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I declare this is my own work.

A-level

CHEMISTRY

Paper 2 Organic and Physical Chemistry

7405/2

Tuesday 18 June 2024

Morning

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]



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.**
- **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.

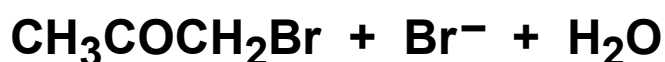
DO NOT TURN OVER UNTIL TOLD TO DO SO



Answer ALL questions in the spaces provided.

0 1

Propanone reacts with bromine in alkaline conditions.



The rate equation for this reaction is

$$\text{Rate} = k [\text{CH}_3\text{COCH}_3] [\text{OH}^-]$$

0 1 . 1

Sketch a graph on the axes provided, on the opposite page, to show how, at constant temperature, the concentration of bromine changes during this reaction.
[1 mark]



$[\text{Br}_2] / \text{mol dm}^{-3}$



Time / s

[Turn over]





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 ₃ COCH 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	

6

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]



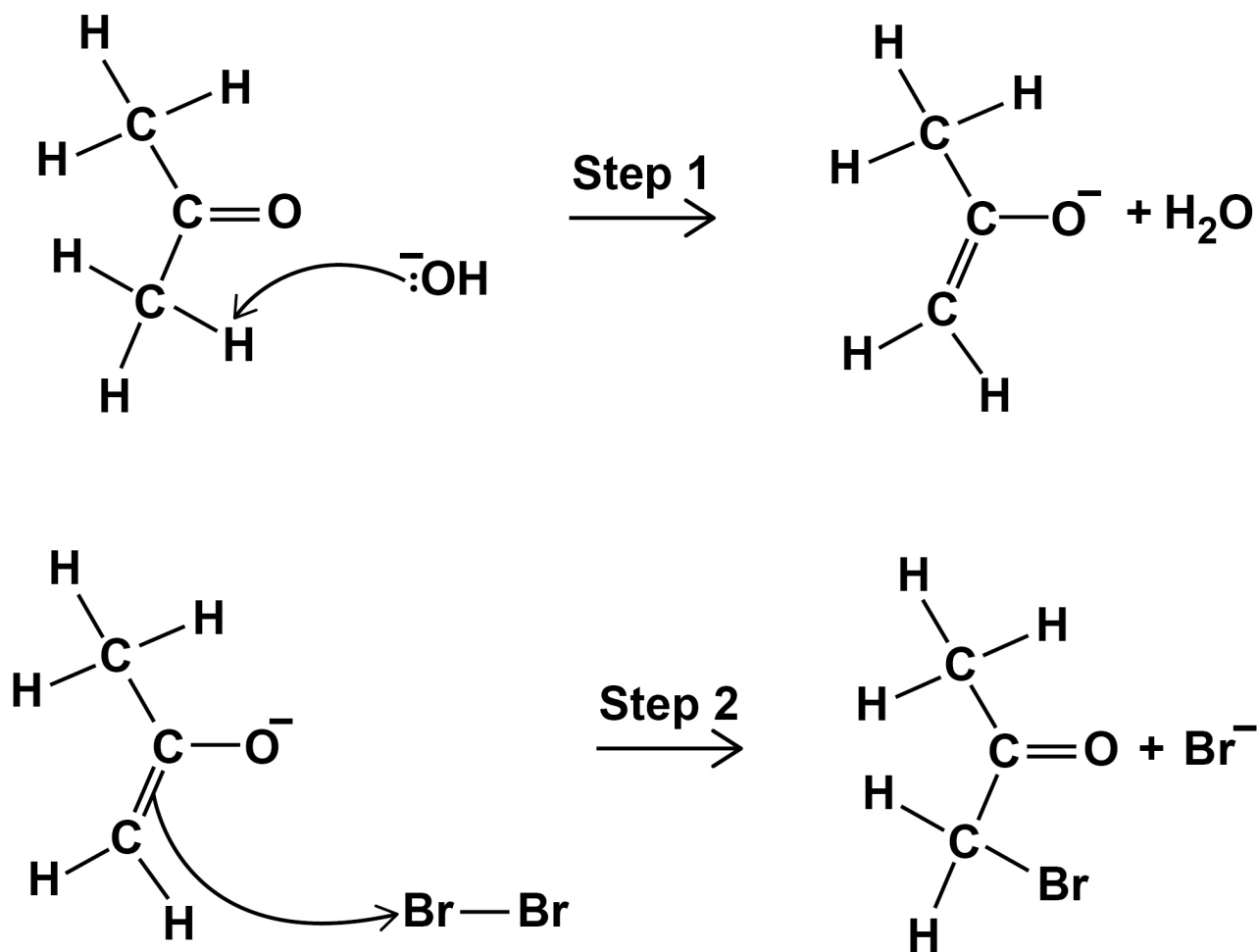
k _____ **Units** _____

[Turn over]

01.3

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]



01.4

Use evidence from the rate equation to explain why Step 1 is the rate determining step. [1 mark]

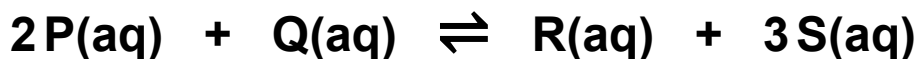
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11



0 2

This question is about an equilibrium.



A 25.0 cm³ sample of a solution of P is added to a 20.0 cm³ 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 cm³ sample.
[2 marks]



Amount of P _____ mol

Concentration _____ mol dm⁻³

[Turn over]



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]

[Turn over]

8



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.



Complete the equation for this reaction.

Give a suitable catalyst for this reaction. [2 marks]

Catalyst _____



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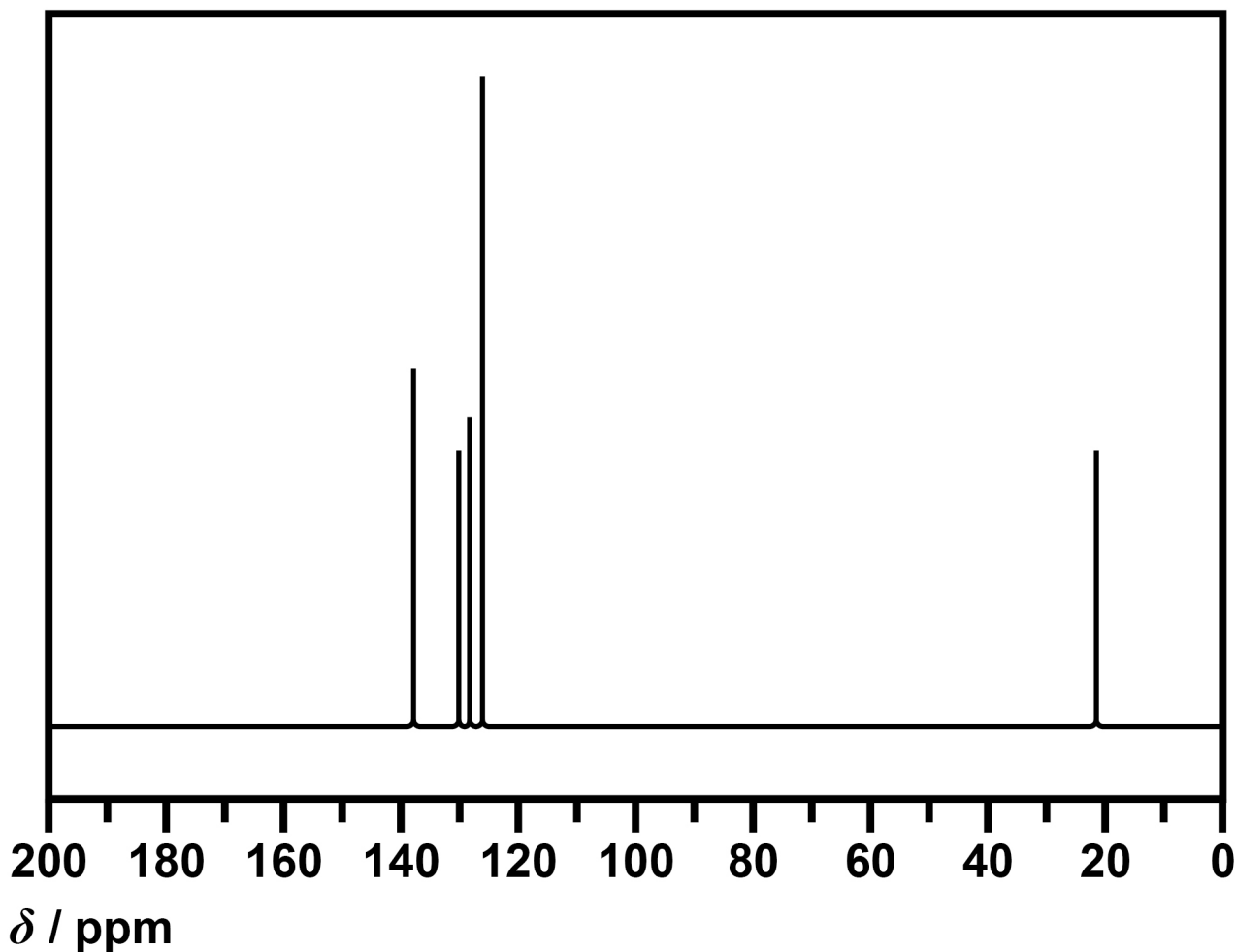
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03.2

FIGURE 2 shows the ^{13}C NMR spectrum for the aromatic hydrocarbon C_8H_{10}

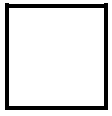
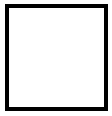
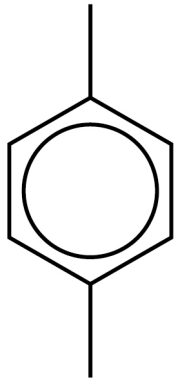
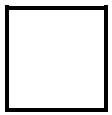
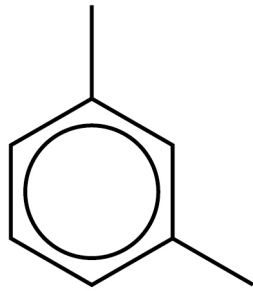
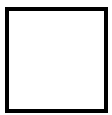
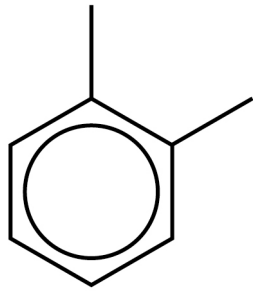
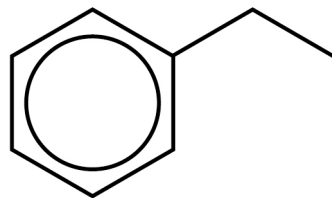
FIGURE 2



Which of these, on the opposite page, is the structure of C_8H_{10} ? [1 mark]

Tick (✓) ONE box.



**A****B****C****D****[Turn over]**

03.3

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

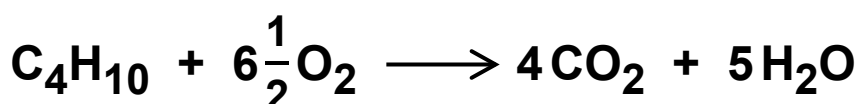
State the type of product that is formed in high percentage in this type of cracking. [1 mark]

03.4

A sample of butane has a volume of 20 cm³ at room temperature and pressure.

The sample is burned completely in 1350 cm³ of air.

The final mixture is cooled to room temperature and pressure.



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 _____ cm³

[Turn over]



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



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 _____

[Turn over]



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

STEP 1 Mix 10 cm³ of propan-2-ol with 10 cm³ 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 cm³ 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.



04.2

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]

[Turn over]





04.3

In **STEP 2**, on page 22, 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, on page 22. [1 mark]

0 4 . 5

Suggest how the purity of the ester can be confirmed during the distillation in STEP 4, on page 22. [1 mark]

[Turn over]

13



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



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[Turn over]



05.2

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 _____

[Turn over]

—
5



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 _____

[Turn over]



0	6	.	4
---	---	---	---

Isomer X has three singlets with integration ratio 1:3:6 in its ^1H NMR spectrum.

Deduce the structure of X.

Explain why the peaks in the ^1H NMR spectrum are singlets. [2 marks]

Structure

Explanation



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[Turn over]



06.5

TABLE 2 shows information about the peaks in the ^1H 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 $\delta = 3.65$ ppm



Part of structure from peak at $\delta = 1.19$ ppm

Structure of Y

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

[Turn over]

12



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 _____

[Turn over]

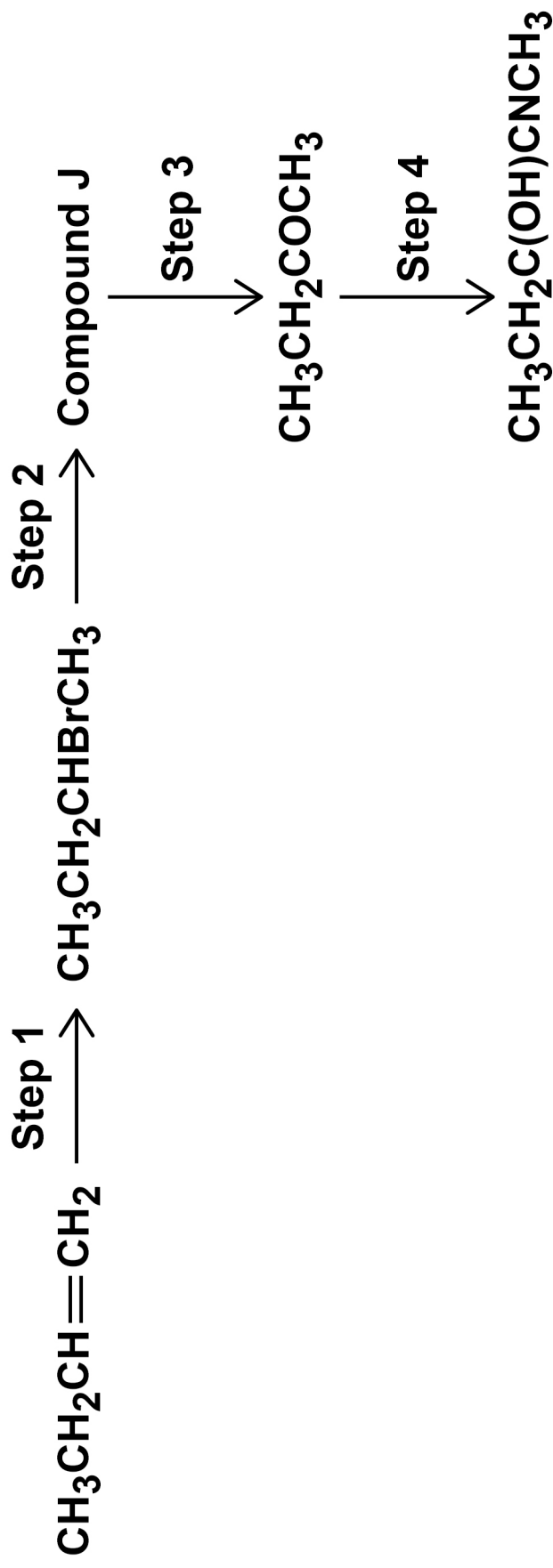
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4





08

This question is about an organic synthesis.





08.1

Name the mechanism in Step 1.

State the reagent(s) used for Step 1. [2 marks]

Name of mechanism _____

Reagent(s) _____

08.2

Identify compound J.

State the reagent(s) and conditions needed for Step 2. [2 marks]

Compound J _____

Reagent(s) and conditions _____

[Turn over]



08.3

State the reagent(s) used for Step 4 on page 40.

Outline the mechanism for Step 4. [5 marks]

Reagent(s) _____

Mechanism



08.4

Explain why Step 4, on page 40, produces a racemic mixture. [3 marks]

[Turn over]

12

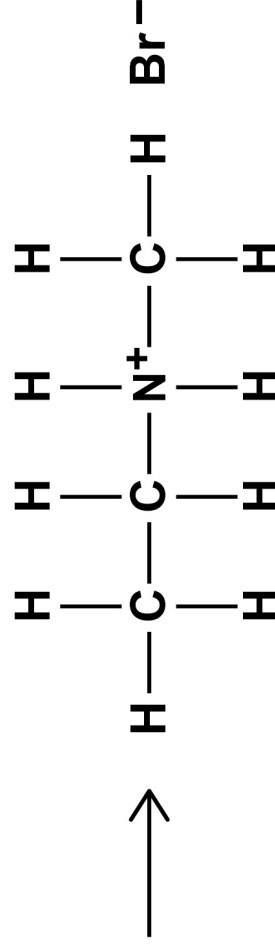
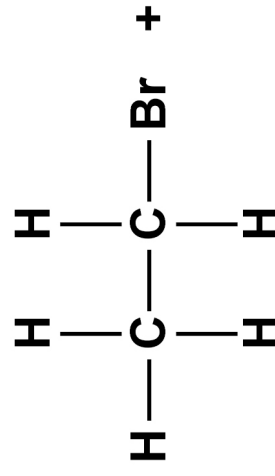


09

This question is about amines.

09.1

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





Complete the equation, on the opposite page.

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

Name the secondary amine formed. [2 marks]

Amine name _____

[Turn over]

09.2

CH₃CHBrCH₂CH₃ reacts with NH₃

Draw the skeletal formula of the major organic product formed when

- an excess of NH₃ is used**
- an excess of CH₃CHBrCH₂CH₃ is used.**

[2 marks]

Product with excess NH₃

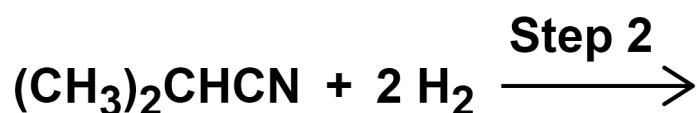
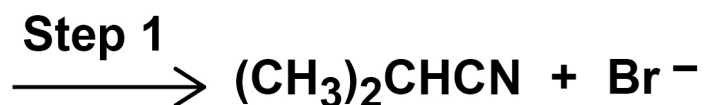
Product with excess CH₃CHBrCH₂CH₃



0	9	.	3
---	---	---	---

FIGURE 3 shows a two-step synthesis to make amine G.

FIGURE 3



Amine G

Complete FIGURE 3 by drawing the mechanism for Step 1 and the displayed formula of amine G. [3 marks]

[Turn over]

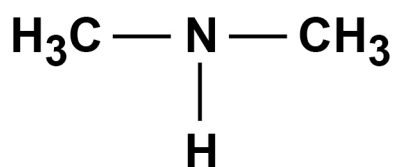


09.4

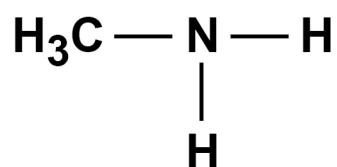
FIGURE 4 shows two amines, P and Q.

FIGURE 4

Amine P



Amine Q



Explain why P is a stronger base than Q. [2 marks]

9



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[Turn over]



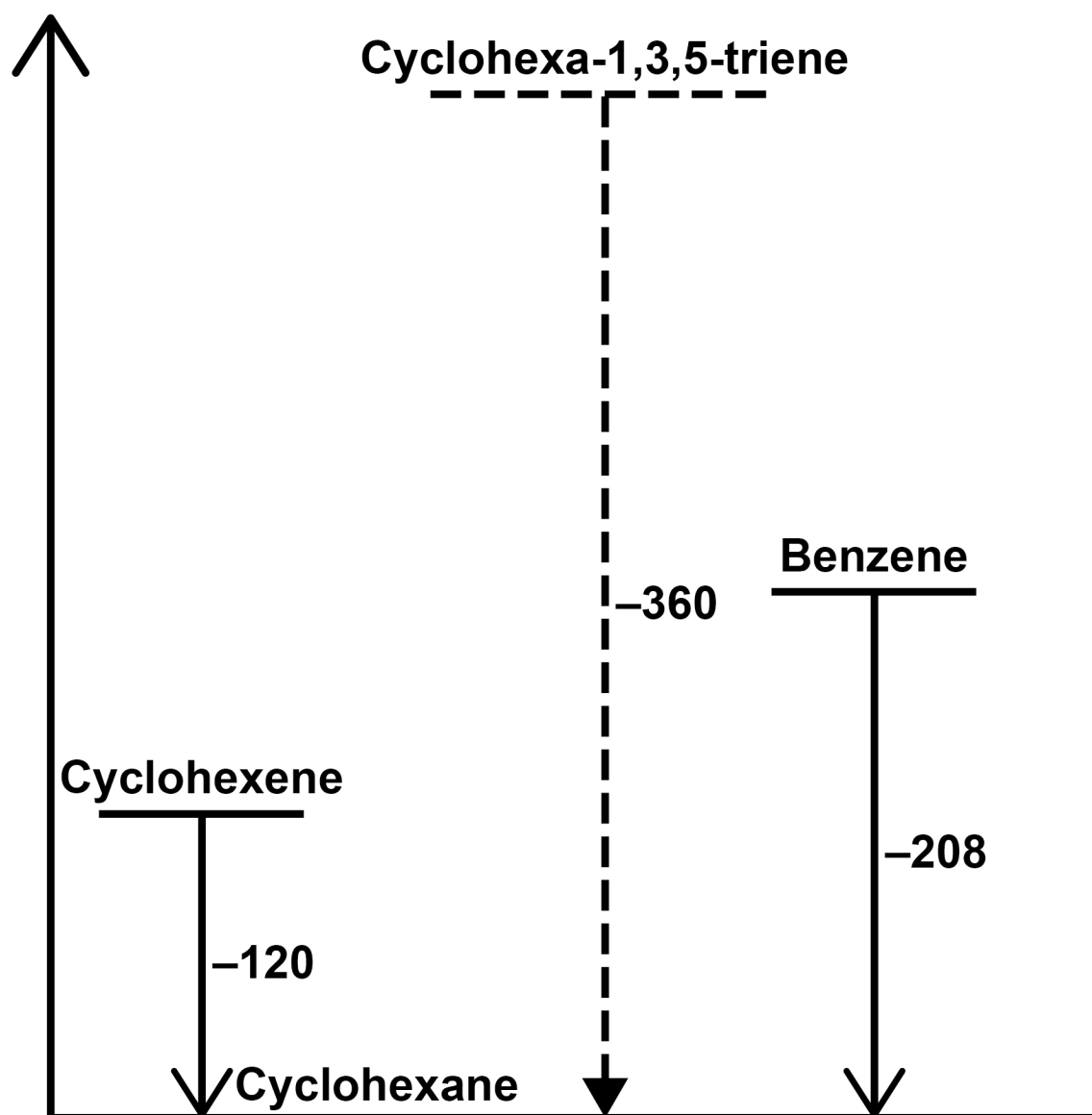
10

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

Enthalpy of
hydrogenation
/ kJ mol^{-1}



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]

[Turn over]



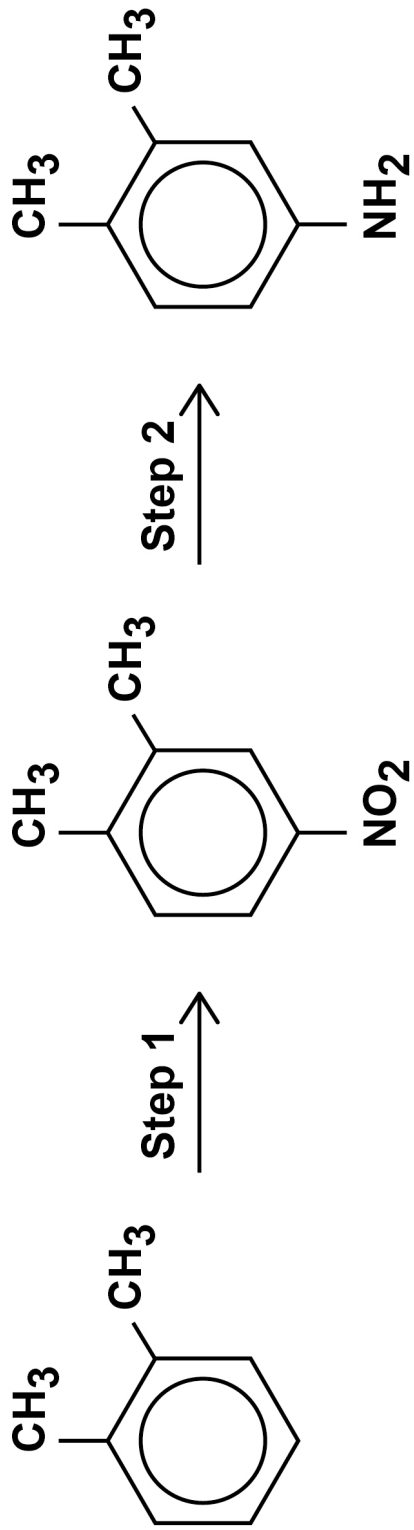
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[Turn over]





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





10.2

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 _____

[Turn over]



1 0 . 3

Outline below a mechanism for Step 1 on page 54. [3 marks]



1 0 . 4

State the reagent(s) needed for Step 2 on page 54. [1 mark]

1 0 . 5

State a possible use for the amine formed in Step 2 on page 54. [1 mark]

[Turn over]

12

1 1

This question is about enthalpy of combustion.

1 1 . 1

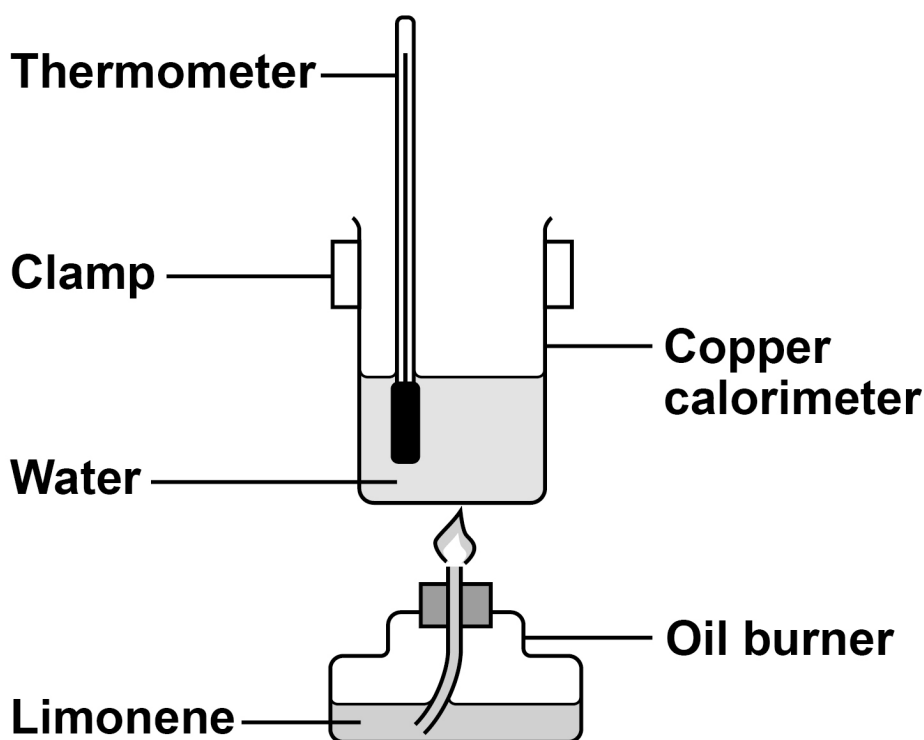
Limonene is found in the skin of citrus fruits.

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 ($\text{C}_{10}\text{H}_{16}$). [4 marks]

Enthalpy of combustion _____ kJ mol^{-1}

[Turn over]



11.2

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



END OF QUESTIONS

9



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Question	Mark
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2	
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9	
10	
11	
TOTAL	

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