(aq)$$

The rate equation for this reaction is

$$rate = k[B]^2[H^+]$$

Table 1 shows how the values of the relative initial rate vary with different concentrations of each reagent at the same temperature.

Table 1

Experiment	[A] / mol dm^{-3}	[B] / mol dm^{-3}	[H$^+$] / mol dm^{-3}	Relative initial rate
1	0.40	0.20	0.10	1.00
2	0.50	0.20	0.10	
3	0.40		0.10	0.64
4	0.50	0.30	0.06	

0 2 . 1 Complete **Table 1** by calculating the missing values.

[3 marks]

0 2 . 2 A suggested mechanism for the reaction is shown.

Step 1 $B + H^+ \rightarrow BH^+$

Step 2 $BH^+ + B \rightarrow B_2H^+$

Step 3 $B_2H^+ + A \rightarrow C + D$

Deduce the rate-determining step for this reaction.

Give a reason for your answer.

[2 marks]

Rate-determining step _____

Reason _____

_____

_____

5

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Turn over for the next question

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ANSWER IN THE SPACES PROVIDED

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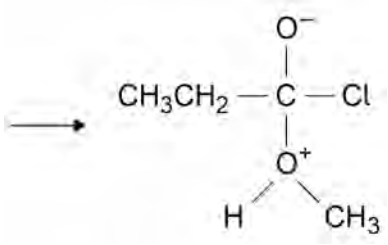
0 3 This question is about intermediates in reaction mechanisms.

0 3 . 1 **Figure 3** shows an intermediate formed in the first step of a nucleophilic addition–elimination mechanism.

Figure 3



Complete **Figure 3** to show the structures of the two reactant species with curly arrows and relevant lone pairs of electrons involved in the formation of the intermediate.

Draw curly arrows and relevant lone pairs of electrons on the intermediate to show how the final products are formed.

[4 marks]

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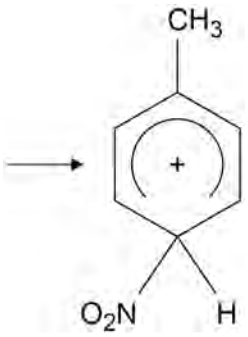
0 3 . 2 **Figure 4** shows an intermediate formed in the first step of a reaction mechanism of methylbenzene.

Figure 4



Complete **Figure 4** to show the reactant species and any curly arrows involved in the formation of the intermediate.

Draw a curly arrow on the intermediate to show how the product is formed.

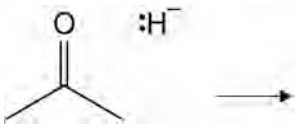
Give the name of the reaction mechanism.

[4 marks]

Name of mechanism _____

0 3 . 3 **Figure 5** shows the reactant species involved in the first step of a mechanism.

Figure 5



Complete **Figure 5** to show the structure of the intermediate formed with curly arrows involved in its formation.

Give the name of the reaction mechanism.

[4 marks]

Name of mechanism _____

12

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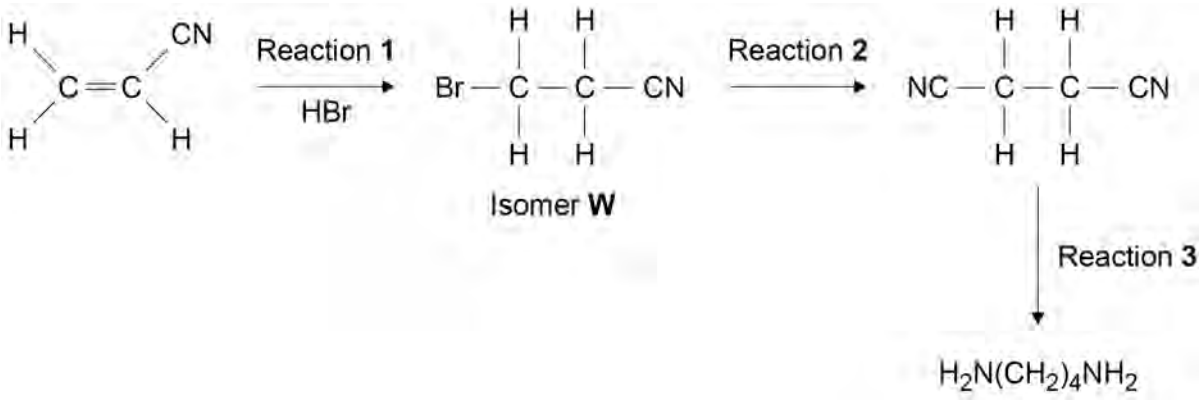
0 4 Acrylonitrile, $H_2C=CHCN$, can be used as a starting material for the synthesis of butane-1,4-diamine, as shown in this reaction scheme.



0 4 . 1 Use IUPAC rules to name isomer **W**.

[1 mark]

0 4 . 2 Reaction **1** produces a mixture of **W** and two other isomers.

Draw the structures of the two other isomers.

Explain, by considering the mechanism of this reaction, why all three isomers are formed.

[6 marks]

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Question 4 continues on the next page

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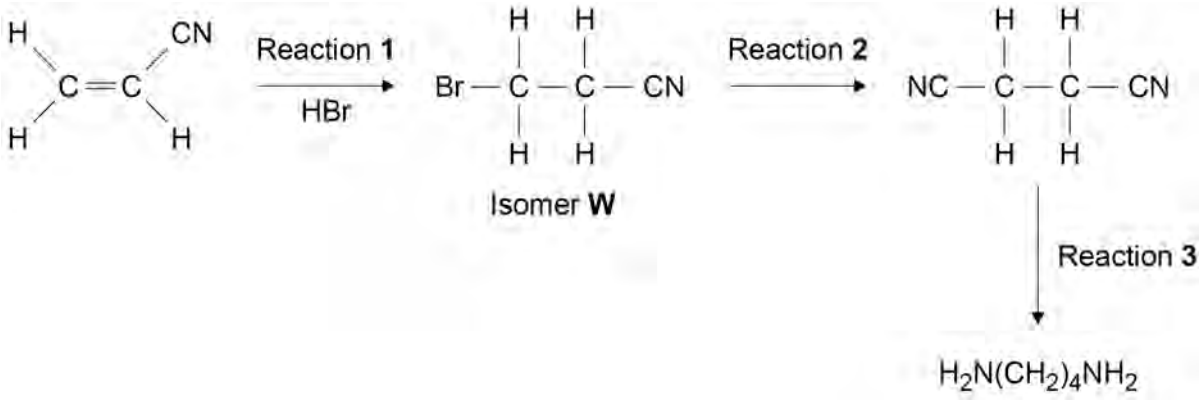
The reaction scheme is repeated here.



0 4 . 3 Identify the reagent that is warmed with isomer **W** in reaction **2**.

State the other reaction condition needed.

[2 marks]

Reagent _____

Condition _____

0 4 . 4 State the reagent and reaction conditions needed for reaction **3**.

Give an equation for reaction **3**.

[2 marks]

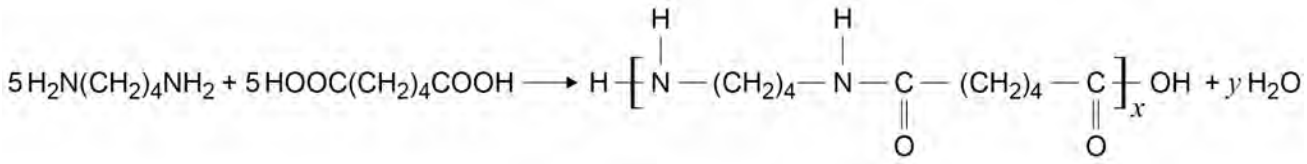
Reagent and conditions _____

Equation

_____

Do not write outside the box

0 4 . 5 An incomplete equation for the formation of nylon 4,6 from five molecules of butane-1,4-diamine and five molecules of hexanedioic acid is shown.



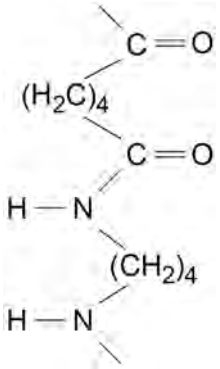
Deduce the values of x and y in this equation.

[2 marks]

x _____ y _____

0 4 . 6 **Figure 6** shows a section of the nylon 4,6 polymer molecule.

Figure 6



Draw, on **Figure 6**, another section of nylon 4,6 polymer showing two hydrogen bonds between the two sections.

[2 marks]

15

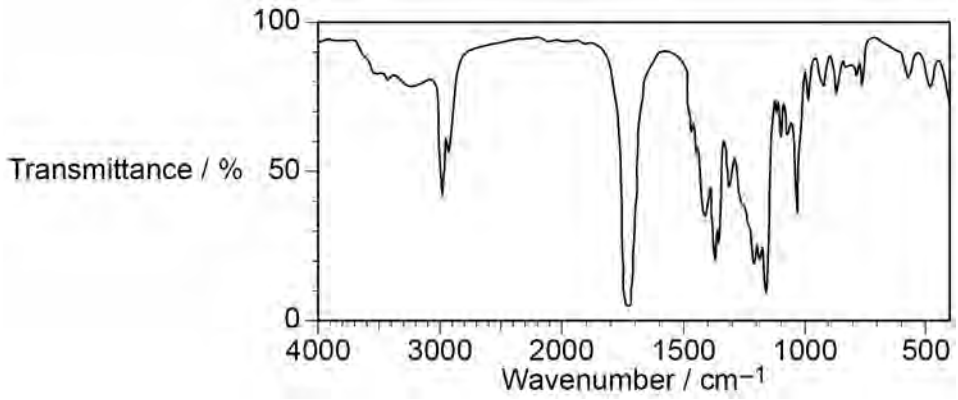
Turn over ►

Do not write outside the box

0 5 This question is about compound **Z**, with molecular formula $C_7H_{12}O_3$

Figure 7 shows the infrared spectrum of **Z**.

Figure 7

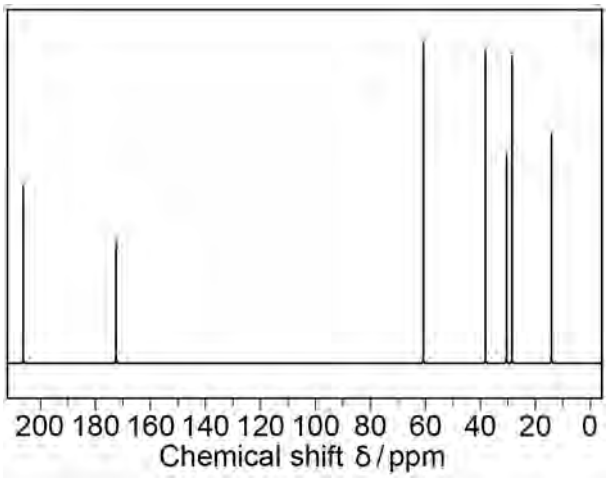


0 5 . 1 Identify the bond that causes the absorption at 1725 cm^{-1}

[1 mark]

Figure 8 shows the ^{13}C NMR spectrum of **Z**.

Figure 8



0 5 . 2 How many different carbon environments are there in a molecule of **Z**?

[1 mark]

	5	6	7	8
Tick (✓) **one** box				

0 5 . 3 State the type of carbon environment that causes the peak at δ = 174 ppm

Use **Table C** in the Data Booklet to help you answer this question.

[1 mark]

Do not write outside the box

0 5 . 4 **Table 2** shows data from the ^{1}H NMR spectrum for compound **Z**.

Table 2

Chemical shift δ / ppm	4.10	2.60	2.56	2.19	1.26
Integration ratio	2	2	2	3	3
Splitting pattern	quartet	triplet	triplet	singlet	triplet

Explain what can be deduced from the splitting patterns and chemical shift values for the peaks at δ = 4.10 ppm and at δ = 1.26 ppm

Deduce the part of the structure of **Z** that causes the peaks at δ = 4.10 ppm and δ = 1.26 ppm

Use **Table B** in the Data Booklet to help you answer this question.

[5 marks]

Peak at δ = 4.10 ppm _____

_____

_____

Peak at δ = 1.26 ppm _____

_____

_____

Part of structure

0 5 . 5 Deduce the part of the structure of **Z** that causes the peak at δ = 2.19 ppm

[1 mark]

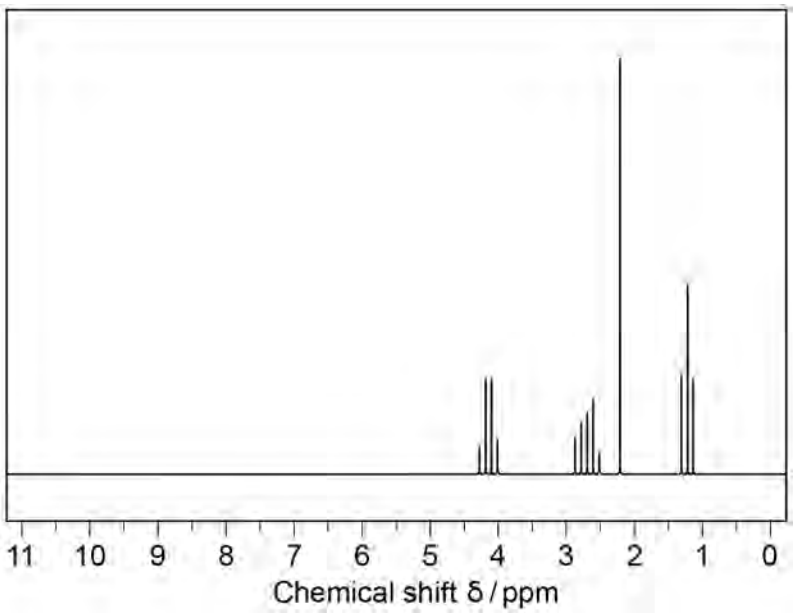
Part of structure

Turn over ►

Do not write outside the box

Figure 9 shows the ^{1}H NMR spectrum of compound **Z**.

Figure 9



0 5 . 6 Suggest why it would be difficult to determine the structure of **Z** using the spectrum in **Figure 9**, without the information in **Table 2** on page 13.

[1 mark]

0 5 . 7 Deduce the structure of **Z**.

[1 mark]

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11

Turn over for the next question

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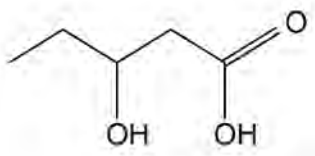
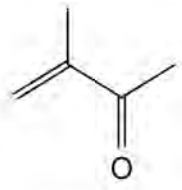
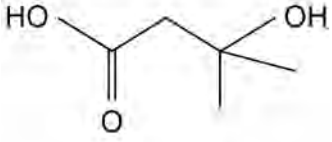
0 6 A student plans a series of chemical tests to confirm the identities of four organic liquids.



Liquid **J**



Liquid **K**



Liquid **L**

Liquid **M**

This is the student's method.

To separate test tubes containing samples of each liquid:

Test 1 add potassium dichromate(VI) solution and warm gently

Test 2 add Fehling's solution and cool in iced water

Test 3 add sodium hydrogencarbonate solution and test any gas produced with a lighted splint

Test 4 add bromine water and shake at room temperature.

0 6 . 1 Identify the missing reagent needed in **Test 1**.

[1 mark]

Do not write outside the box

0 6 . 2 In addition to the missing reagent in **Test 1**, there is a mistake in the method for **two** of the other tests.

State the **two** mistakes.

Suggest how each of the mistakes should be corrected.

[2 marks]

Mistake 1 _____

Suggestion _____

_____

Mistake 2 _____

Suggestion _____

_____

0 6 . 3 The missing reagent is added and the mistakes are corrected.

Identify the liquid(s), **J**, **K**, **L** and **M**, that would react in each test.

State the expected observation for each reaction.

[8 marks]

Liquid(s) that react in **Test 1** _____

Expected observation _____

_____

Liquid(s) that react in **Test 2** _____

Expected observation _____

_____

Liquid(s) that react in **Test 3** _____

Expected observation _____

_____

Liquid(s) that react in **Test 4** _____

Expected observation _____

_____

Do not write outside the box

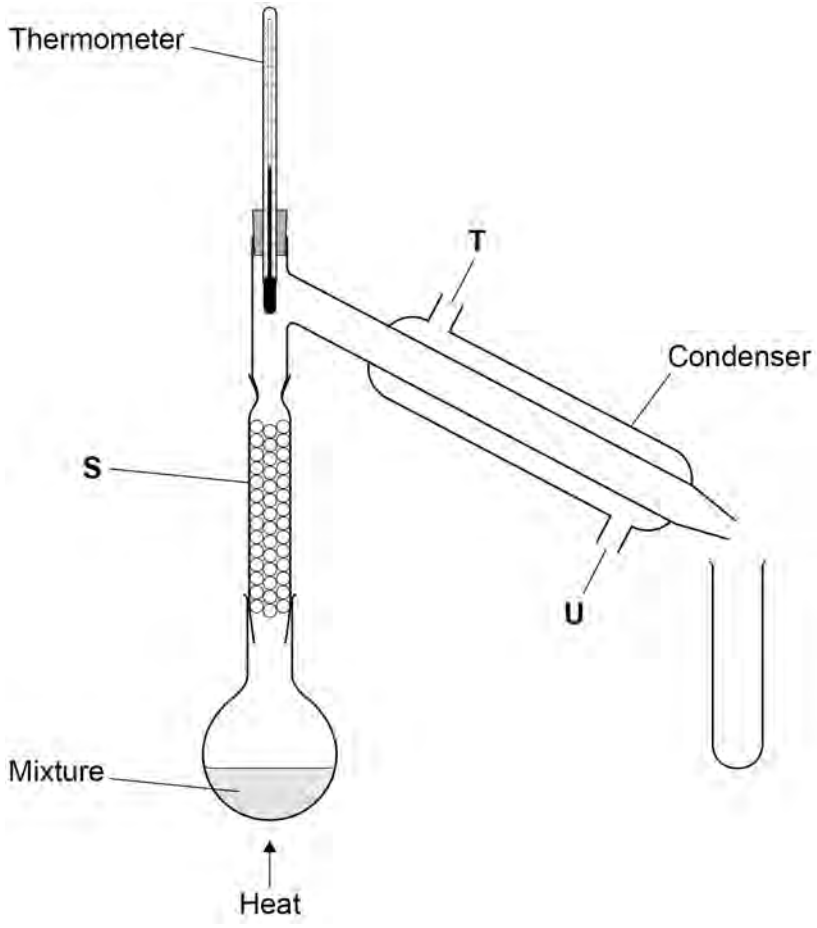
0 6 . 4 **Figure 10** shows the apparatus that is used to separate a mixture of liquids **K** and **M** using fractional distillation.

Suggest labels that should be added to positions **S**, **T** and **U** in **Figure 10**.

Explain why fractional distillation is preferred to simple distillation to separate liquids **K** and **M**.

[3 marks]

Figure 10



Label **S** _____

Label **T** _____

Label **U** _____

Explanation _____

_____

14

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Turn over for the next question

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ANSWER IN THE SPACES PROVIDED

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0 7 A gas syringe that does not have any graduations is calibrated using a known mass of propanone (boiling point = 56.2 °C).

The sealed gas syringe contains 0.146 g of propanone (M_r = 58.0) at a temperature of 95 °C and a pressure of 103 kPa

0 7 . 1 Calculate the volume, in cm^3, of propanone in the gas syringe.

The gas constant, R = 8.31 J K^{-1} mol^{-1}

[4 marks]

Volume of propanone _____ cm^3

0 7 . 2 The gas syringe is then cooled to 75 °C, without changing the pressure.

Calculate the decrease in volume.

(If you were unable to calculate the volume in Question **07.1**, you should use the volume 89 cm^3. This is not the correct answer.)

[2 marks]

Decrease in volume _____ cm^3

Do not write outside the box

0 7 . 3 The total uncertainty in using the balance to measure the mass of propanone in Question **07.1** is ±0.001 g

Calculate the uncertainty that this causes in the volume, in cm^3, of propanone calculated in Question **07.1**.

(If you were unable to calculate the volume in Question **07.1**, you should use the volume 89 cm^3. This is not the correct answer.)

[2 marks]

Uncertainty _____ cm^3

0 7 . 4 A 600 cm^3 sample of propanone is mixed with 2800 cm^3 of oxygen in a container at 60 °C and 100 kPa. The mixture is ignited.
When the reaction is complete, the remaining mixture of gases is cooled to 60 °C at 100 kPa

$$CH_3COCH_3(g) + 4\,O_2(g) \rightarrow 3\,CO_2(g) + 3\,H_2O(l)$$

Calculate the total volume of the remaining gas mixture.

[2 marks]

Volume _____ cm^3

10

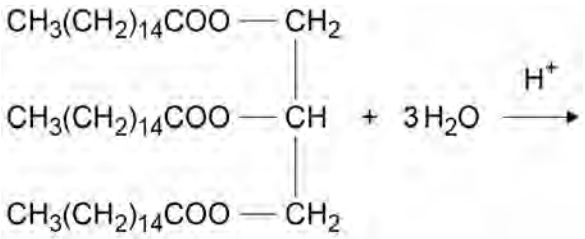
Do not write outside the box

0 8 This question is about biofuels.

Palmitic acid, $CH_3(CH_2)_{14}COOH$, can be made by hydrolysis of the triester in palm oil under acidic conditions.
Palmitic acid can be used as a biofuel.

0 8 . 1 Complete the equation for the hydrolysis of the triester in palm oil under acidic conditions.

[2 marks]



0 8 . 2 Palmitic acid burns in air.

In a calorimetry experiment, combustion of 387 mg of palmitic acid increases the temperature of 0.150 kg of water from 23.9 °C to 37.5 °C

Calculate a value, in kJ mol^{-1}, for the enthalpy of combustion of palmitic acid in this experiment.
Give your answer to the appropriate number of significant figures.

The specific heat capacity of water is 4.18 J K^{-1} g^{-1}

[5 marks]

Enthalpy of combustion _____ kJ mol^{-1}

Do not write outside the box

0 8 . 3 State how the value calculated in Question **08.2** is likely to differ from data book values.

Give one reason, other than heat loss, for this difference.

[2 marks]

Difference _____

Reason _____

_____

0 8 . 4 A sample of a different biofuel, made from sewage sludge, is found to contain 37.08% carbon, 5.15% hydrogen and 24.72% oxygen by mass.
The rest of the sample is sulfur.

Calculate the empirical formula of this biofuel.

[3 marks]

Empirical formula _____

0 8 . 5 Complete combustion of the biofuel made from sewage sludge produces the greenhouse gas carbon dioxide.

Suggest **one** other possible environmental problem with the complete combustion of this biofuel.

State the formula of the pollutant responsible for this problem.

[2 marks]

Environmental problem _____

_____

Formula _____

Do not write outside the box

0 8 . 6 Ethanol is a biofuel that can be produced by the fermentation of glucose.

$$C_6H_{12}O_6 \rightarrow 2\,C_2H_5OH + 2\,CO_2$$

Glucose has the structural formula shown.

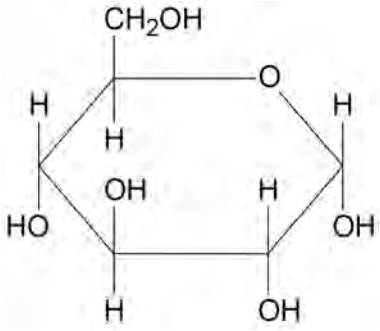


Table 3 shows some mean bond enthalpy values.

Table 3

	C–H	C–C	C–O	C=O	O–H
Mean bond enthalpy / kJ mol^{-1}	412	348	360	805	463

Use the equation and the data in **Table 3** to calculate an approximate value of Δ*H* for the fermentation of glucose. For this calculation you should assume that all the substances are in the gaseous state.

[3 marks]

Δ*H* _____ kJ mol^{-1}

Do not write outside the box

0 8 . 7 The carbon dioxide produced from fermentation can be reacted with steam to make more ethanol.

The equation for this reaction is

$$2\,CO_2(g) + 3\,H_2O(g) \rightarrow C_2H_5OH(g) + 3\,O_2(g)$$

Table 4 shows some standard enthalpies of formation.

Table 4

	$CO_2(g)$	**$O_2(g)$**	**$C_2H_5OH(g)$**	**$H_2O(g)$**
$\Delta_f H^{\ominus}$ / kJ mol^{-1}	–394	0	–235	–242

Use the data in **Table 4** to calculate a standard enthalpy change value for this reaction.

[2 marks]

Standard enthalpy change _____ kJ mol^{-1}

19

Turn over for the next question

Do not write outside the box

0 9 This question is about ethanoic anhydride.

In the gas phase, ethanoic anhydride $(CH_3CO)_2O$ decomposes to form ethenone.

The equation is

$$(CH_3CO)_2O \rightarrow H_2C{=}C{=}O + CH_3COOH$$
Ethenone

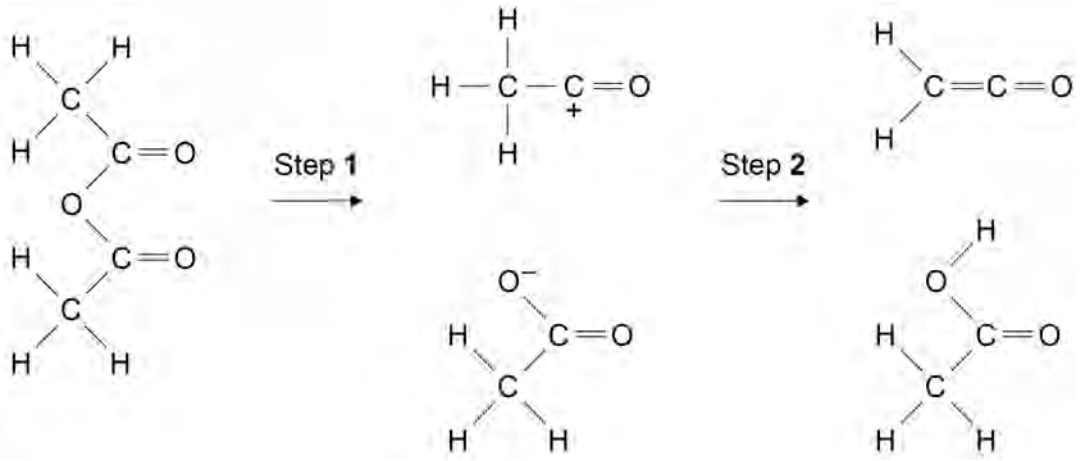
0 9 . 1 Ethenone is the simplest member of the ketene homologous series.
Ketenes all contain one C=C double bond and one C=O double bond.

Deduce the general formula for the ketene homologous series.

[1 mark]

0 9 . 2 **Figure 11** shows an incomplete suggested mechanism for the decomposition of ethanoic anhydride.

Figure 11



Complete the mechanism in **Figure 11** by adding three curly arrows and any relevant lone pairs of electrons.

[3 marks]

Do not write outside the box

0 9 . 3 For a chemical reaction the relationship between the rate constant, k, and the temperature, T, is shown by the Arrhenius equation.

$$k = Ae^{\frac{-E_a}{RT}}$$

For the decomposition of gaseous ethanoic anhydride

the activation energy, E_a = 34.5 kJ mol^{-1}
the Arrhenius constant, A = 1.00 × 10^{12} s^{-1}

At temperature T_1 the rate constant, k = 2.48 × 10^{8} s^{-1}

Calculate T_1

The gas constant, R = 8.31 J K^{-1} mol^{-1}

[3 marks]

T_1 _____ K

Question 9 continues on the next page

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0 9 . 4 Sketch the Maxwell–Boltzmann distribution of molecular energies for gaseous ethanoic anhydride at temperature T_1 and at a higher temperature T_2

Include a label for each axis, and mark on the appropriate axis a typical position for the activation energy.

Explain why the rate of reaction is faster at T_2

[5 marks]

Explanation

12

END OF QUESTIONS

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ANSWER IN THE SPACES PROVIDED

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Question number	**Additional page, if required.** **Write the question numbers in the left-hand margin.**

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Question number	**Additional page, if required.** **Write the question numbers in the left-hand margin.**
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