A

Surname ______________________________

Forename(s) ______________________________

Centre Number ______________________________

Candidate Number ______________________________

Candidate Signature ______________________________

I declare this is my own work.

A-level

CHEMISTRY

Paper 2 Organic and Physical Chemistry

7405/2

Monday 19 June 2023 **Afternoon**

Time allowed: 2 hours

At the top of the page, write your surname and forename(s), your centre number, your candidate number and add your signature.

[Turn over]

JUN237405201

MATERIALS

For this paper you must have:

- **the Periodic Table/Data Sheet, 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.**
- **Answer ALL questions.**
- **You must answer the questions in the spaces provided. Do NOT write 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.

DO NOT TURN OVER UNTIL TOLD TO DO SO

Answer ALL questions in the spaces provided.

0 1

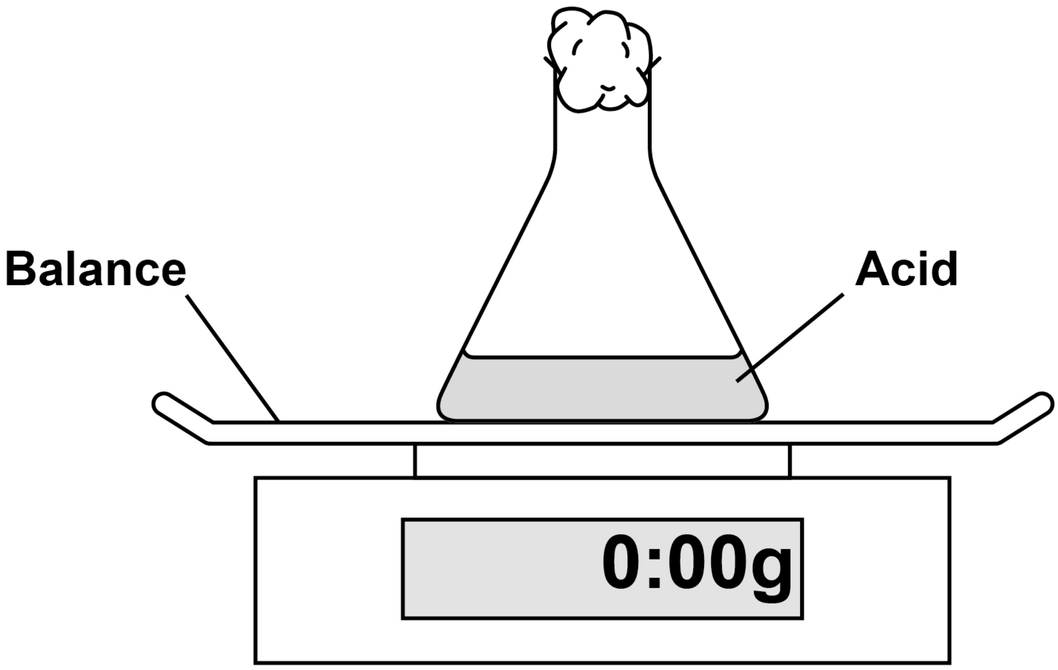
This question is about rates of reaction.

FIGURE 1, on the opposite page, 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]

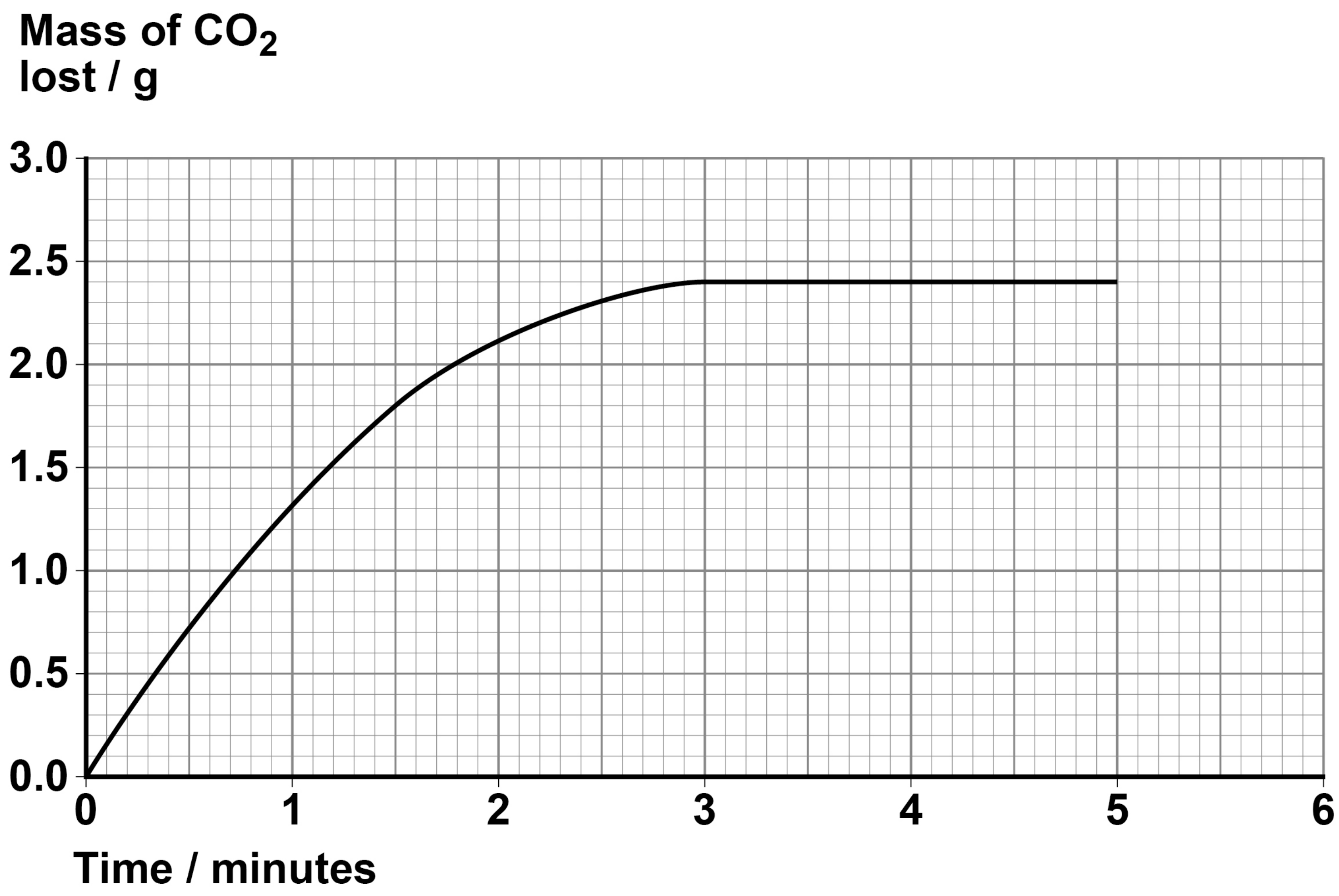
____

____

____

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** ______________________________

[Turn over]

0 1 . 3

Chloroethanoic acid is a stronger acid than ethanoic acid.

Sketch, on FIGURE 2 on page 6, 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.

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

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 $B + H^+ \longrightarrow BH^+$

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

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

Deduce the rate-determining step for this reaction.

Give a reason for your answer. [2 marks]

Rate-determining step ______________________________

Reason ______________________________

____

____

____

___
5

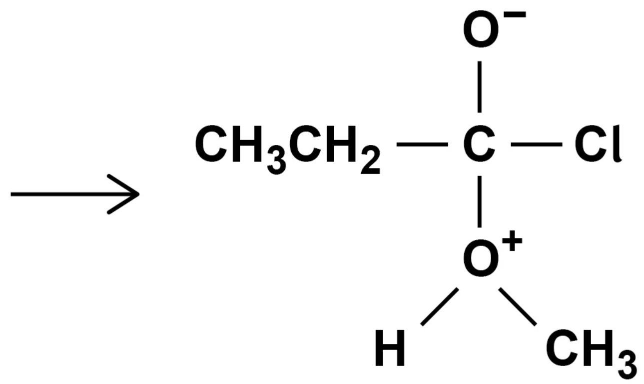
0 3

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



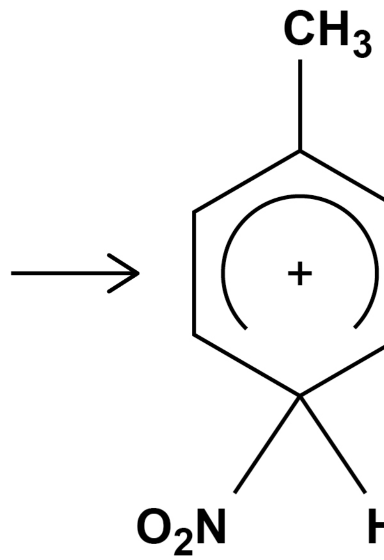
Complete FIGURE 3 to show the structures of the two reactant species with curly arrows and relevant lone pairs of electrons involved in the formation of the intermediate.

Draw curly arrows and relevant lone pairs of electrons on the intermediate to show how the final products are formed. [4 marks]

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 ______________________________

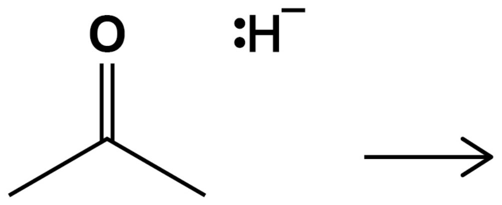
____

[Turn over]

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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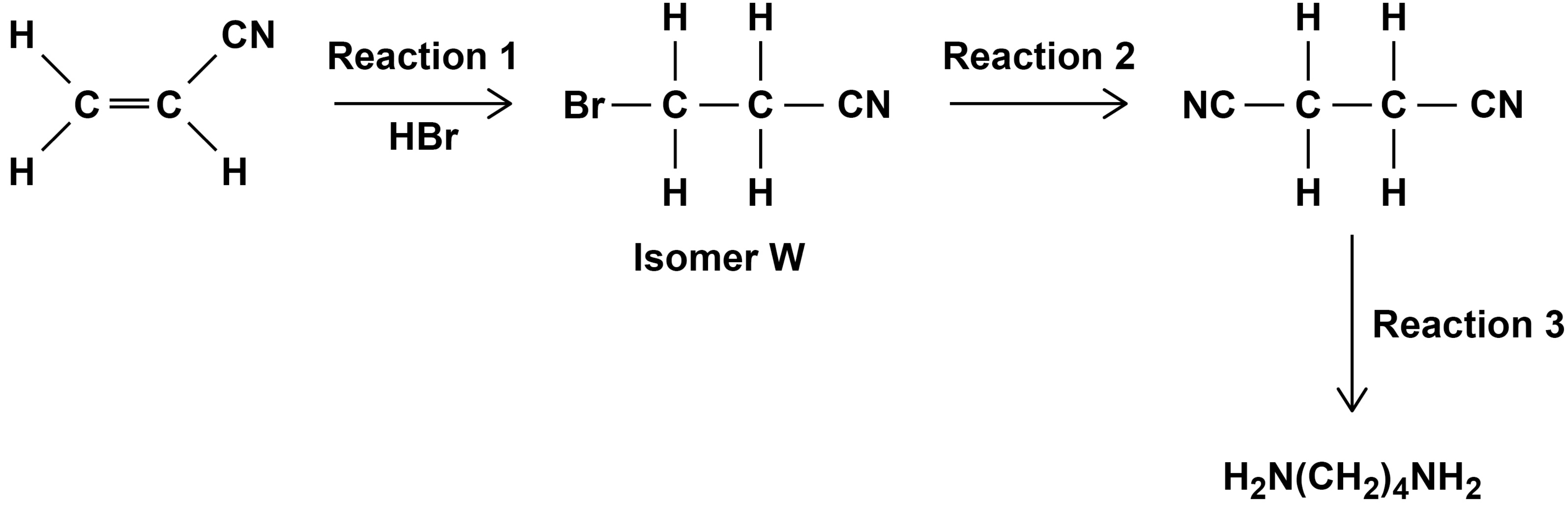
[Turn over]

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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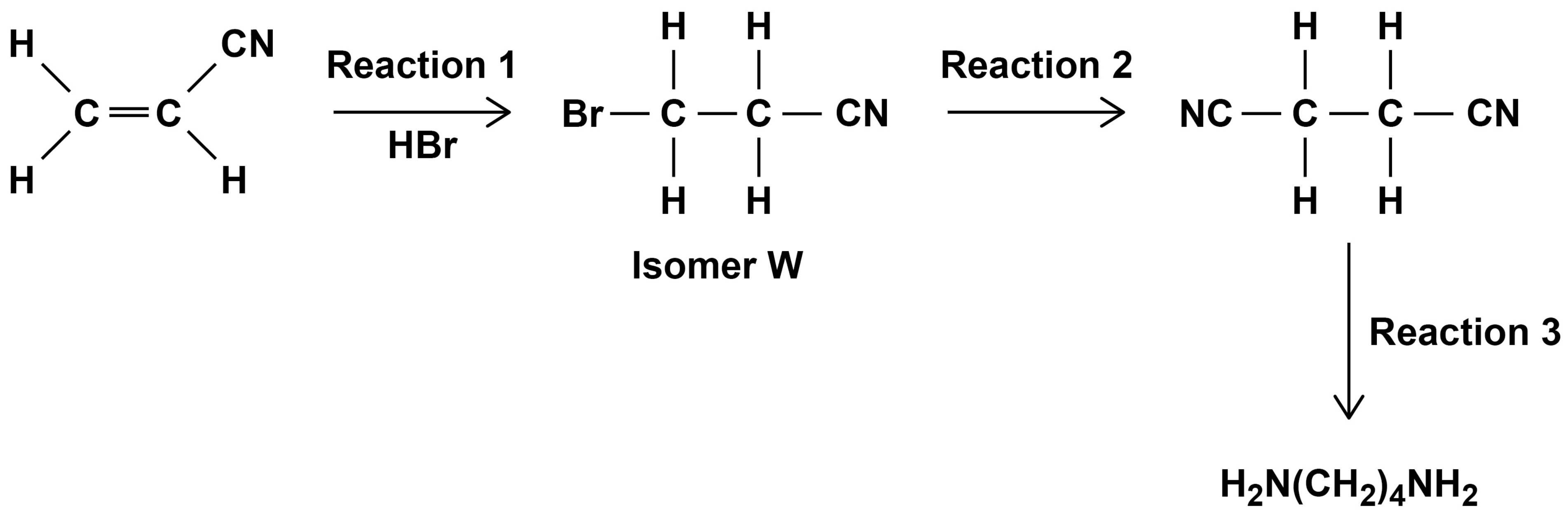
[Turn over]

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

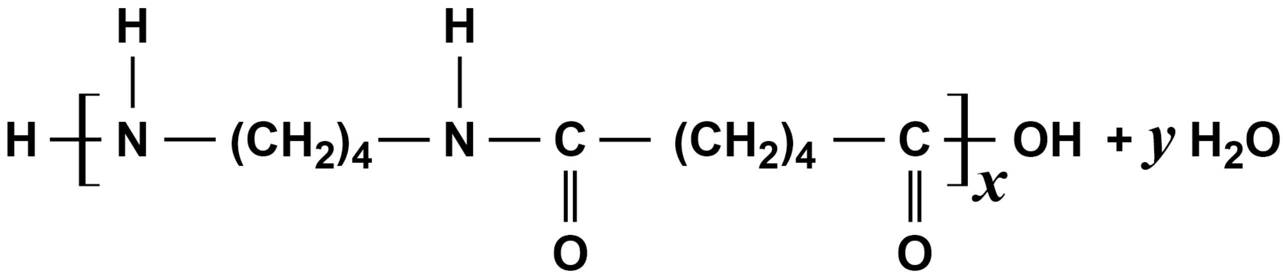
____

[Turn over]

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.

$5\,H_2N(CH_2)_4NH_2 + 5\,HOOC(CH_2)_4COOH \longrightarrow$



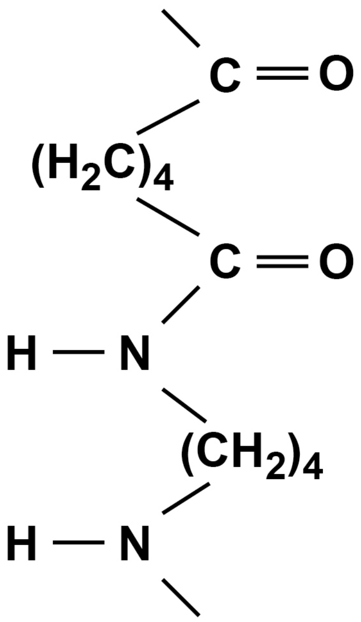
Deduce the values of *x* and *y* in this equation. [2 marks]

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]

[Turn over]

15

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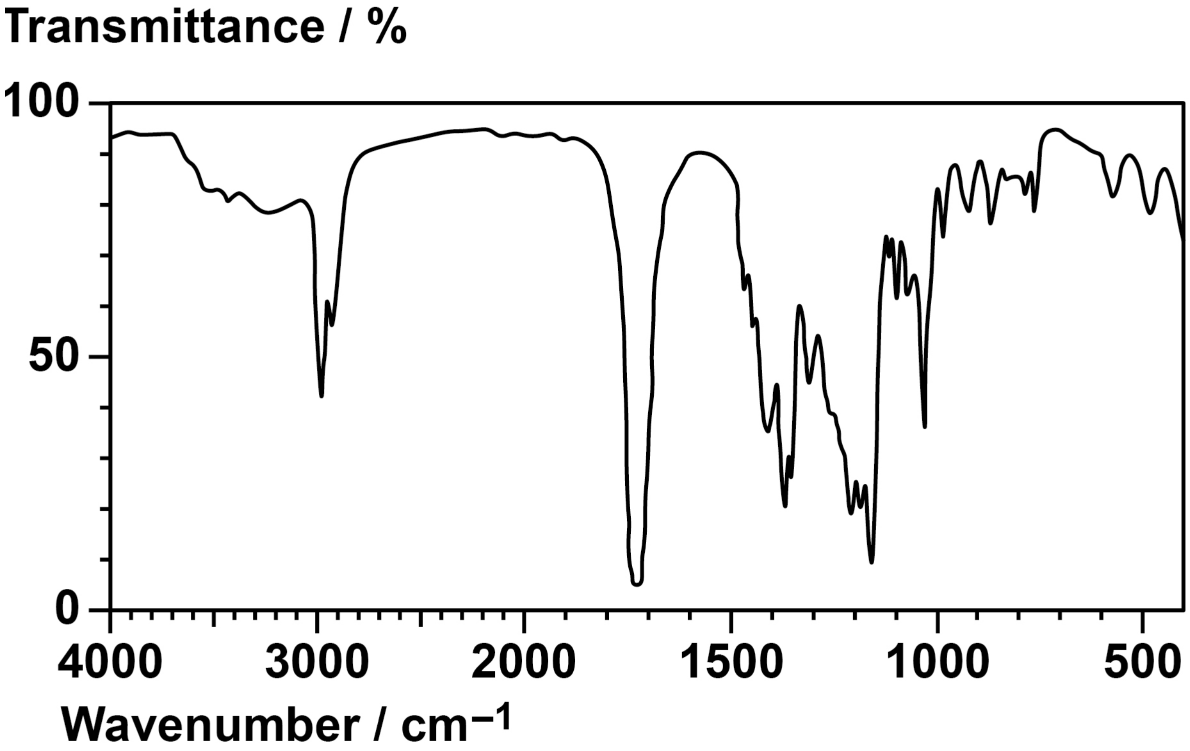
0 5

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

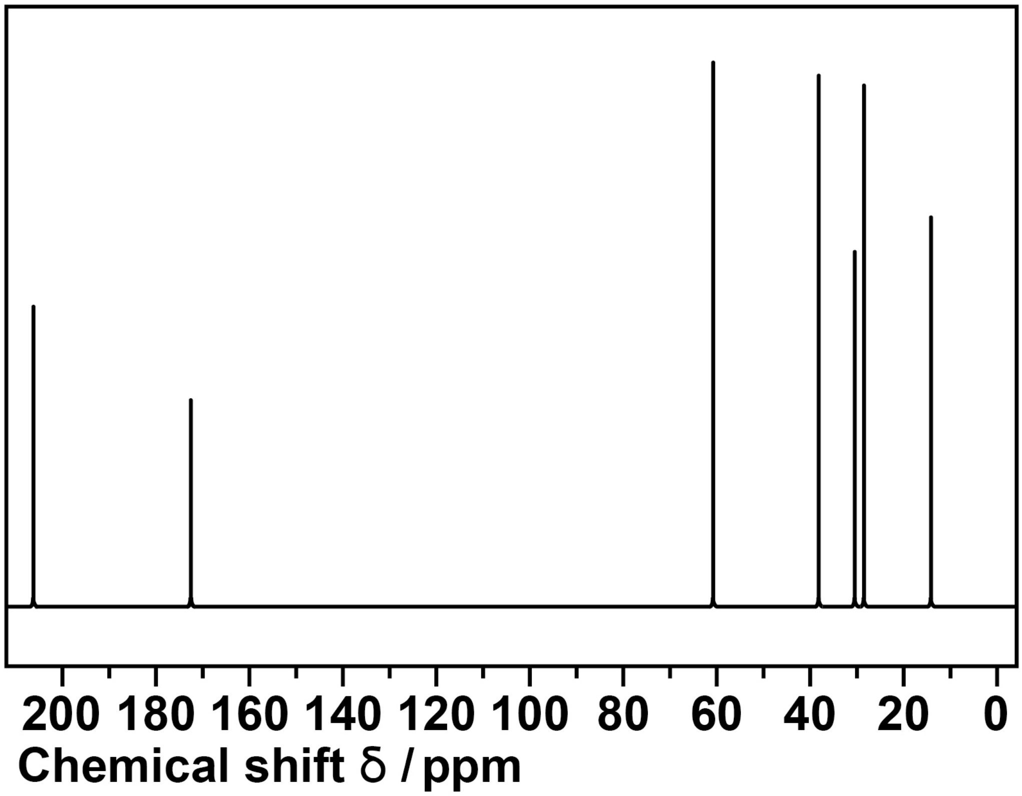
Identify the bond that causes the absorption at 1725 cm^{-1} [1 mark]

____

____

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]

[Turn over]

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

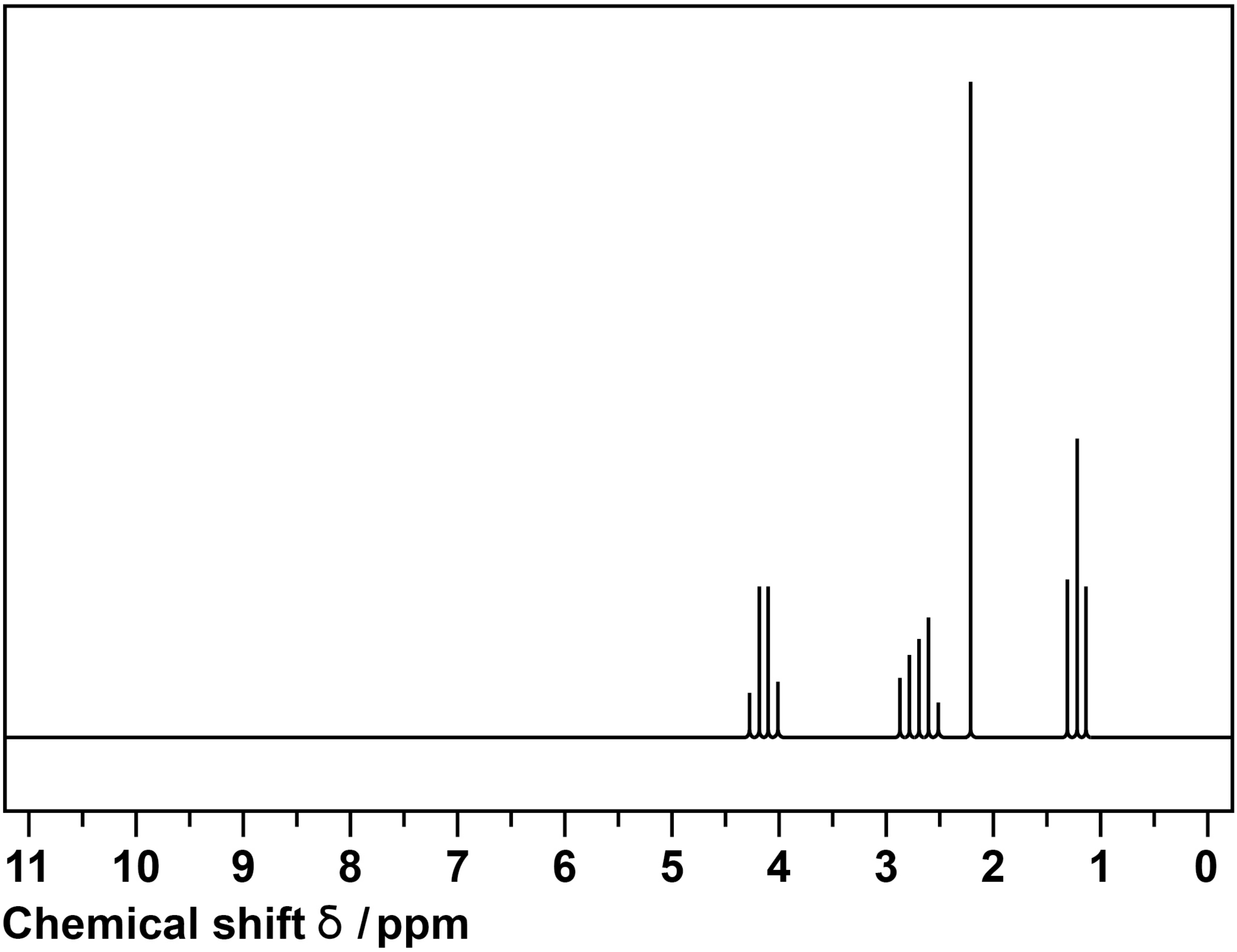
05.5

Deduce the part of the structure of Z that causes the peak at δ = 2.19 ppm [1 mark]

Part of structure

FIGURE 9 shows the ^1H 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 30. [1 mark]

___

___

05.7

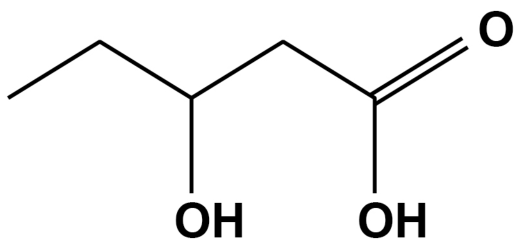
Deduce the structure of Z. [1 mark]

[Turn over]

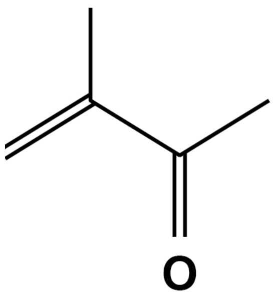
11

0 6

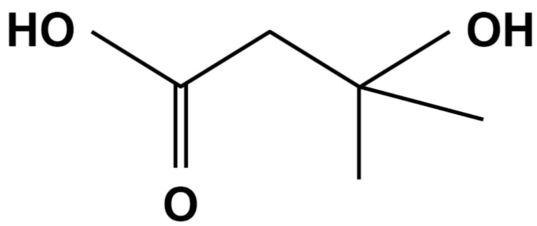
A student plans a series of chemical tests to confirm the identities of four organic liquids.



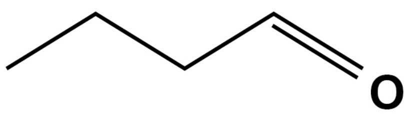
Liquid J



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]

___

___

[Turn over]

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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 ______________________________________

____

____

[Turn over]

0 6 . 4

FIGURE 10, on the opposite page, 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]

Label S ____

____

Label T ____

____

Label U ____

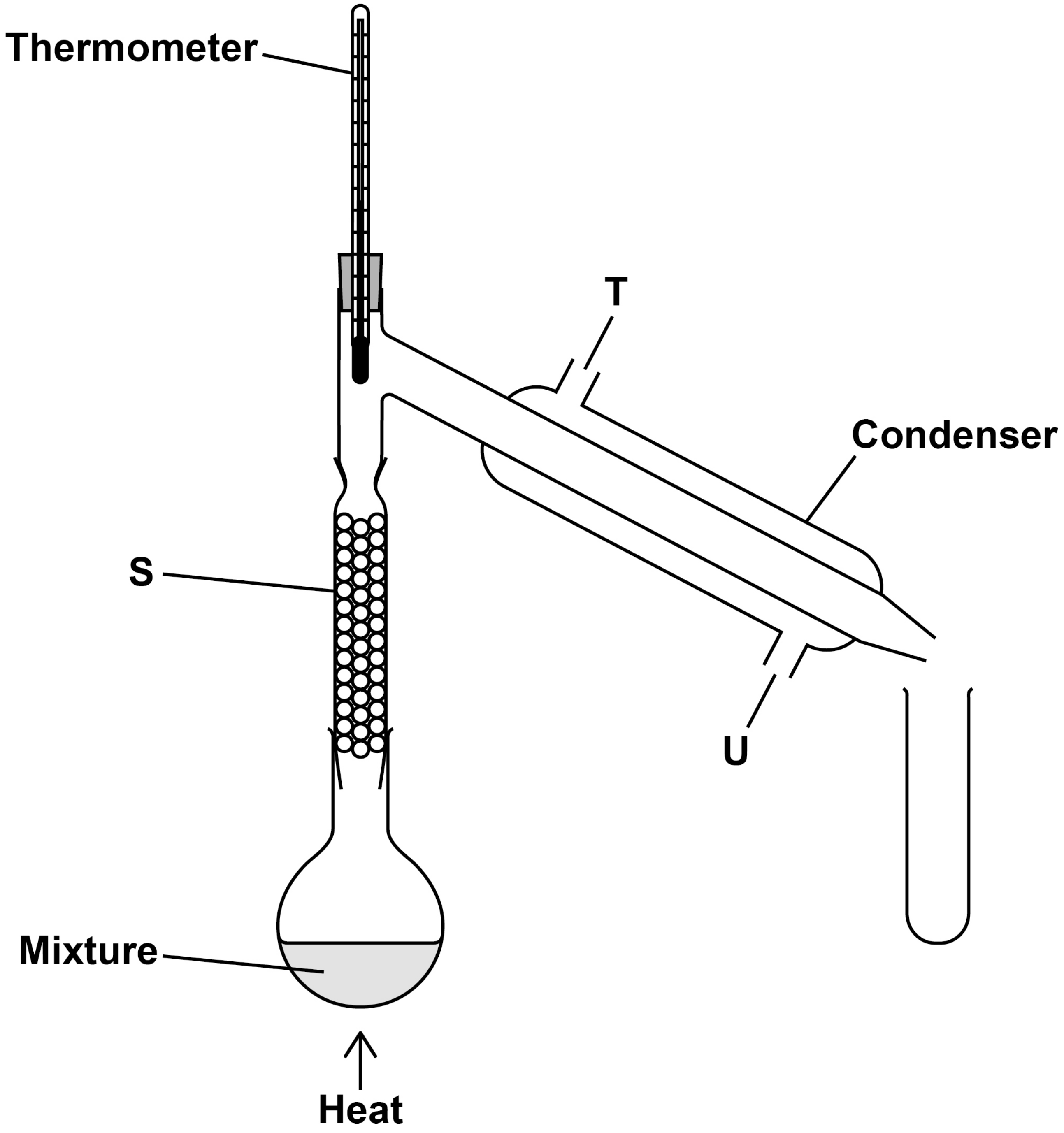
____

Explanation ____

____

____

FIGURE 10



14

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

[Turn over]

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

07.3

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

[Turn over]

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

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

Calculate the total volume of the remaining gas mixture.
[2 marks]

Volume ______________________________ **cm^3**

10

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[Turn over]

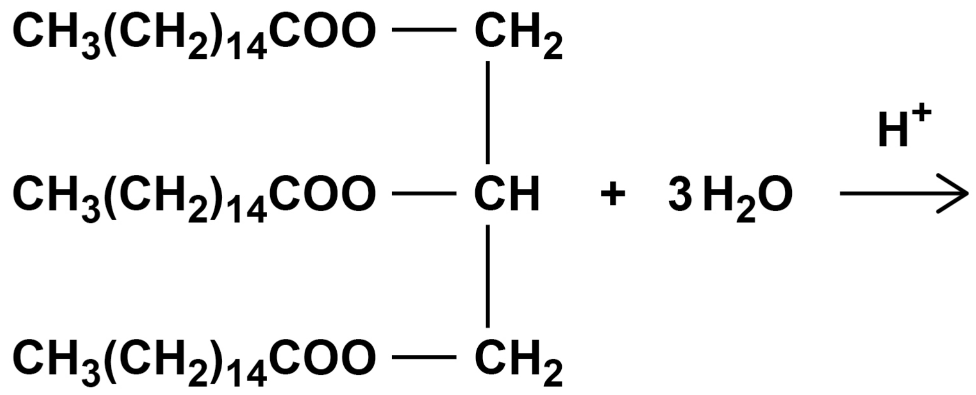
0 8

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]



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[Turn over]

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}

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 ____

____

____

[Turn over]

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 ______________________________

08.5

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 ______________________________________

____

[Turn over]

0 8 . 6

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

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$$

Glucose has the structural formula shown.

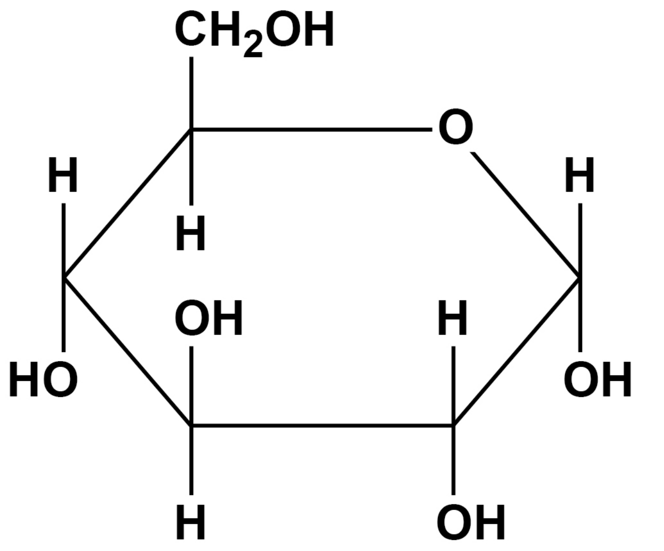


TABLE 3 shows some mean bond enthalpy values.

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}

[Turn over]

0 8 . 7

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

The equation for this reaction is

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

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}

[Turn over]

____
19

0 9

This question is about ethanoic anhydride.

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

The equation is

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

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.

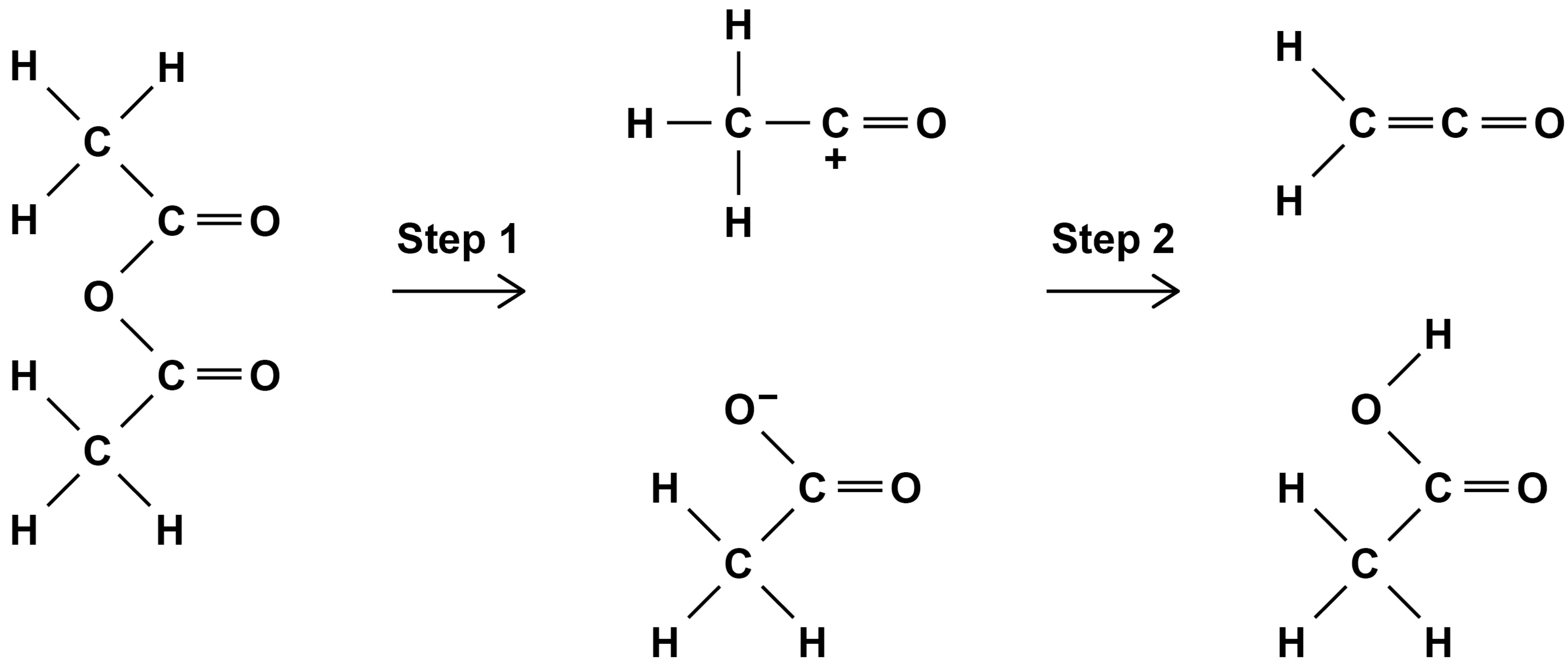
Deduce the general formula for the ketene homologous series. [1 mark]

____

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]

[Turn over]

0 9 . 3

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

$$k = \text{A}e^{\frac{-E_a}{RT}}$$

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

[Turn over]

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 ____________________________________

____

END OF QUESTIONS

12

Additional page, if required.

Write the question numbers in the left-hand margin.

Additional page, if required.

Write the question numbers in the left-hand margin.

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For Examiner's Use	
Question	Mark
1	
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2 3 6 A 7 4 0 5 / 2