

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.

AS CHEMISTRY

Paper 2 Organic and Physical Chemistry

Tuesday 23 May 2023

Morning

Time allowed: 1 hour 30 minutes

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.
- 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 80.

Advice

You are advised to spend about 65 minutes on **Section A** and 25 minutes on **Section B**.

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



J U N 2 3 7 4 0 4 2 0 1

Section A

Answer **all** questions in this section.

0 1

This question is about the analysis of organic compounds.

For each pair of compounds in Questions **01.1** and **01.2**, give a reagent (or combination of reagents) that could be added separately to each compound in a single reaction to distinguish between them.

State what is observed in each case.

0 1 . 1

 $\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$ and $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3$

[3 marks]

Reagent(s) Tollens' reagent (ammoniacal silver nitrate), warm

Observation with $\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$ A silver mirror forms

Observation with $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3$ No visible change (no reaction), stays colourless

0 1 . 2

Cyclohexane and cyclohexene

[3 marks]

Reagent(s) Bromine water

Observation with cyclohexane No visible change: stays orange (no reaction)

Observation with cyclohexene Orange bromine water is decolourised (turns colourless)



0 1 3

Table 1 gives the precise relative molecular masses (M_r) of some organic compounds measured using high resolution mass spectrometry.

Table 1

Molecular formula	C_5H_{12}	C_5H_{10}	C_6H_6
M_r	72.1416	70.1260	to be calculated

Use these data to find the relative atomic masses (A_r) of hydrogen and carbon.
Give your answers to 4 decimal places.

Use these calculated A_r values to find the relative molecular mass (M_r) of C_6H_6
Give your answer to 4 decimal places.

[3 marks]

$$C_5H_{12} - C_5H_{10}: 2H = 72.1416 - 70.1260 = 2.0156$$

$$H = 2.0156 \div 2 = 1.0078$$

A_r of hydrogen 1.0078

$$5C = 72.1416 - (12 \times 1.0078) = 72.1416 - 12.0936 = 60.0480$$

$$C = 60.0480 \div 5 = 12.0096$$

A_r of carbon 12.0096

$$M_r \text{ of } C_6H_6 = (6 \times 12.0096) + (6 \times 1.0078)$$

$$= 72.0576 + 6.0468 = 78.1044$$

M_r of C_6H_6 78.1044

9

Turn over ►

0 2

This question is about fuels.

0 2 . 1

Crude oil is separated into fractions by fractional distillation.

State the meaning of the term 'fraction' in this context.

[1 mark]

A mixture of compounds (hydrocarbons) with similar boiling points.

0 2 . 2

Petrol for cars contains branched and cyclic alkanes produced by catalytic cracking.

Identify the catalyst used in this process.

[1 mark]

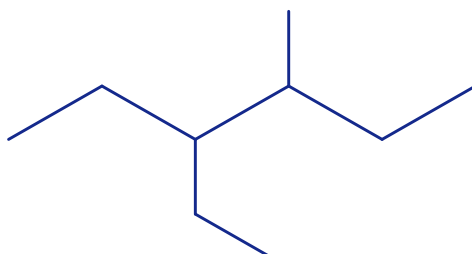
Zeolites (aluminosilicates)

0 2 . 3

3-Ethyl-4-methylhexane is a branched alkane in petrol.

Draw the skeletal formula of this alkane.

[1 mark]



0 2 . 4

Give the equation for the complete combustion of 3-ethyl-4-methylhexane.
Use the molecular formula for 3-ethyl-4-methylhexane in your equation.

[2 marks]

Molecular formula: $C_{20}H_{42}$ *$C_{20}H_{42} + 14O_2 \rightarrow 14CO_2 + 11H_2O$* 

0 2 . 5

Carbon dioxide is a product from the combustion of petrol in cars. Carbon dioxide acts as a greenhouse gas when it absorbs infrared radiation.

Give **one** reason why carbon dioxide absorbs infrared radiation.

[1 mark]

The C=O bonds vibrate (at the frequency of IR radiation), causing a net change in the dipole moment of the molecule during this (asymmetric) vibration.

0 2 . 6

Nitrogen monoxide (NO) is formed when petrol is burned in cars.

State **one** environmental problem that NO causes.

State what is used to remove NO from the exhaust gases formed in petrol-fuelled cars.

[2 marks]

Environmental problem *Acid rain (NO is oxidised to NO₂) and respiratory problems.*

Removal of NO *Catalytic converters (platinum / rhodium catalyst)*

0 2 . 7

Petrol sold in the UK contains 10% bioethanol. Bioethanol is ethanol made from crops by fermentation and is considered to be carbon-neutral.

State what is meant by the term 'carbon-neutral'.

[1 mark]

There are no net emissions of carbon dioxide (CO₂) to the atmosphere: the CO₂ taken in by the crops equals the CO₂ released when the ethanol burns.

9

Turn over for the next question

Turn over ►



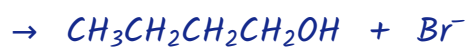
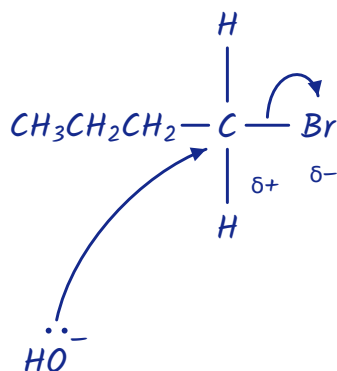
0 3

This question is about reactions of halogenoalkanes with hydroxide ions.

0 3. 1

Outline the mechanism for the nucleophilic substitution reaction of 1-bromobutane with sodium hydroxide.

[2 marks]

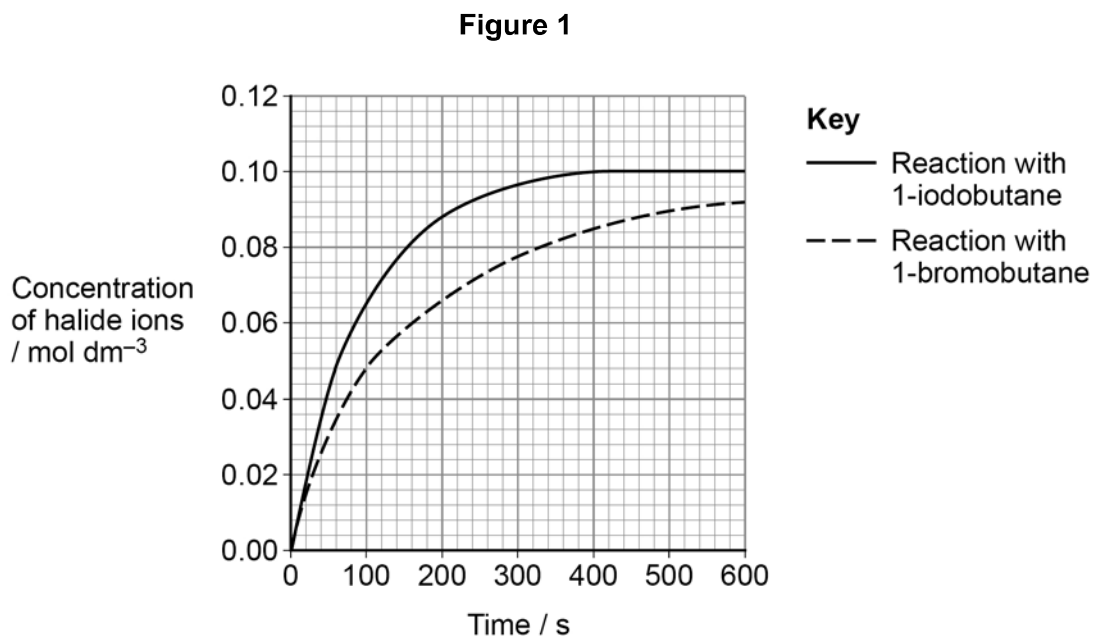


A student investigated the rate of nucleophilic substitution of halogenoalkanes with hydroxide ions.

Identical concentrations of 1-bromobutane and 1-iodobutane were reacted separately with sodium hydroxide solution under the same conditions.

The concentration of halide ions was monitored during each experiment.

Figure 1 shows the student's results.



0 3 . 2

State how **Figure 1** shows that the rate of reaction of 1-iodobutane is faster than the rate of reaction of 1-bromobutane.

State why the rates are different.

[2 marks]

The concentration of iodide ions increases more rapidly than that of bromide ions; the gradient of the 1-iodobutane curve is steeper.

This is because the C-I bond is weaker than the C-Br bond (lower bond enthalpy), so the C-I bond breaks more easily.

4

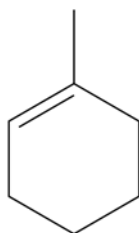
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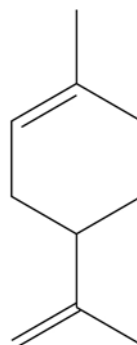


0 4

1-Methylcyclohexene and limonene are cyclic alkenes with a citrus smell. 1-Methylcyclohexene is manufactured and used in the chemical industry. Limonene is found naturally in orange peel.



1-methylcyclohexene



limonene

0 4 . 1

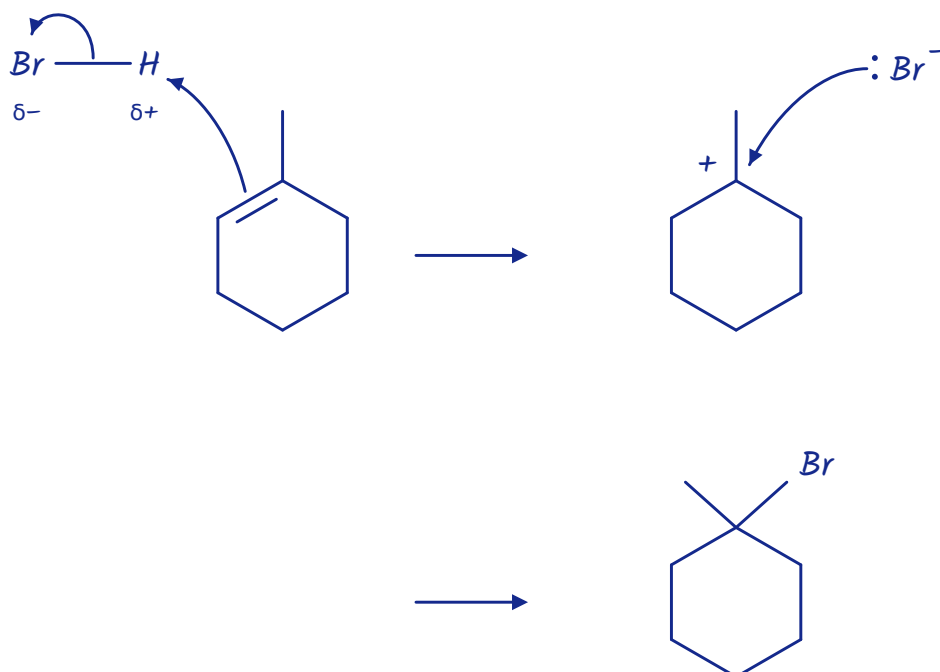
1-Methylcyclohexene reacts with HBr to form two structural isomers. The major product is 1-bromo-1-methylcyclohexane.

Name and outline the mechanism for the formation of this major product.

[5 marks]

Name of mechanism Electrophilic addition

Outline of mechanism



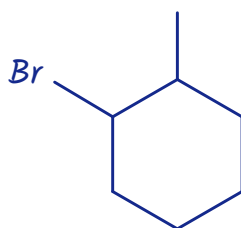
0 4 . 2

Draw the skeletal formula of the minor product formed in the reaction in Question 04.1.

Explain why the products are formed in different amounts.

[4 marks]

Skeletal formula



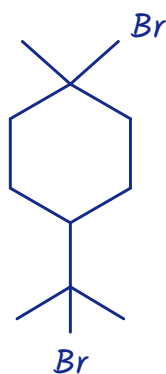
Explanation *1-Bromo-1-methylcyclohexane (major) is formed via a tertiary carbocation, which is more stable than the secondary carbocation that forms the minor product.*

The tertiary carbocation is more stable because it has more alkyl groups attached to the positive carbon; these are electron-releasing (a greater positive inductive effect).

0 4 . 3

Draw the structure of the major product when an excess of HBr reacts with limonene.

[1 mark]



Turn over for the next question

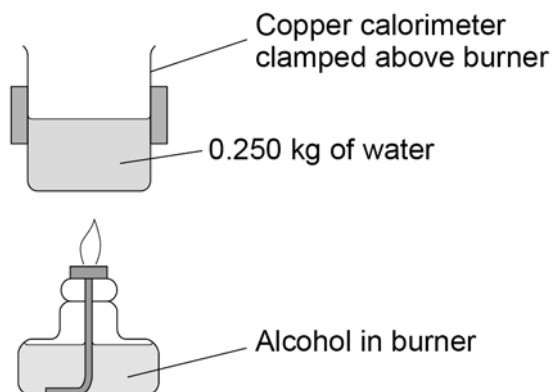


0 5

A student is provided with a 0.0300 mol sample of an alcohol. The student decides to identify the alcohol using an experiment to determine its enthalpy of combustion.

Figure 2 shows the apparatus used.

Figure 2



0 5 . 1

The student finds that when **all** the alcohol is burned, the temperature of the water increases from 18.9 °C to 78.1 °C

Calculate the enthalpy of combustion, in kJ mol⁻¹, for the alcohol.
The specific heat capacity of water, $c = 4.18 \text{ J g}^{-1} \text{ K}^{-1}$

[3 marks]

$$\text{Temperature rise } \Delta T = 78.1 - 18.9 = 59.2 \text{ }^{\circ}\text{C (K)}$$

$$\text{Mass of water } m = 0.250 \text{ kg} = 250 \text{ g}$$

$$q = mc\Delta T = 250 \times 4.18 \times 59.2 = 61\,864 \text{ J} = 61.864 \text{ kJ}$$

$$\Delta H = -61.864 \div 0.0300 = -2062 \text{ kJ mol}^{-1}$$

Enthalpy of combustion -2062 kJ mol⁻¹



0 5 . 2 Table 2 shows the enthalpies of combustion of some alcohols.

Table 2

Alcohol	Enthalpy of combustion / kJ mol^{-1}
Ethanol	-1367
Propan-1-ol	-2021
Butan-1-ol	-2676

Explain how your answer to Question 05.1 suggests that the alcohol is butan-1-ol.

(If you have been unable to obtain an answer for Question 05.1, assume that the answer is $-2120 \text{ kJ mol}^{-1}$)

[2 marks]

The experimental value is less exothermic than the true value, because heat is lost to the surroundings, combustion is incomplete and some alcohol evaporates.

So the true value must be more exothermic than $-2062 \text{ kJ mol}^{-1}$.

Ethanol and propan-1-ol are both less exothermic than this, so it cannot be either of them; it must be butan-1-ol.

Question 5 continues on the next page

Turn over ►



0 5 . 3 The equation for the complete combustion of gaseous pentan-1-ol is shown.

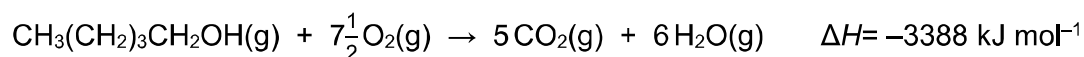


Table 3 shows some bond enthalpy data.

Table 3

	C-H	C-O	O-H	C=O	O=O
Bond enthalpy / kJ mol ⁻¹	412	360	463	805	496

Use data from **Table 3** to calculate a value for the mean C-C bond enthalpy in pentan-1-ol.

[3 marks]

$$\begin{aligned} \text{Bonds broken: } & 4(\text{C}-\text{C}) + 11(\text{C}-\text{H}) + (\text{C}-\text{O}) + (\text{O}-\text{H}) + 7\frac{1}{2}(\text{O}=\text{O}) \\ & = 4B(\text{C}-\text{C}) + 11(412) + 360 + 463 + 7\frac{1}{2}(496) = 4B(\text{C}-\text{C}) + 9075 \end{aligned}$$

$$\text{Bonds formed: } 10(\text{C}=\text{O}) + 12(\text{O}-\text{H}) = 10(805) + 12(463) = 13\,606$$

$$\Delta H = \Sigma \text{ bonds broken} - \Sigma \text{ bonds formed}$$

$$-3388 = 4B(\text{C}-\text{C}) + 9075 - 13\,606$$

$$4B(\text{C}-\text{C}) = 13\,606 - 9075 - 3388 = 1143$$

$$B(\text{C}-\text{C}) = 1143 \div 4 = 285.75 = 286 \text{ kJ mol}^{-1}$$

C-C bond enthalpy +286 kJ mol⁻¹



0 5 . 4

The energy stored in fuels can be compared using energy density values measured in kJ dm^{-3}

Calculate the energy density of butan-1-ol.

enthalpy of combustion of butan-1-ol = $-2676 \text{ kJ mol}^{-1}$

density of butan-1-ol = 0.810 kg dm^{-3}

relative molecular mass (M_r) of butan-1-ol = 74.0

[2 marks]

$$\text{Mass of } 1 \text{ dm}^3 = 0.810 \text{ kg} = 810 \text{ g}$$

$$\text{Moles in } 1 \text{ dm}^3 = 810 \div 74.0 = 10.95 \text{ mol}$$

$$\text{Energy released} = 10.95 \times 2676 = 29\,291 \text{ kJ}$$

Energy density 29 300 kJ dm^{-3}

10

Turn over for the next question

Turn over ►



0 6

This question is about intermolecular forces in some organic compounds.

Table 4 gives some information about three organic compounds.

Table 4

Compound	dichloromethane	tetrachloromethane	propan-1-ol
Boiling point / °C	40	77	97
Polarity of molecules	polar	non-polar	polar

0 6 . 1

State why the C–Cl bonds in dichloromethane and tetrachloromethane are polar.

[1 mark]

Cl is more electronegative than C, so the electrons in the bond are not shared equally.

0 6 . 2

Suggest why tetrachloromethane molecules are non-polar.

[1 mark]

The molecule is symmetrical (tetrahedral), so the dipoles of the four polar C–Cl bonds cancel out.

0 6 . 3

Explain why tetrachloromethane has a higher boiling point than dichloromethane.

[2 marks]

*CCl₄ has many more electrons than CH₂Cl₂ (larger M_r), so the van der Waals' forces between CCl₄ molecules are stronger than the combined van der Waals' and dipole–dipole forces between CH₂Cl₂ molecules.
So more energy is needed to overcome the forces between CCl₄ molecules.*



0 6 . 4

Propan-1-ol has a higher boiling point than the other two compounds because of hydrogen bonding.

Describe the hydrogen bonding in propan-1-ol.

[2 marks]

A hydrogen bond is an attraction between a lone pair of electrons on the O atom of one propan-1-ol molecule and the $\delta+$ H atom of the O-H group on another molecule.

The O-H bond is very polar because O is much more electronegative than H.

6

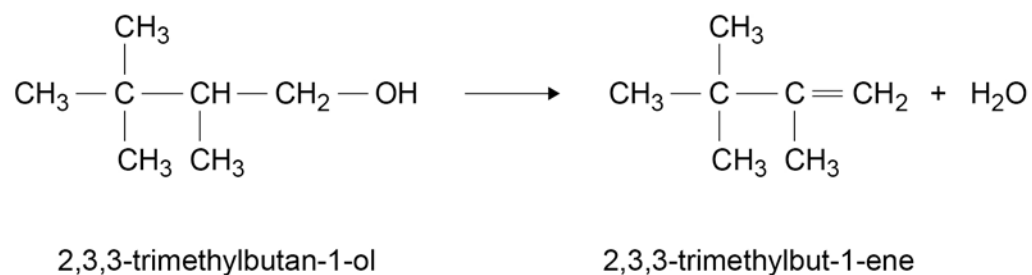
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0 7

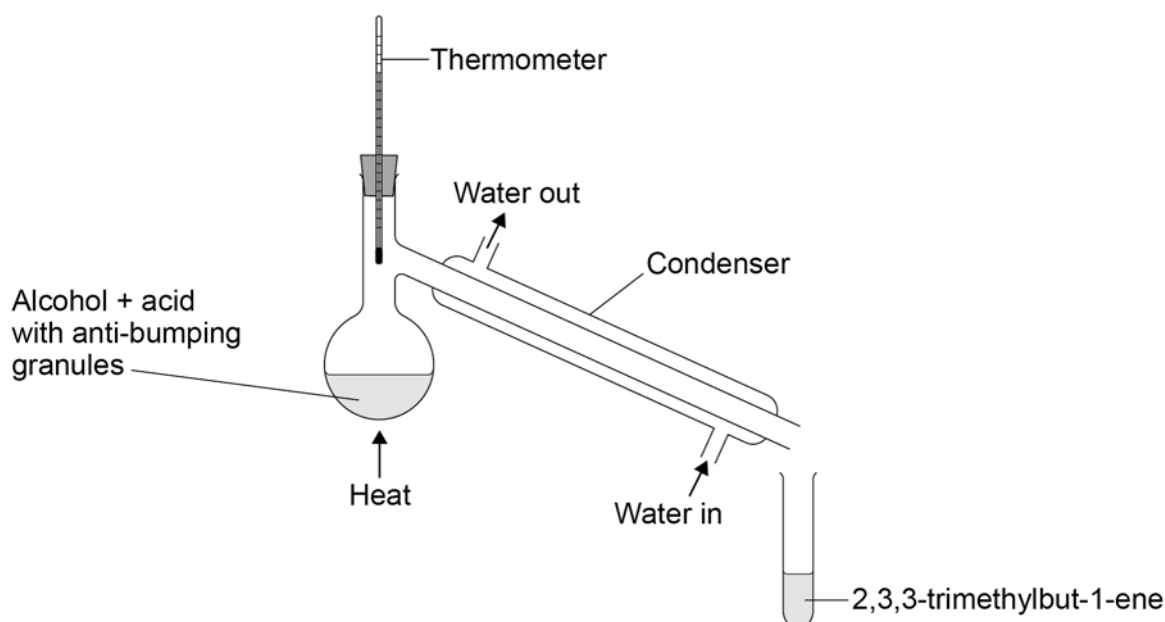
This question is about the preparation of 2,3,3-trimethylbut-1-ene.



The preparation is done by heating the alcohol with concentrated phosphoric acid, that acts as a catalyst.

Figure 3 shows the apparatus used.

Figure 3



The distillate is collected in the range 77–82 °C

0 7 . 1

Explain why the water should enter the condenser at the bottom and not at the top.

[2 marks]

Water entering at the bottom ensures the condenser jacket fills completely with water.

This keeps the whole condenser cool, so more of the vapour condenses.

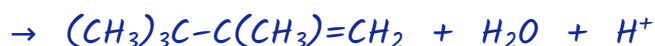
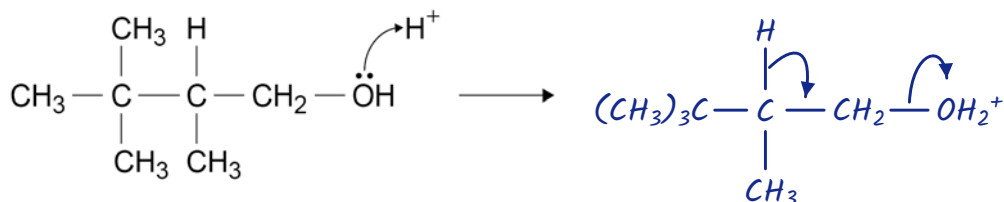
Water entering at the top would drain out without filling the jacket.



0 7 . 2

Name and complete the mechanism for this reaction.

[4 marks]

Name of mechanism Elimination

0 7 . 3

In a similar experiment, 12.0 cm³ of 2,3,3-trimethylbutan-1-ol ($M_r = 116.0$) produces 6.12 g of 2,3,3-trimethylbut-1-ene.

Calculate the percentage yield.

density of 2,3,3-trimethylbutan-1-ol = 0.818 g cm⁻³

[5 marks]

$$\text{Mass of alcohol} = 12.0 \times 0.818 = 9.816 \text{ g}$$

$$\text{Moles of alcohol} = 9.816 \div 116.0 = 0.08462 \text{ mol}$$

$$M_r \text{ of alkene } (\text{C}_7\text{H}_{14}) = 98.0$$

$$\text{Mass of alkene expected} = 0.08462 \times 98.0 = 8.293 \text{ g}$$

$$\% \text{ yield} = (6.12 \div 8.293) \times 100 = 73.8\%$$

Percentage yield 73.8%

11

Turn over ►

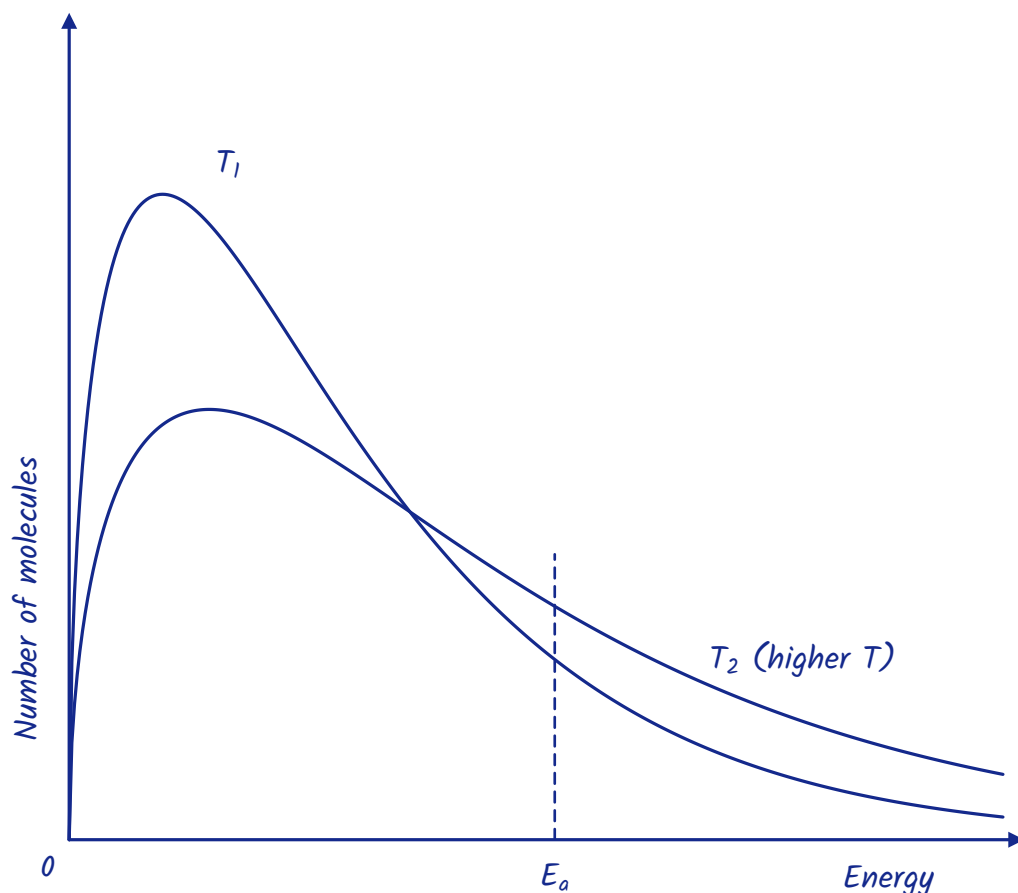


0 8

Draw the Maxwell–Boltzmann distribution curves for a fixed mass of a gas at two different temperatures.
This gas decomposes when heated.

By reference to these distribution curves, explain why the rate of decomposition of this gas increases at higher temperatures.

[6 marks]



The curves show the distribution of molecular energies at a lower temperature T_1 and a higher temperature T_2 . Both curves start at the origin, and neither touches the energy axis at high energy because there is no maximum energy.

At the higher temperature T_2 the peak is lower and moves to the right, to higher energy. The area under both curves is the same, because the number of molecules (fixed mass of gas) is the same. The two curves cross only once.

At the higher temperature the molecules have more (kinetic) energy, so



they move faster and collide more often.

Most importantly, many more molecules have energy greater than or equal to the activation energy, E_a : the area under the T_2 curve to the right of E_a is much larger than the area under the T_1 curve.

So a higher proportion of collisions have enough energy to break bonds and are successful. The frequency of successful collisions increases, so the rate of decomposition increases.



Section B

Answer **all** questions in this section.Only **one** answer per question is **allowed**.For each question **completely fill** in the circle alongside the appropriate answer.

CORRECT METHOD



WRONG METHODS



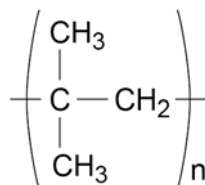
If you want to change your answer you must cross out your original answer as shown.

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.

You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

0 9

Which monomer forms this polymer?



[1 mark]

A but-1-ene

☐B *E*-but-2-ene☐C *Z*-but-2-ene☐

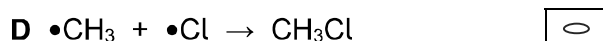
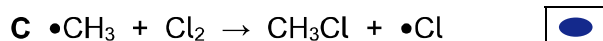
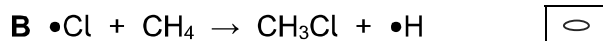
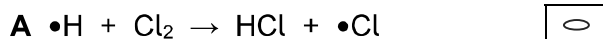
D methylpropene

☒

1 0

Which equation represents a propagation step in the chlorination of methane?

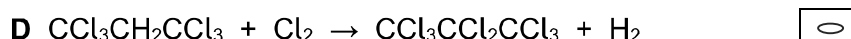
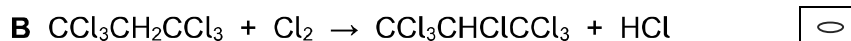
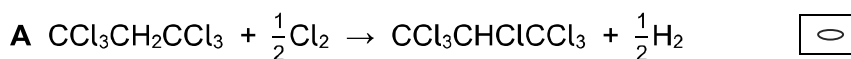
[1 mark]



1 1

Which is the overall equation for the reaction of $\text{CCl}_3\text{CH}_2\text{CCl}_3$ with an excess of chlorine in ultraviolet radiation?

[1 mark]



1 2

Most scientists believe that ozone in the upper atmosphere should not be allowed to become depleted.

Which is a valid reason for this belief?

[1 mark]

A Ozone absorbs ultraviolet radiation. ☒

B Ozone helps to prevent global warming. ☐

C Ozone helps to remove pollutants such as chloroalkanes. ☐

D Ozone is an efficient disinfectant. ☐

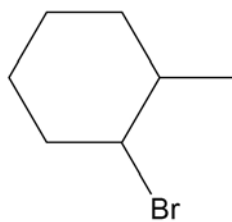
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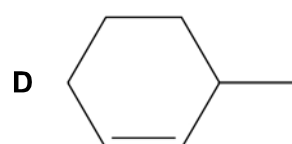
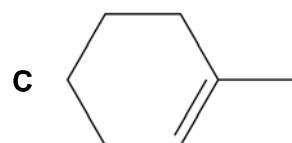
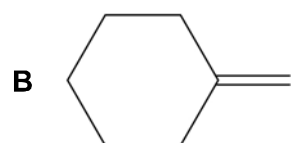
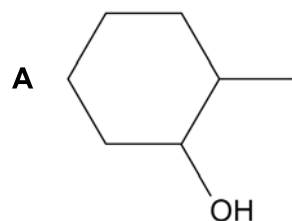


1 3

Which is **not** a possible product of the reaction of this compound with potassium hydroxide?

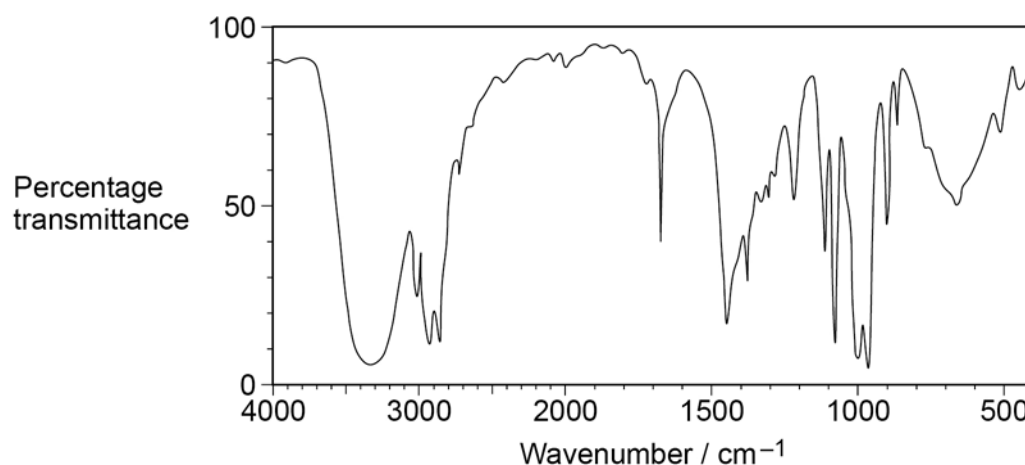


[1 mark]



1 4

The infrared spectrum of an organic compound is shown.



Which compound could produce this spectrum?

[1 mark]

- A but-1-ene ☐
- B but-2-en-1-ol ☒
- C butanoic acid ☐
- D butan-2-ol ☐

1 5

Which reaction results in an overall change in shape around a carbon atom?

[1 mark]

- A oxidation of propanal with acidified potassium dichromate(VI) ☐
- B polymerisation of tetrafluoroethene ☒
- C reaction of bromoethane with an excess of concentrated ammonia ☐
- D reaction of methane with an excess of chlorine in ultraviolet radiation ☐

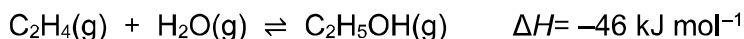
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1 6

Which statement about the industrial production of ethanol from ethene at 300 °C is correct?



[1 mark]

A An increase in pressure decreases the equilibrium yield of ethanol.

☐

B An increase in pressure increases the value of K_c .

☐

C An increase in temperature increases the equilibrium yield of ethanol.

☐

D An increase in temperature decreases the value of K_c .

☒

1 7

What is the minimum volume, in dm^3 , of air needed for the complete combustion of 1 dm^3 of methane?

Assume that air contains 20% of oxygen by volume.

Assume that all volumes are measured at the same temperature and pressure.

[1 mark]

A 1

☐

B 2

☐

C 5

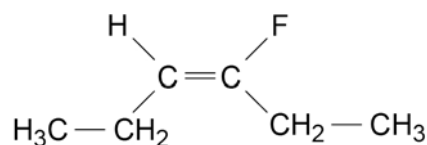
☐

D 10

☒

1 8

Which is the IUPAC name for this compound?



[1 mark]

A *E*-3-fluorohex-3-ene

☒

B *E*-4-fluorohex-3-ene

☐

C *Z*-3-fluorohex-3-ene

☐

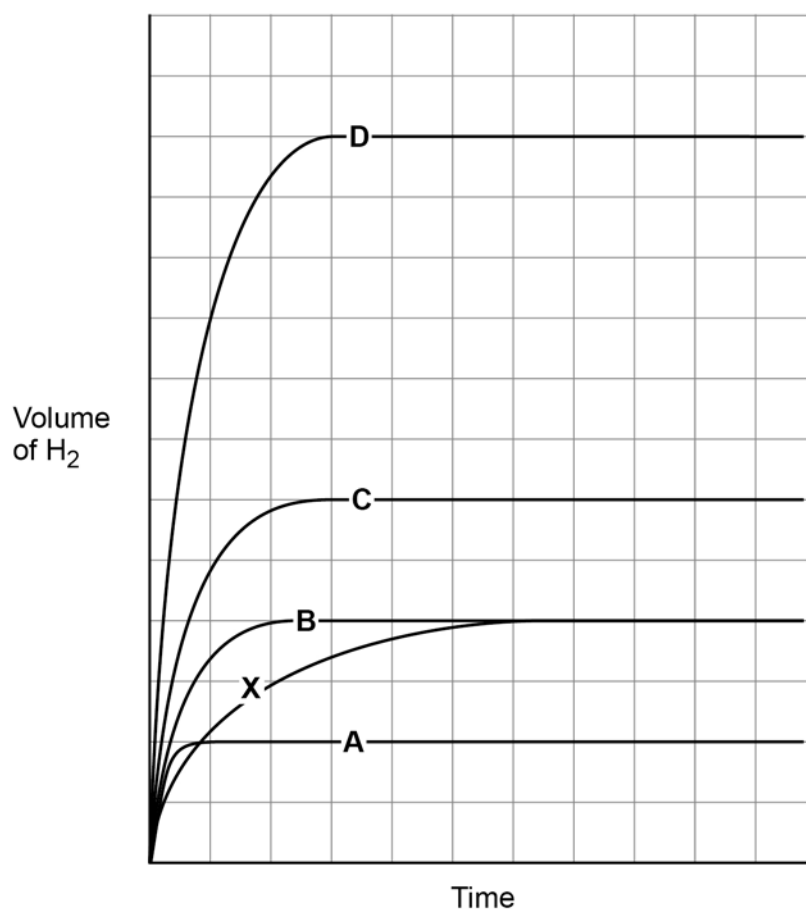
D *Z*-4-fluorohex-3-ene

☐

1 9

Magnesium reacts with an acid to form hydrogen gas.

Line **X** on the graph shows how the volume of hydrogen gas varies with time when 50 cm^3 of 0.50 mol dm^{-3} acid reacts with an excess of magnesium.



The reaction is repeated under the same conditions but using 25 cm^3 of 1.50 mol dm^{-3} acid. The magnesium is in excess.

Which line represents this second reaction?

[1 mark]

A line A

☐

B line B

☐

C line C

☒

D line D

☐

Turn over for the next question

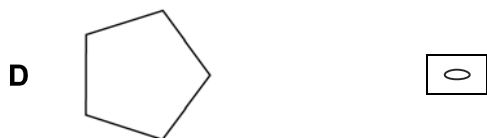
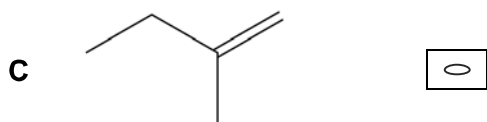
Turn over ►



2 0

Which compound has the greatest M_r ?

[1 mark]



2 1

Which compound has the empirical formula C_2H_4O ?

[1 mark]



2 2

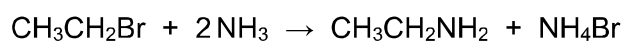
The alcohol $CH_3CH_2CH_2OH$ can be oxidised.Which compound **cannot** be produced by oxidation of this alcohol?

[1 mark]



2	3
---	---

What is the atom economy for the formation of ethylamine in this reaction?



[1 mark]

A 31.5%

☒

B 35.7%

☐

C 36.1%

☐

D 41.3%

☐

15

END OF QUESTIONS



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3 2



2 3 6 A 7 4 0 4 / 2