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

Tuesday 18 June 2024 Morning 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	
10	
11	
TOTAL	

Do not write outside the box

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

0 1 Propanone reacts with bromine in alkaline conditions.

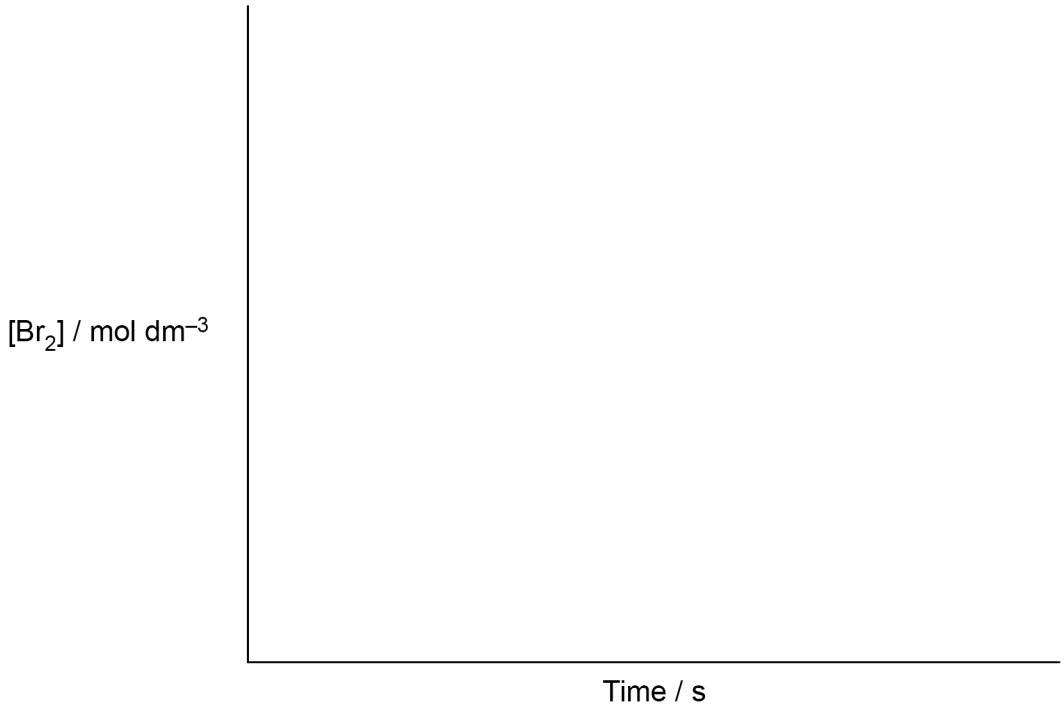
$$CH_3COCH_3 + Br_2 + OH^- \longrightarrow CH_3COCH_2Br + Br^- + H_2O$$

The rate equation for this reaction is

$$Rate = k\,[CH_3COCH_3]\,[OH^-]$$

0 1 . 1 Sketch a graph on the axes provided to show how, at constant temperature, the concentration of bromine changes during this reaction.

[1 mark]



Do not write outside the box

0 1 . 2 **Table 1** shows the initial rate of this reaction for experiments using different mixtures containing propanone, bromine and hydroxide ions.

Table 1

Experiment	$[CH_3COCH_3]$ / mol dm^{-3}	$[Br_2]$ / mol dm^{-3}	$[OH^-]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	1.50×10^{-2}	2.50×10^{-2}	2.50×10^{-2}	2.75×10^{-11}
2	1.50×10^{-2}	2.50×10^{-2}		8.25×10^{-11}
3	3.75×10^{-3}	5.00×10^{-2}	1.00×10^{-1}	

Complete **Table 1**.

Use the data from experiment **1** to calculate the rate constant *k* for this reaction.

Give the units for the rate constant.

[5 marks]

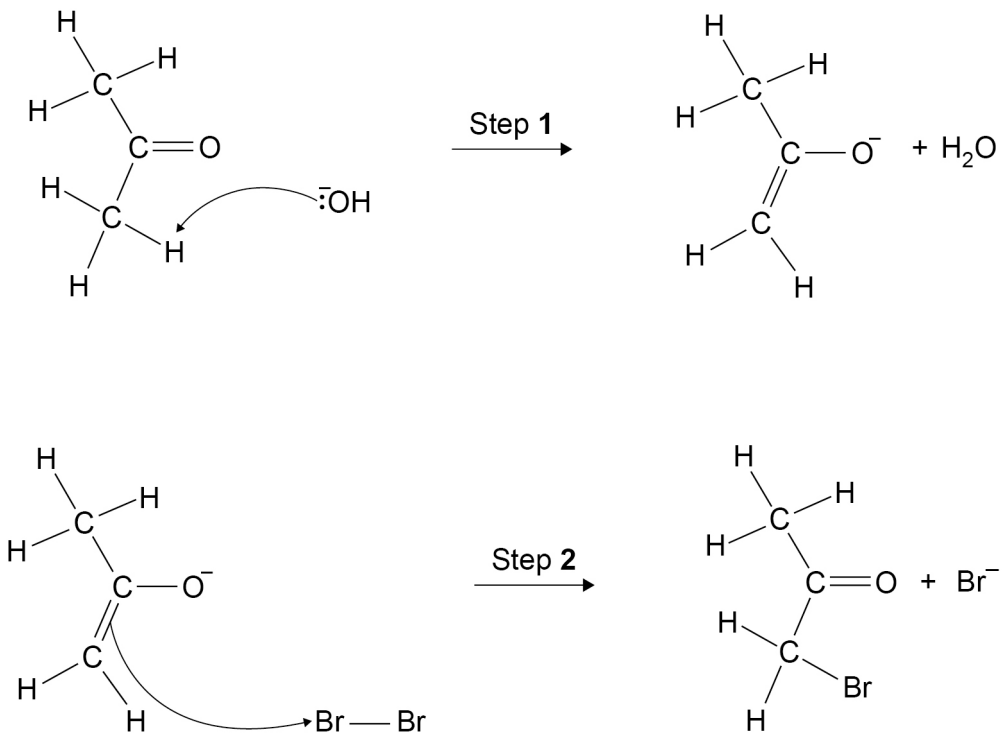
k _____ Units _____

Question 1 continues on the next page

Do not write outside the box

0 1 . 3 **Figure 1** shows an incomplete mechanism for this reaction.

Figure 1



Complete the mechanism in **Figure 1** by adding four curly arrows and any relevant lone pair(s) of electrons.

[4 marks]

0 1 . 4 Use evidence from the rate equation to explain why Step **1** is the rate determining step.

[1 mark]

_____

_____

11

Do not write outside the box

Turn over for the next question

DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED

Do not write outside the box

0 2 This question is about an equilibrium.

$$2\,\mathbf{P}(aq) + \mathbf{Q}(aq) \rightleftharpoons \mathbf{R}(aq) + 3\,\mathbf{S}(aq)$$

A 25.0 cm^3 sample of a solution of **P** is added to a 20.0 cm^3 sample of a solution of **Q**. The mixture is allowed to reach equilibrium.

The amounts in the equilibrium mixture are

P = 0.0145 mol **Q** = 0.0275 mol **R** = 0.0115 mol **S** = 0.0345 mol

0 2 . 1 Calculate the amount, in moles, of **P** before the reaction with **Q**.

Use your answer to calculate the concentration, in mol dm^{-3}, of **P** in the initial 25.0 cm^3 sample.

[2 marks]

Amount of **P** _____ mol

Concentration _____ mol dm^{-3}

Do not write outside the box

0 2 . 2 Give the expression for the equilibrium constant, K_c

Calculate the value of K_c and deduce its units.

[4 marks]

K_c

Value of K_c _____ Units _____

0 2 . 3 Explain why the amount of **S** increases when water is added to the equilibrium mixture.

[2 marks]

_____

_____

_____

_____

8

Turn over for the next question

Do not write outside the box

0 3 This question is about hydrocarbons.

0 3 . 1 Eicosane ($C_{20}H_{42}$) can be cracked by heating to 700 K in the presence of a catalyst.

The products are

- an aromatic hydrocarbon C_8H_{10}
- an alkane C_6H_{14}
- another alkane.

$$C_{20}H_{42} \longrightarrow C_8H_{10} + C_6H_{14} + _____$$

Complete the equation for this reaction.

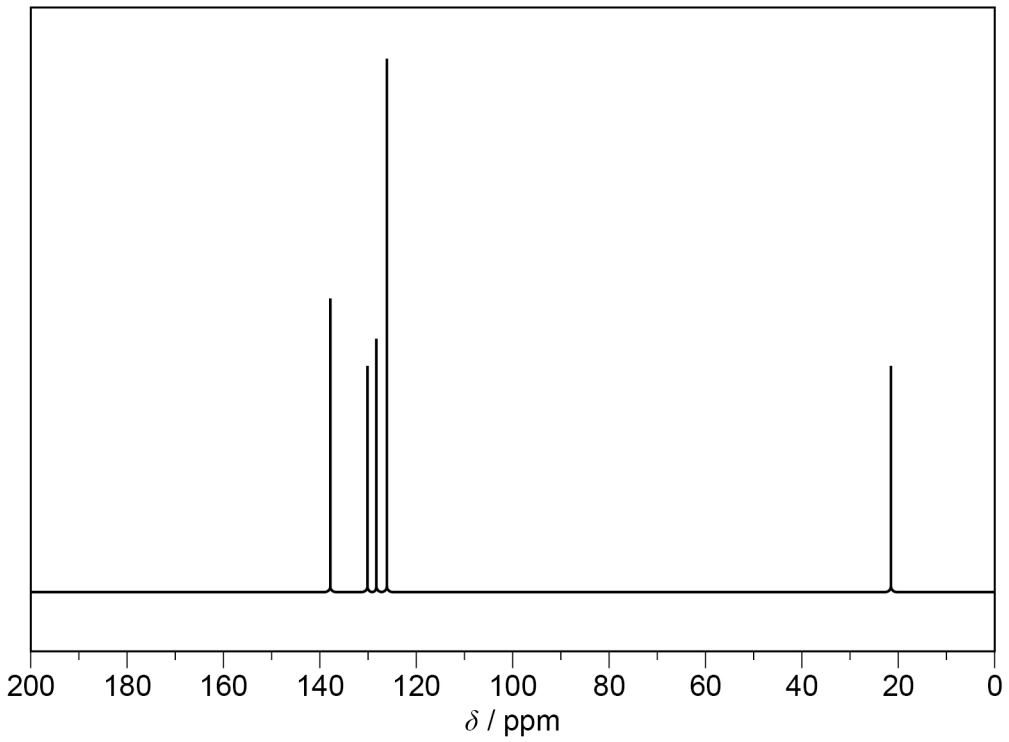
Give a suitable catalyst for this reaction.

[2 marks]

Catalyst _____

0 3 . 2 **Figure 2** shows the ^{13}C NMR spectrum for the aromatic hydrocarbon C_8H_{10}

Figure 2



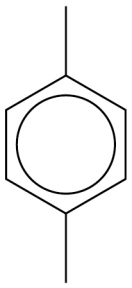
Do not write outside the box

Which of these is the structure of C_8H_{10}?

[1 mark]

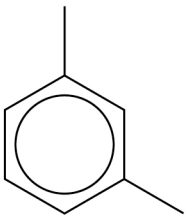
Tick (✓) **one** box.

A



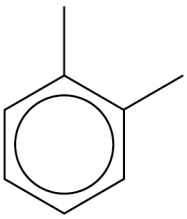
☐

B



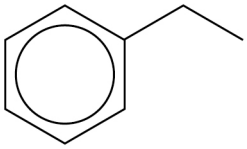
☐

C



☐

D



☐

0 3 . 3 Cracking can also be done without a catalyst, using a temperature of 1200 K and a pressure of 7000 kPa

State the type of product that is formed in high percentage in this type of cracking.

[1 mark]

_____

Question 3 continues on the next page

Do not write outside the box

0 3 . 4 A sample of butane has a volume of 20 cm^3 at room temperature and pressure.

The sample is burned completely in 1350 cm^3 of air.

The final mixture is cooled to room temperature and pressure.

$$C_4H_{10} + 6\tfrac{1}{2}O_2 \longrightarrow 4\,CO_2 + 5\,H_2O$$

Calculate the total volume of gas in the final mixture.
Assume that air contains 21% by volume of oxygen.

[4 marks]

Total volume of gas remaining _____ cm^3

0 3 . 5 Natural gas is used in power stations to produce electricity.

Natural gas contains sulfur impurities. Sulfur dioxide forms when these impurities are burned.

State an environmental problem caused by sulfur dioxide.

Give the formula of a compound that is used to help remove sulfur dioxide from the combustion products.

[2 marks]

Environmental problem _____

Formula of compound _____

10

Do not write outside the box

Turn over for the next question

DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED

Do not write outside the box

0 4 This question is about the preparation of an ester.

0 4 . 1 Ester **F** can be prepared from propan-2-ol and ethanoic acid.

Give an equation for this reaction.

Name ester **F**.

[2 marks]

Equation

Name

This method is used to prepare a sample of ester **F**.

Step 1 Mix 10 cm^3 of propan-2-ol with 10 cm^3 of ethanoic acid.
Add 5 drops of concentrated sulfuric acid.
Reflux this reaction mixture for 20 minutes.

Step 2 Transfer the cooled reaction mixture to a separating funnel.
Add 20 cm^3 of aqueous sodium carbonate and shake the mixture.

Step 3 Transfer the organic layer to a beaker and add 5 g of anhydrous magnesium sulfate.
Decant off the organic liquid.

Step 4 Collect the ester using simple distillation.

0 4 . 2 Describe how **Step 1** should be done.

In your description you should

- give details of suitable equipment used to add each reagent to the reflux apparatus
- draw a labelled diagram of the apparatus used for refluxing the reaction mixture
- explain any safety precautions needed other than eye protection.

[6 marks]

Do not write outside the box

Question 4 continues on the next page

Do not write outside the box

0 4 . 3 In **Step 2** the reaction mixture from **Step 1** is shaken with aqueous sodium carbonate.

State the purpose of the sodium carbonate.

Suggest a precaution that should be taken while this mixture is shaken in the separating funnel.

Give a reason for your suggested precaution.

[3 marks]

Purpose of sodium carbonate _____

_____

Precaution _____

_____

Reason _____

_____

0 4 . 4 Give the reason for the use of anhydrous magnesium sulfate in **Step 3**.

[1 mark]

_____

_____

0 4 . 5 Suggest how the purity of the ester can be confirmed during the distillation in **Step 4**.

[1 mark]

_____

_____

13

Do not write outside the box

0 5 This question is about simple test-tube reactions to identify organic liquids.

0 5 . 1 Silver nitrate solution can be used to distinguish between propanoyl chloride and 1-chloropropane.

Give the observations you would expect when a few drops of silver nitrate solution are added to separate samples of propanoyl chloride and 1-chloropropane.

[2 marks]

Observation with propanoyl chloride _____

_____

Observation with 1-chloropropane _____

_____

0 5 . 2 Three unlabelled bottles are known to contain either propan-1-ol, propanal, or propanone.

A sample of each liquid is warmed with a few drops of Fehling's solution.

Identify the liquid that reacts with Fehling's solution and give the expected observation.

Suggest a further simple test-tube reaction that can be used to distinguish between the remaining two liquids.

Give the expected observation with the liquid that reacts.

[3 marks]

Liquid that reacts with Fehling's solution _____

Observation _____

_____

Further test _____

_____

Observation _____

_____

5

Do not write outside the box

0 6 Compounds **V**, **W**, **X** and **Y** are isomers with the molecular formula $C_5H_{10}O_2$

Isomers **V** and **W** are carboxylic acids with formulas that can be written as C_4H_9COOH

0 6 . 1 Give an equation for the reaction of C_4H_9COOH with sodium hydrogencarbonate.

[1 mark]

0 6 . 2 Isomer **V** has an asymmetric carbon atom.

Deduce the structure of **V**.

[1 mark]

0 6 . 3 Isomer **W** has four peaks in its ^1H NMR spectrum.

Deduce the structure of **W**.

Deduce the integration ratio for the four peaks in the ^1H NMR spectrum of **W**.

[2 marks]

Structure

Integration ratio _____

Do not write outside the box

0 6 . 4 Isomer **X** has three singlets with integration ratio 1:3:6 in its ^{1}H NMR spectrum.

Deduce the structure of **X**.

Explain why the peaks in the ^{1}H NMR spectrum are singlets.

[2 marks]

Structure

Explanation _____

_____

_____

Question 6 continues on the next page

Do not write outside the box

0 6 . 5 **Table 2** shows information about the peaks in the ^{1}H NMR spectrum of isomer **Y**.

Table 2

Chemical shift δ / ppm	Integration ratio	Splitting pattern
3.65	2	singlet
1.19	3	singlet

Draw the parts of the structure of **Y** that can be deduced from each of these peaks.

Deduce the structure of **Y**.

State how many peaks are in the ^{13}C NMR spectrum of **Y**.

[6 marks]

Part of structure from peak at δ = 3.65 ppm

Part of structure from peak at δ = 1.19 ppm

Structure of **Y**

Number of peaks in ^{13}C NMR spectrum of **Y** _____

12

Do not write outside the box

0 7 Compound **L** (M_r = 88.0) contains carbon, hydrogen and oxygen only.

A 6.56×10^{-4} mol sample of **L** burns completely in air to form 2.62×10^{-3} mol of water and 2.62×10^{-3} mol of carbon dioxide.

Deduce the formula of **L**.
Show your working.

[4 marks]

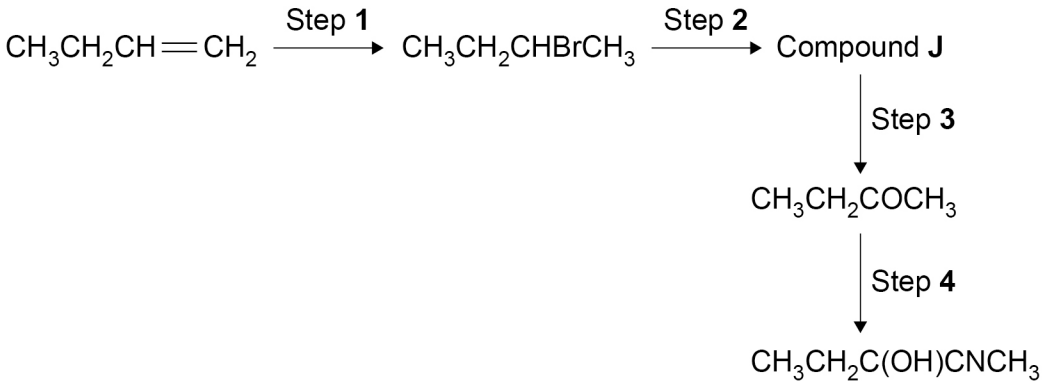
Formula of **L** _____

4

Turn over ►

Do not write outside the box

0 8 This question is about an organic synthesis.



0 8 . 1 Name the mechanism in Step **1**.

State the reagent(s) used for Step **1**.

[2 marks]

Name of mechanism _____

Reagent(s) _____

0 8 . 2 Identify compound **J**.

State the reagent(s) and conditions needed for Step **2**.

[2 marks]

Compound **J** _____

Reagent(s) and conditions _____

_____

Do not write outside the box

0 8 . 3 State the reagent(s) used for Step **4**.

Outline the mechanism for Step **4**.

[5 marks]

Reagent(s) _____

Mechanism

0 8 . 4 Explain why Step **4** produces a racemic mixture.

[3 marks]

_____

_____

_____

_____

_____

_____

12

Do not write outside the box

0 9 This question is about amines.

0 9 . 1 An incomplete equation for Step **1** in the reaction between bromoethane and an amine is shown.

Complete the equation.

In Step **2** of this reaction, the product of Step **1** forms a secondary amine.

Name the secondary amine formed.

[2 marks]

Amine name _____

0 9 . 2 $CH_3CHBrCH_2CH_3$ reacts with NH_3

Draw the skeletal formula of the major organic product formed when

- an excess of NH_3 is used
- an excess of $CH_3CHBrCH_2CH_3$ is used.

[2 marks]

Product with excess NH_3

Product with excess $CH_3CHBrCH_2CH_3$

Do not write outside the box

0 9 . 3 **Figure 3** shows a two-step synthesis to make amine **G**.

Figure 3

$$\xrightarrow{\text{Step } \mathbf{1}} (CH_3)_2CHCN + Br^-$$

$$(CH_3)_2CHCN + 2\,H_2 \xrightarrow{\text{Step } \mathbf{2}}$$

Amine **G**

Complete **Figure 3** by drawing the mechanism for Step **1** and the displayed formula of amine **G**.

[3 marks]

0 9 . 4 **Figure 4** shows two amines, **P** and **Q**.

Figure 4

Amine **P** Amine **Q**

Explain why **P** is a stronger base than **Q**.

[2 marks]

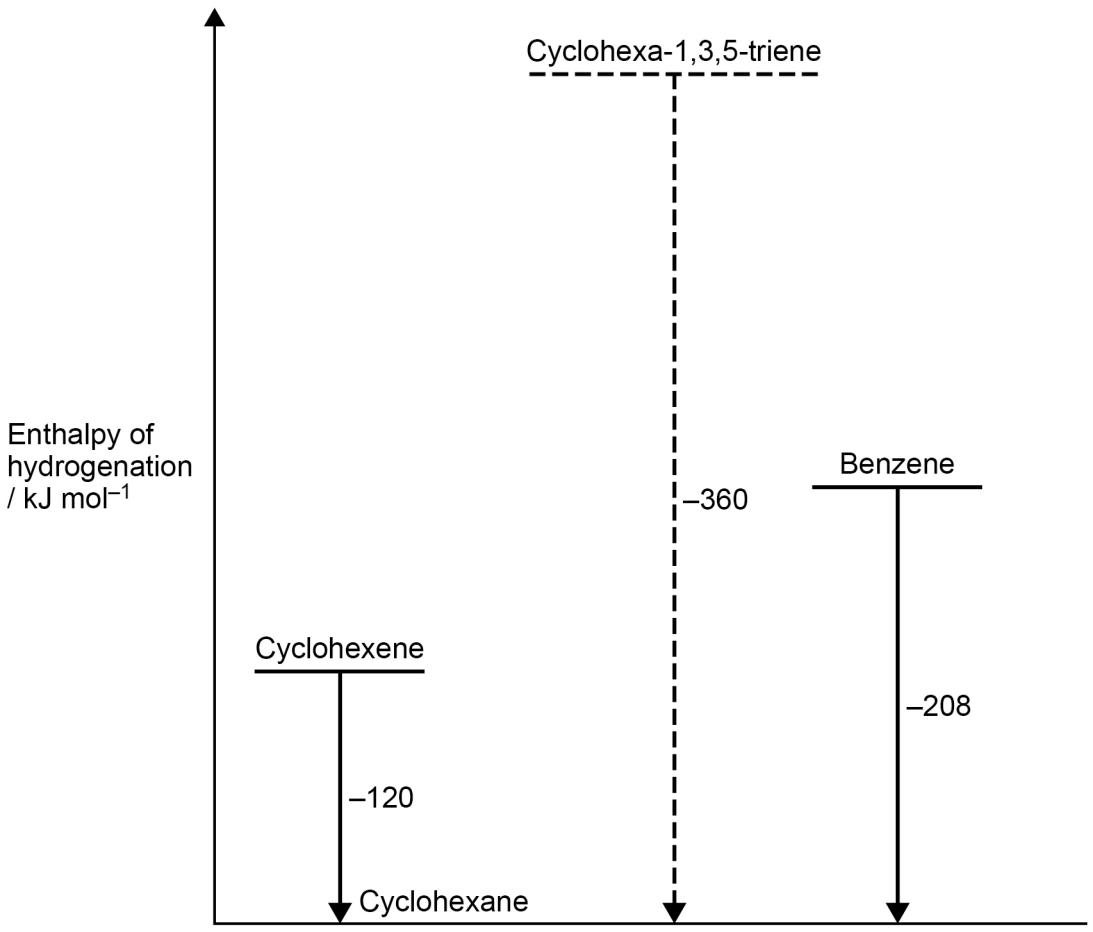
9

Do not write outside the box

1 0 **Figure 5** shows enthalpy of hydrogenation data for cyclohexene and benzene.

It also shows predicted data for the theoretical molecule cyclohexa-1,3,5-triene.

Figure 5



Do not write outside the box

1 0 . 1 Compare benzene and the theoretical molecule cyclohexa-1,3,5-triene in terms of:

- stability
- shape
- carbon–carbon bond lengths.

For each of these properties, suggest reasons for any differences.

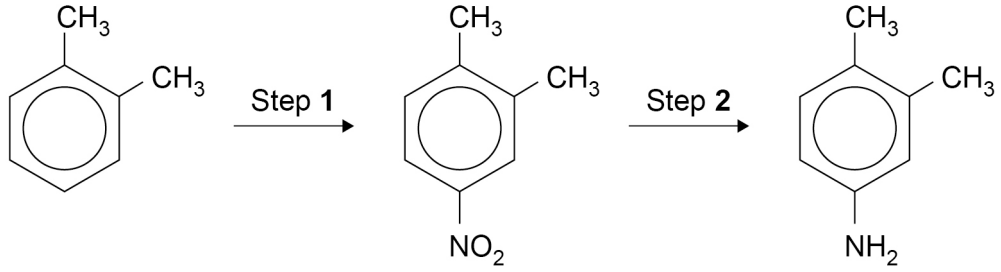
Use data from **Figure 5** in your answer.

[5 marks]

Question 10 continues on the next page

Do not write outside the box

Two steps in the synthesis of an aromatic amine are shown.



1 0 . 2 State the **two** reagents needed for Step **1**.

Give an equation to show the formation of the reactive intermediate from these two reagents.

[2 marks]

Reagents _____

_____

Equation

_____

1 0 . 3 Outline a mechanism for Step **1**.

[3 marks]

Do not write outside the box

1 0 . 4 State the reagent(s) needed for Step **2**.

[1 mark]

_____

1 0 . 5 State a possible use for the amine formed in Step **2**.

[1 mark]

_____

_____

12

Turn over for the next question

Do not write outside the box

1 1 This question is about enthalpy of combustion.

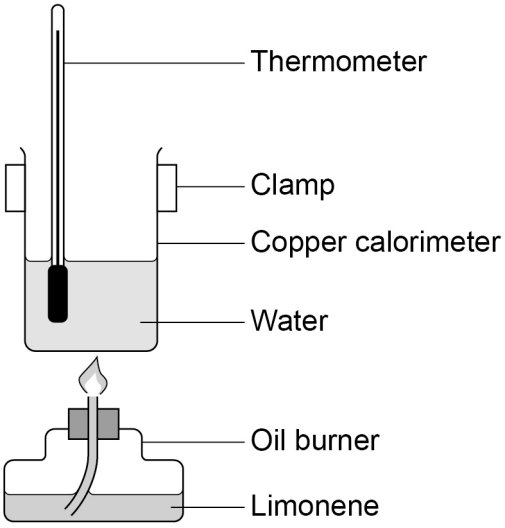
1 1 . 1 Limonene is found in the skin of citrus fruits.

Figure 6 shows a diagram of the apparatus used in an experiment to determine a value for the enthalpy of combustion of limonene.

When 1.31 g of limonene are burned, the temperature of the 60.0 g of water in the copper calorimeter increases by 52.1 °C

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

Figure 6



Calculate a value for the enthalpy of combustion, in kJ mol^{-1}, of limonene ($C_{10}H_{16}$).

[4 marks]

Enthalpy of combustion _____ kJ mol^{-1}

Do not write outside the box

1 1 . 2 **Table 3** shows values, obtained by different methods, for the enthalpy of combustion of a different liquid hydrocarbon.

Table 3

Method		Enthalpy of combustion / kJ mol^{-1}
1	Standard enthalpy of combustion $\Delta_c H^{\ominus}_{298}$	–4194
2	Value calculated from a calorimetry experiment	–1100
3	Value calculated using mean bond enthalpies	–3159

Suggest reasons for the differences between the values obtained by each of Methods **2** and **3**, and the value obtained by Method **1** in **Table 3**.

[5 marks]

9

END OF QUESTIONS

Do not write outside the box

There are no questions printed on this page

DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED

Do not write outside the box

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

Do not write outside the box

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

Copyright information

For confidentiality purposes, all acknowledgements of third-party copyright material are published in a separate booklet. This booklet is published after each live examination series and is available for free download from www.aqa.org.uk

Permission to reproduce all copyright material has been applied for. In some cases, efforts to contact copyright-holders may have been unsuccessful and AQA will be happy to rectify any omissions of acknowledgements. If you have any queries please contact the Copyright Team.

Copyright © 2024 AQA and its licensors. All rights reserved.