

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname

StemUp Model Solution

Forename(s)

Candidate signature

I declare this is my own work.

A-level CHEMISTRY

Paper 2 Organic and Physical Chemistry

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	
TOTAL	

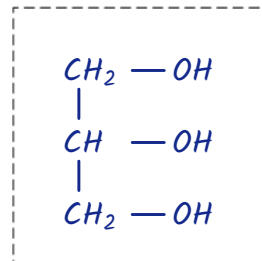
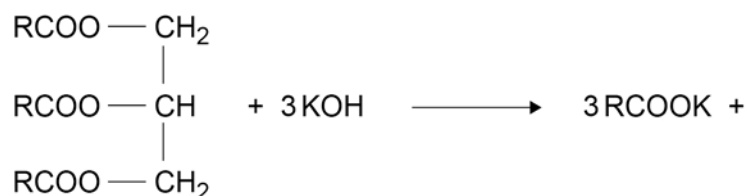


J U N 2 1 7 4 0 5 2 0 1

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

0 1

Coconut oil contains a triester with three identical R groups.
This triester reacts with potassium hydroxide.



0 1 . 1

Complete the equation by drawing the structure of the other product of this reaction in the box.

Name the type of compound shown by the formula RCOOK

Give **one** use for this type of compound.

[3 marks]

Type of compound (Potassium) carboxylate salt

Use Soap

0 1 . 2

The triester in coconut oil has a relative molecular mass, $M_r = 638.0$
In the equation shown at the start of Question 01, R represents an alkyl group that can be written as $\text{CH}_3(\text{CH}_2)_n$

Deduce the value of n in $\text{CH}_3(\text{CH}_2)_n$
Show your working.

[3 marks]

$$C_3H_5(COO)_3 \text{ part: } M_r = 173; R = CH_3(CH_2)_n = 15 + 14n$$

$$638.0 = 173 + 3(15 + 14n)$$

$$638 - (173 + 45) = 420$$

$$42n = 420$$

n 10



0 1 3

A 1.450 g sample of coconut oil is heated with 0.421 g of KOH in aqueous ethanol until all of the triester is hydrolysed.

The mixture is cooled.

The remaining KOH is neutralised by exactly 15.65 cm³ of 0.100 mol dm⁻³ HCl

Calculate the percentage by mass of the triester ($M_r = 638.0$) in the coconut oil.

[6 marks]

$$n(\text{HCl}) = 0.100 \times 15.65 \div 1000 = 1.565 \times 10^{-3} \text{ mol} = n(\text{KOH left over})$$

$$\text{initial } n(\text{KOH}) = 0.421 \div 56.1 = 7.50 \times 10^{-3} \text{ mol}$$

$$n(\text{KOH}) \text{ used} = 7.50 \times 10^{-3} - 1.565 \times 10^{-3} = 5.939 \times 10^{-3} \text{ mol}$$

$$n(\text{triester}) = 5.939 \times 10^{-3} \div 3 = 1.980 \times 10^{-3} \text{ mol}$$

$$\text{mass of triester} = 1.980 \times 10^{-3} \times 638.0 = 1.263 \text{ g}$$

$$\text{percentage by mass} = (1.263 \div 1.450) \times 100 = 87.1 \%$$

Percentage by mass 87.1 %

Turn over ►



0 1 . 4

Suggest why aqueous ethanol is a suitable solvent when heating the coconut oil with KOH.

Give a safety precaution used when heating the mixture.
Justify your choice.

[3 marks]

Reason Ethanol dissolves the oil and water dissolves the KOH, so it acts
as a mutual solvent for both reactants.

Safety precaution Heat the mixture using a water bath (or electric heater),
not a Bunsen flame.

Justification Ethanol is flammable, so this prevents the risk of fire.

15



0 2

This question is about fuels.

0 2 . 1

The petrol fraction obtained from crude oil can be used as fuel in cars.

State the meaning of fraction, as used in the term petrol fraction.

[1 mark]

A group (mixture) of hydrocarbons with similar boiling points (similar chain lengths, C_5 to C_{12}).

0 2 . 2

Hexadecane ($C_{16}H_{34}$) can be cracked at high temperature to form petrol.

Complete the equation to show the cracking of one molecule of hexadecane to form hexane and cyclopentane only.

Give the name of a catalyst used in this cracking reaction.

[3 marks]

Catalyst *Zeolite (aluminosilicate)*

0 2 . 3

Carbon dioxide is formed when petrol is burned.

Carbon dioxide acts as a greenhouse gas when it absorbs infrared radiation.

Give a reason why carbon dioxide absorbs infrared radiation.

[1 mark]

The C=O bonds in CO_2 vibrate at the same frequency as infrared radiation, so they absorb its energy (the C=O bonds are polar).

Question 2 continues on the next page

Turn over ►

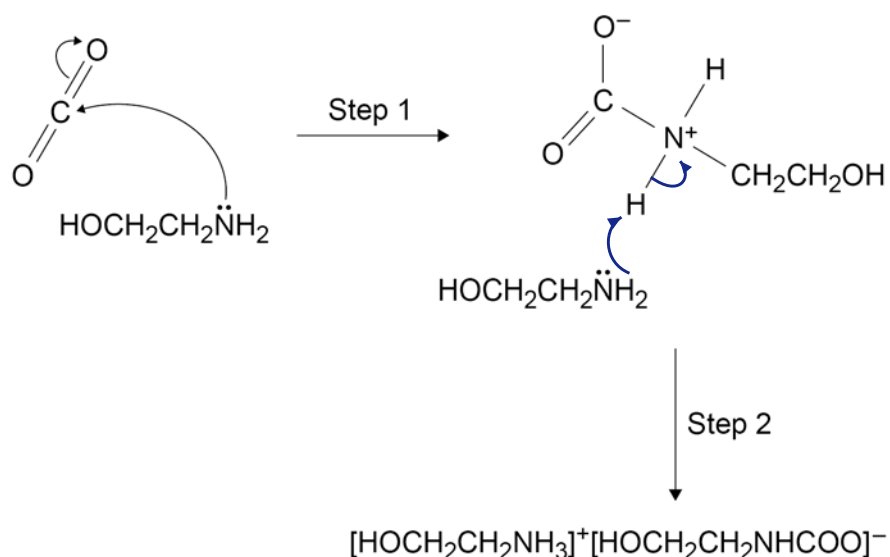


0 2 . 4

Compound **Z** ($\text{HOCH}_2\text{CH}_2\text{NH}_2$) can be used to remove carbon dioxide from the mixture of waste gases produced in some power stations.

Figure 1 shows part of a suggested mechanism for the reaction of **Z** with carbon dioxide.

Figure 1



Draw **two** curly arrows to complete the mechanism in **Figure 1**.

Name compound **Z** ($\text{HOCH}_2\text{CH}_2\text{NH}_2$)

Deduce the role of **Z** in step **2** of the mechanism.

[4 marks]

Name 2-aminoethanol

Role Base (proton acceptor): the lone pair on its N removes an H^+ ion from the N^+ of the intermediate.



0 2 . 5

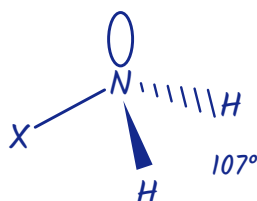
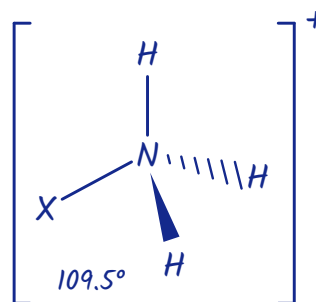
$\text{HOCH}_2\text{CH}_2\text{NH}_2$ can be represented as XNH_2
 $[\text{HOCH}_2\text{CH}_2\text{NH}_3]^+$ can be represented as $[\text{XNH}_3]^+$

Draw the shape of XNH_2 and of $[\text{XNH}_3]^+$

State whether the H-N-H bond angle in XNH_2 is greater than, the same as, or smaller than that in $[\text{XNH}_3]^+$

Explain your answer.

[4 marks]

Shape of XNH_2 Shape of $[\text{XNH}_3]^+$ 

Bond angle Smaller (107° in XNH_2 , 109.5° in $[\text{XNH}_3]^+$)

Explanation N in XNH_2 has a lone pair; lone pair-bond pair repulsion is greater than bond pair-bond pair repulsion.

Question 2 continues on the next page

Turn over ►



0 2 . 6

Bioethanol is used as an alternative to fossil fuels.

This statement appeared on a website.

“The fact that bioethanol is a carbon-neutral fuel outweighs the environmental disadvantages of producing bioethanol.”

Evaluate this statement.

In your answer you should include:

- an outline of how bioethanol is produced
- relevant equations
- analysis of the environmental impacts.

[6 marks]

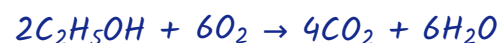
Bioethanol is produced from crops such as sugar cane or maize. As the plants grow they take in CO_2 from the air by photosynthesis:



The glucose is then fermented by yeast (enzymes) at about 35°C under anaerobic conditions, which releases some CO_2 :



The ethanol is separated by fractional distillation and burned as a fuel. Combustion releases CO_2 :



Carbon neutrality: in theory the 6 mol of CO_2 taken in by photosynthesis equals the 2 mol released in fermentation plus the 4 mol released in combustion (6CO_2 in and 6CO_2 out), so there is no net CO_2 added to the atmosphere.

However, bioethanol is not actually carbon-neutral, because fossil fuels are burned to provide energy for farming machinery, making fertilisers, harvesting, transporting the crops, distillation and distribution of the fuel, which releases extra CO_2 .

Other environmental disadvantages: land is used to grow fuel crops instead of food crops (sacrificing land that could be used for food), and



forests may be cut down to make space (deforestation), which reduces the CO_2 taken up by trees and causes loss of habitats and biodiversity.

Evaluation: the carbon-neutral claim is only partly true, so it does not clearly outweigh the disadvantages. The statement is an overstatement, unless the crops are grown on land not needed for food or forests and renewable energy is used in production.

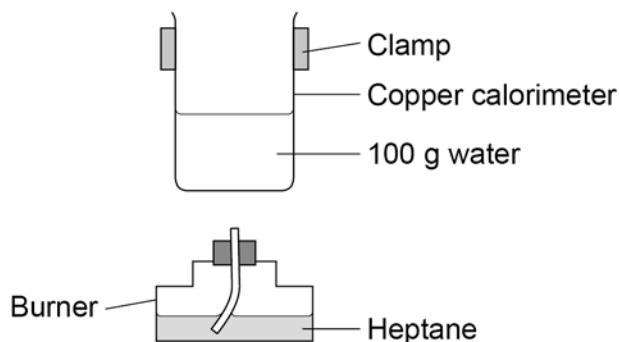


0 3

A student does an experiment to determine a value for the enthalpy of combustion of heptane.

Figure 2 shows some of the apparatus used.

Figure 2



0 3 . 1

Design a table to record all the readings necessary to determine an experimental value for the enthalpy of combustion for heptane in this experiment.

[2 marks]

Reading	Value
Initial temperature of water / °C	
Final temperature of water / °C	
Temperature change, ΔT / °C	
Mass of burner + heptane at start / g	
Mass of burner + heptane at end / g	
Mass of heptane burned / g	

0 3 . 2

The student considered using a glass beaker on a tripod and gauze instead of the clamped copper calorimeter.

Suggest **two** disadvantages of using a glass beaker on a tripod and gauze.

[2 marks]

Disadvantage 1 Glass is a poorer conductor of heat than copper, so less heat reaches the water.

Disadvantage 2 The tripod and gauze absorb heat, reducing heat transfer, and fix the height above the flame.



0 3 . 3

Suggest **two** reasons why the value of enthalpy of combustion from this experiment is less exothermic than a data book value.

[2 marks]

Reason 1 *Heat is lost to the surroundings (and to the copper calorimeter).*

Reason 2 *Incomplete combustion of the heptane.*

0 3 . 4

Suggest **one** addition to this apparatus that would improve the accuracy of the enthalpy value obtained.

[1 mark]

Use a wind shield around the burner and calorimeter (to reduce heat loss).

7

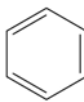
Turn over for the next question

Turn over ►



0 4

Kekulé suggested this structure for benzene.

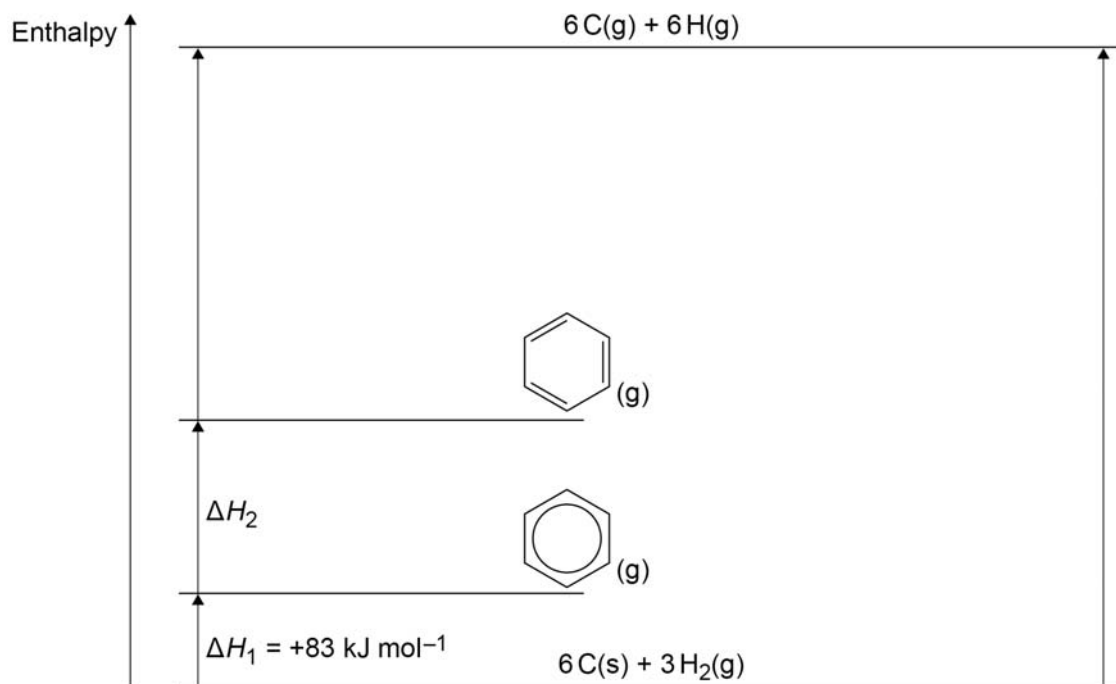


Benzene is now represented by this structure.



Figure 3 shows the relative stability of  compared to .

Figure 3



0 4 . 1

Use **Figure 3** and the data shown in **Table 1** to calculate ΔH_2 **[3 marks]****Table 1**

	$\Delta H / \text{kJ mol}^{-1}$
Enthalpy of atomisation for carbon	+715
Enthalpy of atomisation for hydrogen	+218
Bond enthalpy (C–C)	+348
Bond enthalpy (C=C)	+612
Bond enthalpy (C–H)	+412

Energy to break bonds in Kekulé benzene (to $6\text{C}(g) + 6\text{H}(g)$):

$$(3 \times 612) + (3 \times 348) + (6 \times 412) = 5352 \text{ kJ mol}^{-1}$$

$$6\text{C}(s) + 3\text{H}_2(g) \rightarrow 6\text{C}(g) + 6\text{H}(g): (6 \times 715) + (6 \times 218) = 5598 \text{ kJ mol}^{-1}$$

$$\text{Hess: } 83 + \Delta H_2 + 5352 = 5598$$

$$\Delta H_2 = 5598 - 5352 - 83 = +163 \text{ kJ mol}^{-1}$$

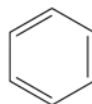
$$\Delta H_2 \quad \underline{\quad +163 \quad} \quad \text{kJ mol}^{-1}$$

0 4 . 2

Explain, in terms of structure and bonding, why



is more thermodynamically stable than

**[1 mark]**

The π electrons are delocalised around the ring, which lowers the energy compared with three localised C=C bonds.

Turn over ►

0 4 . 3

A mixture of concentrated nitric acid and concentrated sulfuric acid reacts with benzene.

Figure 4 shows the incomplete mechanism for this reaction.

Name the mechanism.

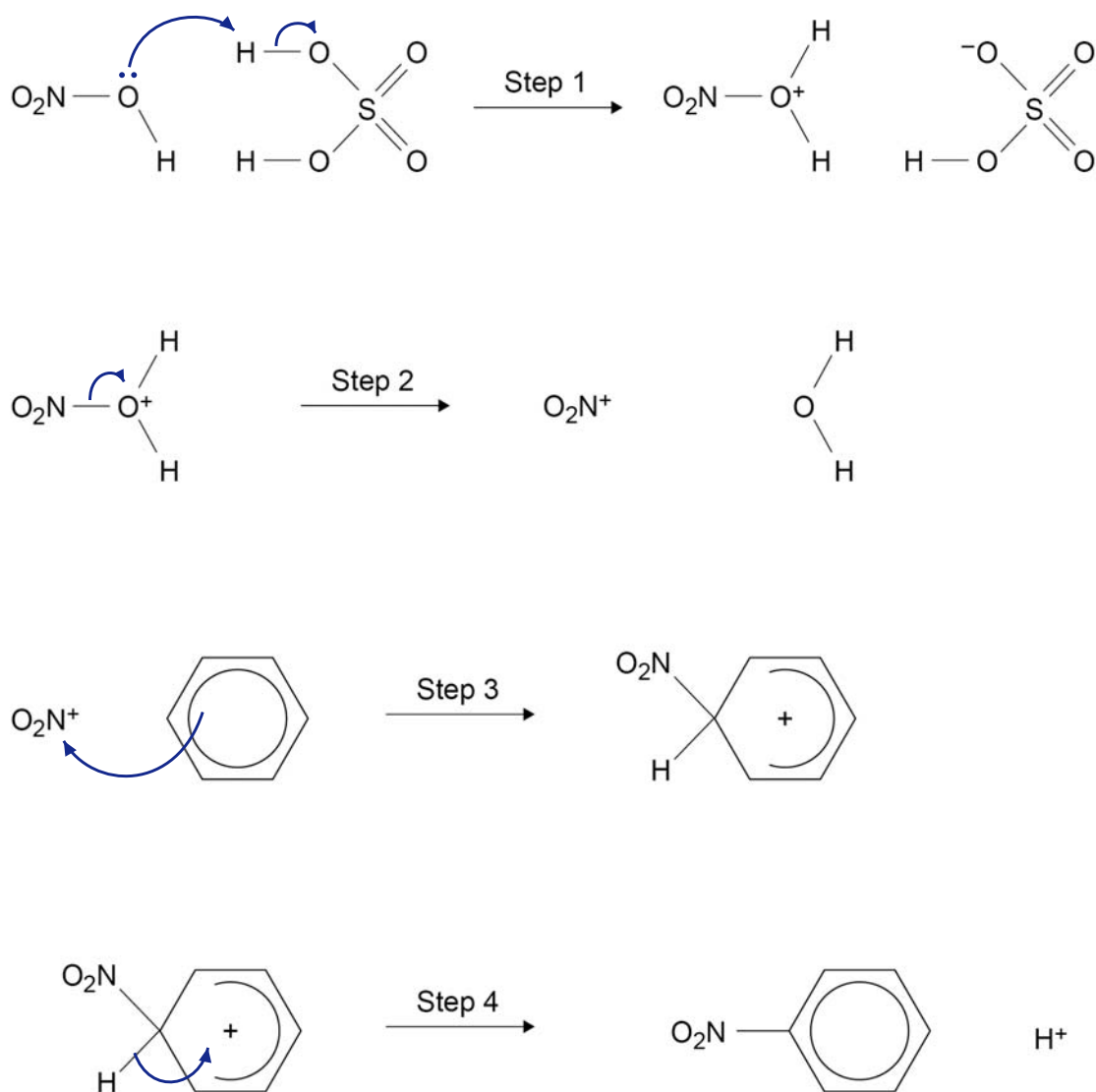
Complete the mechanism in **Figure 4** by adding

- any lone pairs of electrons involved in each step
- **two** curly arrows in step 1
- a curly arrow in step 2
- a curly arrow in step 3
- a curly arrow in step 4.

[5 marks]

Name of mechanism Electrophilic substitution

Figure 4



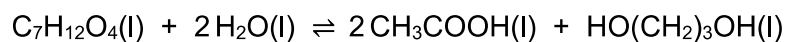
0 5

This question is about equilibrium.

0 5 . 1

1 mol of a diester with molecular formula $C_7H_{12}O_4$ is added to 1 mol of water in the presence of a small amount of catalyst.

The mixture is left to reach equilibrium at a constant temperature.



At equilibrium, x mol of ethanoic acid are present in the mixture.

Complete **Table 2** by deducing the amounts, in terms of x , of the diester, water and diol present in the equilibrium mixture.

[3 marks]

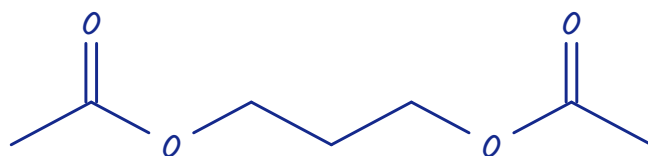
Table 2

Amount in the mixture / mol				
	Diester	Water	Acid	Diol
At the start	1	1	0	0
At equilibrium	$1 - x/2$	$1 - x$	x	$x/2$

0 5 . 2

Deduce the structure of the diester in Question 05.1

[1 mark]



Question 5 continues on the next page

Turn over ►



0 5 . 3

A new equilibrium mixture of the substances from Question 05.1 is prepared at a different temperature.



Table 3 shows the amount of each substance in this new equilibrium mixture.

Table 3

Amount in the mixture / mol				
	Diester	Water	Acid	Diol
At equilibrium	0.971	To be calculated	0.452	0.273

The value of the equilibrium constant, K_c is 0.161 at this temperature.

Calculate the amount of water, in mol, in this new equilibrium mixture.
Show your working.

[3 marks]

$$K_c = \frac{[\text{acid}]^2[\text{diol}]}{[\text{diester}][\text{water}]^2} \quad (\text{the volume } V \text{ cancels, so amounts in mol can be used})$$

$$0.161 = (0.452^2 \times 0.273) \div (0.971 \times n(\text{H}_2\text{O})^2)$$

$$n(\text{H}_2\text{O})^2 = (0.452^2 \times 0.273) \div (0.161 \times 0.971) = 0.357$$

$$n(\text{H}_2\text{O}) = \sqrt{0.357} = 0.597 \text{ mol}$$

Amount of water 0.597 mol

7



0 6

This question is about isomers with the molecular formula $C_5H_{10}O$

0 6 . 1

Draw the skeletal formula of a branched chain aldehyde with molecular formula $C_5H_{10}O$ that is optically active.

[1 mark]



0 6 . 2

Describe how you distinguish between separate samples of the two enantiomers of the branched chain aldehyde $C_5H_{10}O$

[2 marks]

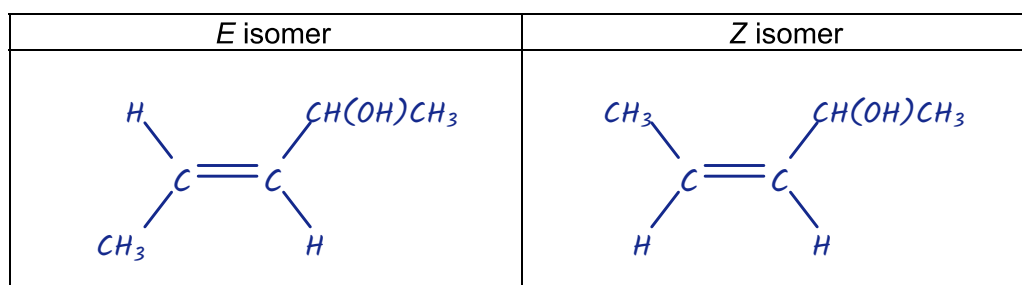
Use plane-polarised light: pass it through each sample separately (in a polarimeter).

The two enantiomers rotate the plane of plane-polarised light in opposite directions (by the same angle).

0 6 . 3

Draw the *E* and *Z* forms of a structural isomer of $C_5H_{10}O$ that shows **both** optical and geometric isomerism.

[2 marks]



Question 6 continues on the next page

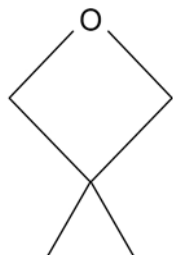
Turn over ►



0 6 . 4

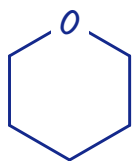
Isomer J is cyclic and has an ether functional group (C–O–C)
Isomer J has only three peaks in its ^{13}C NMR spectrum.

Isomer J

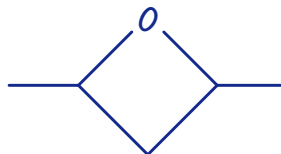


Draw **two** other cyclic isomers of $\text{C}_5\text{H}_{10}\text{O}$ that have an ether functional group and only three peaks in their ^{13}C NMR spectra.

[2 marks]



(3 C environments)



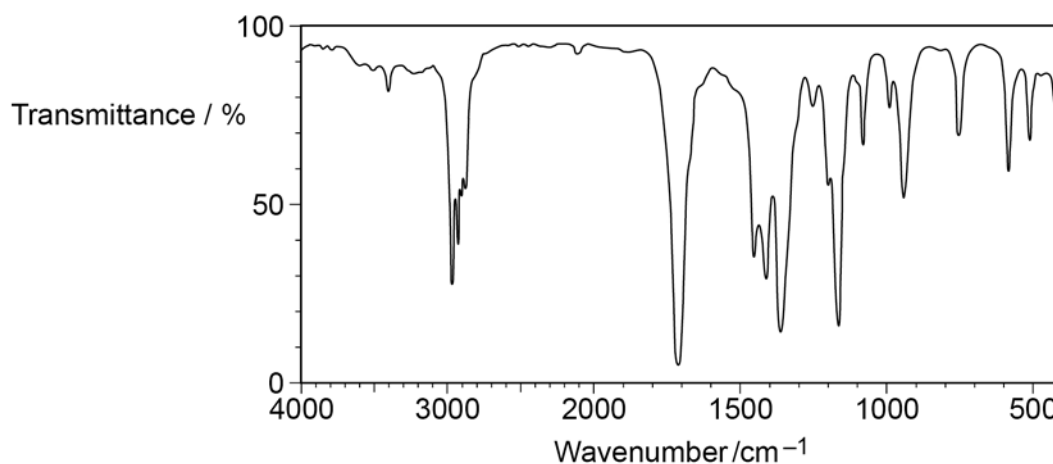
(3 C environments)



0 7

This question is about spectroscopy.

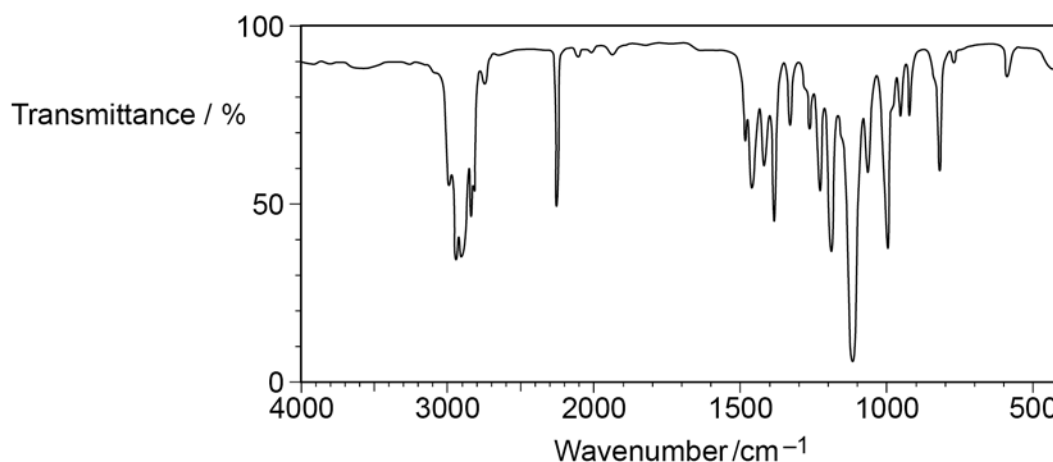
0 7 . 1

Compound **K** has molecular formula C_4H_8O **Figure 5** shows the infrared spectrum of **K**.**Figure 5**Which functional group does **K** contain?Tick (✓) **one** box.**[1 mark]**

Functional Group				
alcohol	alkene	amine	carbonyl	nitrile
			✓	

Question 7 continues on the next page**Turn over ►**

0 7 . 2

Compound **L** has molecular formula C_4H_7NO **Figure 6** shows the infrared spectrum of **L**.**Figure 6****L** reacts with H_2 in the presence of a nickel catalyst to give compound **M**.Suggest **three** ways in which the infrared spectrum of **M** is different from the infrared spectrum of **L**.**[3 marks]**1 The sharp peak at 2220 to 2260 cm^{-1} ($C\equiv N$) disappears.2 A (broad) peak at 3300 to 3500 cm^{-1} ($N-H$) appears.3 The fingerprint region (below 1500 cm^{-1}) is different.

0 7 . 3

Figure 7 shows the ^1H NMR spectrum of **Q**, $\text{C}_3\text{H}_7\text{ClO}$

Figure 7

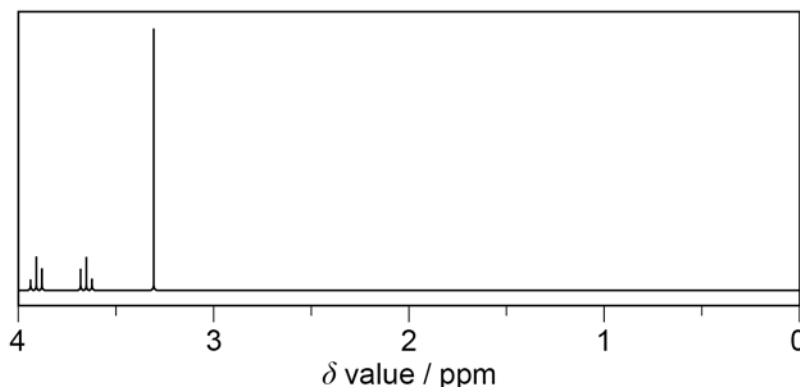
Table 4 shows the chemical shifts (δ values) and integration values for each peak.

Table 4

δ value / ppm	3.95	3.65	3.35
Integration value	0.6	0.6	0.9

Deduce the structure of **Q**.

Explain your answer.

[5 marks]

Integration ratio $0.6 : 0.6 : 0.9 = 2 : 2 : 3$, so **Q** has two CH_2 groups and one CH_3 group.

δ 3.95: triplet, 2H, $\text{Cl}-\text{CH}_2$, next to a CH_2 (2 adjacent H, $n + 1 = 3$), shifted by the Cl.

δ 3.65: triplet, 2H, $\text{O}-\text{CH}_2$, next to a CH_2 (2 adjacent H), shifted by the O.

δ 3.35: singlet, 3H, $\text{O}-\text{CH}_3$, no adjacent H so not split.

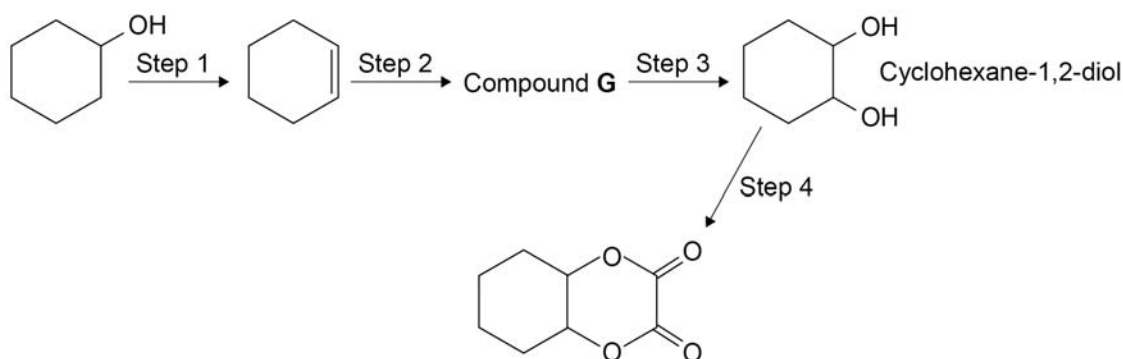
Structure of **Q**: $\text{CH}_3-\text{O}-\text{CH}_2-\text{CH}_2-\text{Cl}$

Turn over ►



0 8

This question is about making a diester from cyclohexanol.



0 8 . 1

State the type of reaction in step 1.

Give the name of the reagent needed for step 1.

[2 marks]

Type of reaction Dehydration (acid-catalysed elimination)

Reagent Concentrated sulfuric acid

0 8 . 2

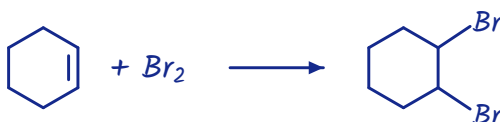
State the reagents needed and give equations for step 2 and step 3.

Show the structure of Compound G in your equations.

[4 marks]

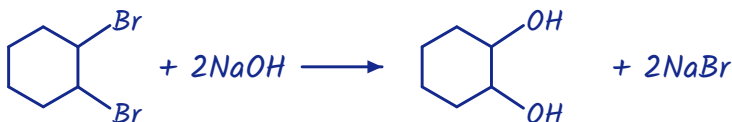
Step 2 reagent Bromine (Br_2)

Step 2 equation



Step 3 reagent Sodium hydroxide (aqueous NaOH), warm

Step 3 equation



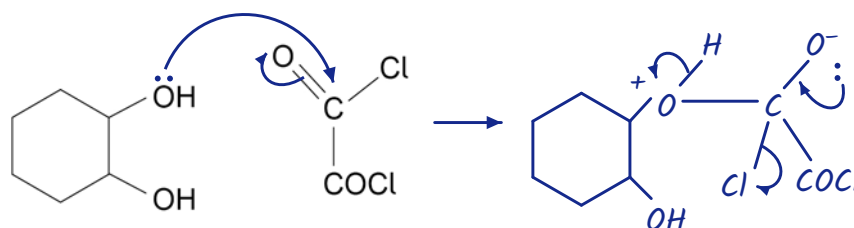
0 8 . 3

Cyclohexane-1,2-diol reacts with ethanedioyl dichloride.

Give the name of the mechanism for this reaction.

Complete the mechanism to show the formation of **one** ester link in the first step of this reaction.**[5 marks]**Mechanism name Nucleophilic addition-elimination

Mechanism



0 8 . 4

Suggest why chemists usually aim to design production methods

- with fewer steps
- with a high percentage atom economy.

[2 marks]

Fewer steps Less energy is used and the overall yield is better, because there are fewer practical losses at each step.

High percentage atom economy Less waste (less pollution) is made, as more of the raw materials end up in useful products, saving resources.



0 9

This question is about the ozone layer in the upper atmosphere.

0 9 . 1

State why the ozone layer is beneficial for living organisms.

[1 mark]

It absorbs harmful UV radiation (reducing the risk of skin cancer).

0 9 . 2

State how chlorofluorocarbons (CFCs) form chlorine atoms in the upper atmosphere.

[1 mark]

UV light breaks the C-Cl bonds homolytically, forming chlorine atoms (Cl· radicals).

0 9 . 3

Give equations to show how chlorine atoms catalyse the decomposition of ozone.

[2 marks]



0 9 . 4

Hydrochlorofluorocarbons (HCFCs) have been used in place of CFCs. In the mechanism to make an HCFC from a fluoroalkane, two incomplete steps are shown.

Complete each step in the mechanism.

Give the name of the type of step shown by both these equations.

[3 marks]



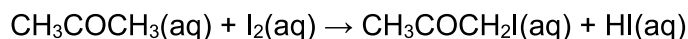
Type of step *Propagation*



1 0

This question is about rates of reaction.

Iodine and propanone react together in an acid-catalysed reaction



A student completed a series of experiments to determine the order of reaction with respect to iodine.

Method

- Transfer 25 cm³ of 1.0 mol dm⁻³ propanone solution into a conical flask.
- Add 10 cm³ of 1.0 mol dm⁻³ HCl(aq)
- Add 25 cm³ of 5.0 × 10⁻³ mol dm⁻³ I₂(aq) and start a timer.
- At intervals of 1 minute, remove a 1.0 cm³ sample of the mixture and add each sample to a separate beaker containing an excess of NaHCO₃(aq)
- Titrate the contents of each beaker with a standard solution of sodium thiosulfate and record the volume of sodium thiosulfate used.

1 0 . 1

Suggest why the 1.0 cm³ portions of the reaction mixture are added to an excess of NaHCO₃ solution.

[2 marks]

The NaHCO₃ neutralises the acid (HCl) catalyst, so the reaction stops (is quenched) and the iodine concentration at that time can be found.

1 0 . 2

Suggest why the order of this reaction with respect to propanone can be ignored in this experiment.

[2 marks]

The concentration (amount) of propanone is much larger than that of iodine, about 200 times larger (0.025 mol compared with 1.25 × 10⁻⁴ mol).

So the concentration of propanone stays almost constant during the experiment; its change is negligible.

Question 10 continues on the next page

Turn over ►



The volume of sodium thiosulfate solution used in each titration is proportional to the concentration of iodine in each beaker.

Table 5 shows the results of the experiment.

Table 5

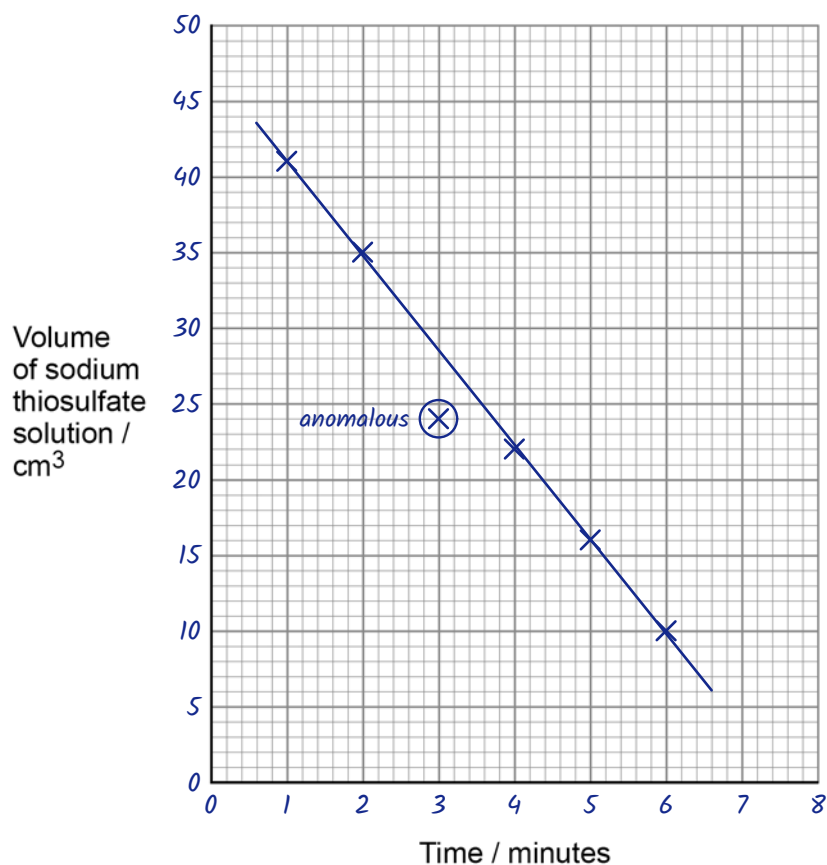
Time / minutes	Volume of sodium thiosulfate solution / cm ³
1	41
2	35
3	24
4	22
5	16
6	10

1 0 . 3

Use the results in **Table 5** to draw a graph of volume of sodium thiosulfate solution against time.

Draw a line of best fit.

[3 marks]



1 0 . 4

Explain how the graph shows that the reaction is zero-order with respect to iodine in the reaction between propanone and iodine.

[2 marks]

The graph is a straight line with a constant gradient, so the iodine is being used up at a constant rate.

So the rate of reaction does not change as the concentration of iodine decreases: rate is independent of $[I_2]$, so the reaction is zero order with respect to iodine.

Question 10 continues on the next page

Turn over ►

1 0 . 5 The Arrhenius equation can be written as

$$\ln k = \frac{-E_a}{RT} + \ln A$$

Figure 8 shows a graph of $\ln k$ against $\frac{1}{T}$ for the reaction

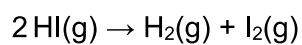
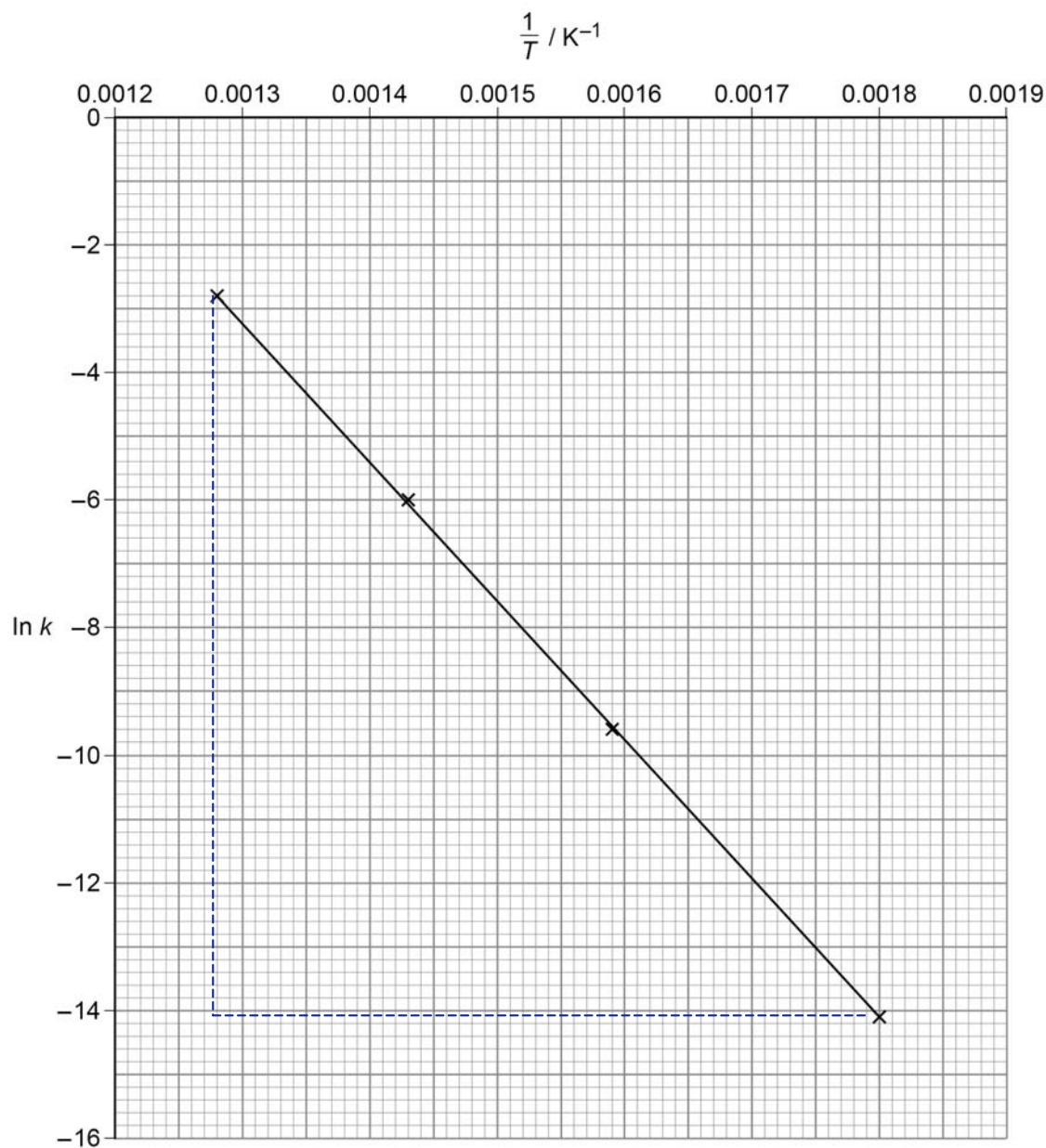


Figure 8



Use **Figure 8** to calculate a value for the activation energy (E_a), in kJ mol^{-1} , for this reaction.

The gas constant $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

[3 marks]

Points read from the line: (0.00128, -2.8) and (0.00180, -14.1)

Gradient = $(-14.1 - (-2.8)) \div (0.00180 - 0.00128)$

= $-11.3 \div 0.00052 = -21\,731 \text{ K}$

Gradient = $-E_a \div R$, so $E_a = 21\,731 \times 8.31 = 180\,583 \text{ J mol}^{-1}$

$E_a = 180\,583 \div 1000 = 181 \text{ kJ mol}^{-1}$

E_a 181 kJ mol^{-1}

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END OF QUESTIONS



There are no questions printed on this page

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