Surname	StemUp Model Solution	Centre Number	Candidate Number
First name(s)			2

GCE AS

B410U20-1

S23-B410U20-1

TUESDAY, 23 MAY 2023 – MORNING

CHEMISTRY – AS component 2

Energy, Rate and Chemistry of Carbon Compounds

1 hour 30 minutes

	For Examiner's use only		
	Question	**Maximum Mark**	**Mark Awarded**
Section A	**1. to 6.**	**10**	
Section B	**7.**	**19**	
	8.	**12**	
	9.	**9**	
	10.	**16**	
	11.	**14**	
	Total	**80**	

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ADDITIONAL MATERIALS

In addition to this examination paper, you will need a:
- calculator;
- **Data Booklet** supplied by WJEC.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen or correction fluid.

You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Section A Answer **all** questions.
Section B Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

The number of marks is given in brackets at the end of each question or part-question.

The maximum mark for this paper is 80.

Your answers must be relevant and must make full use of the information given to be awarded full marks for a question.

The assessment of the quality of extended response (QER) will take place in **Q.9**(a).

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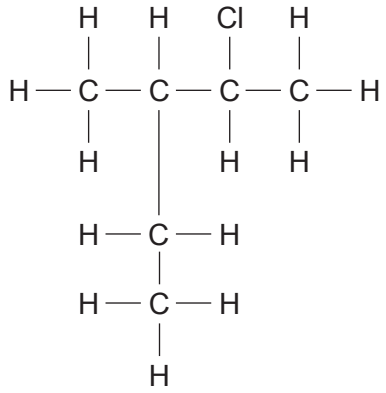
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SECTION A

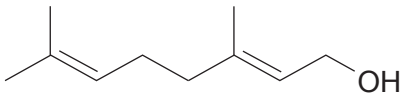
Answer **all** questions.

1. Name the compound whose formula is shown below. [1]



2-chloro-3-methylpentane

2. Geraniol is an alcohol which occurs in the essential oils of many aromatic plants. Its skeletal formula is shown below.



Give the **molecular** formula of geraniol. [1]

$C_{10}H_{18}O$

3. State the meaning of the term homolytic bond fission. [1]

When the covalent bond breaks, each of the bonded atoms receives one electron of the bonding pair, forming two radicals.

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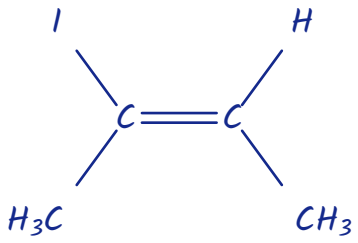
4. Hydrofluorocarbons, HFCs, are synthetic compounds which have replaced chlorofluorocarbons, CFCs, as refrigerants in cooling systems because they do not deplete the ozone layer.

Explain why HFCs do not deplete the ozone layer. [2]

The C–F bond is very strong, too strong to be broken by the UV radiation in the stratosphere.

So no halogen radicals are formed to break down (catalyse the decomposition of) ozone.

5. Draw the structure of (*E*)-2-iodobut-2-ene. [2]



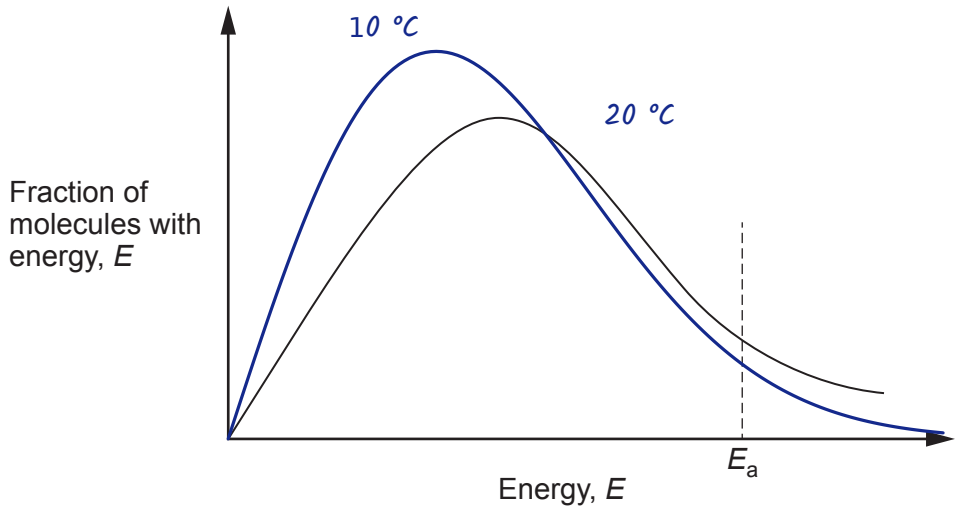
(E)-2-iodobut-2-ene

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6. The diagram below shows the distribution of energies of gas molecules in a reaction at 20 °C.



(a) On the same axes, draw a curve to show the distribution of energies of the same gas molecules with the reaction at 10 °C. [1]

(b) Use the diagram to explain the difference in reaction rate between the two reactions. [2]

Only molecules with energy equal to or greater than E_a are able to react.

The area under the curve beyond E_a is larger at 20 °C, so many more molecules have the required activation energy and the rate is higher at 20 °C than at 10 °C.

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SECTION B

Answer **all** questions.

7. (a) Propan-2-ol is the simplest example of a secondary alcohol. It is a common ingredient in many antiseptics.

A student carried out an experiment to determine the enthalpy change of combustion of propan-2-ol.

A spirit burner containing propan-2-ol was placed under a beaker containing 100 cm^3 of water. The burner was ignited and the alcohol allowed to burn until the temperature of the water rose by 25.4 °C. After the burner had cooled it was found that 0.362 g of propan-2-ol had been burned.

(i) State what is meant by a secondary alcohol. [1]

One in which the –OH group is joined to a carbon atom that is bonded to two other carbon atoms (and one hydrogen atom).

(ii) Write an equation for the complete combustion of propan-2-ol. [1]

$CH_3CH(OH)CH_3 + 4½O_2 \rightarrow 3CO_2 + 4H_2O$

(iii) Calculate a value for the enthalpy change of combustion of propan-2-ol in $kJ\,mol^{-1}$. [4]

$q = mc\Delta T = 100 \times 4.18 \times 25.4 = 10\,617\ J$

$n = 0.362 \div 60.1 = 6.025 \times 10^{-3}\ mol$

$\Delta_cH = -q \div n = -10\,617 \div 6.025 \times 10^{-3}$

$= -1\,762\,191\ J\ mol^{-1}$

$= -1762\ kJ\ mol^{-1}$

$\Delta_cH =$ −1762 $kJ\,mol^{-1}$

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(iv) The teacher said that the actual value for the enthalpy change of combustion of propan-2-ol is $-2006\,kJ\,mol^{-1}$.

Calculate the percentage error in the student's experimental value. [1]

% error = (−2006 − (−1762)) ÷ (−2006) × 100

= 244 ÷ 2006 × 100 = 12.2%

Percentage error = 12.2 %

(v) Suggest **one** reason, other than heat loss, why the value obtained for the enthalpy change of combustion is smaller than the theoretical value. [1]

Incomplete combustion of the propan-2-ol (some CO / soot formed).

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(b) The equation for the combustion of propene is as shown.

$$C_3H_6(g) + 4\tfrac{1}{2}O_2(g) \longrightarrow 3CO_2(g) + 3H_2O(g) \qquad \Delta_c H^\theta = -2058 \text{ kJ mol}^{-1}$$

(i) Use this and the average bond enthalpy values given in the table to calculate the average bond enthalpy for the O═O bond. [4]

Bond	Average bond enthalpy / kJ mol^{-1}
C═C	612
C—C	348
C—H	412
C═O	805
O—H	463

Bonds broken: (C=C) + (C–C) + 6(C–H) + 4½(O=O)

= 612 + 348 + 2472 + 4½(O=O) = 3432 + 4½(O=O)

Bonds formed: 6(C=O) + 6(O–H) = 4830 + 2778 = 7608

ΔH = broken – formed: 3432 + 4½(O=O) – 7608 = –2058

4½(O=O) = 2118

(O=O) = 2118 ÷ 4.5 = 471 kJ mol^{-1}

Average bond enthalpy = 471 kJ mol^{-1}

(ii) Suggest why the student could not use the method in (a) to determine the enthalpy change of combustion of propene. [1]

Propene is a gas, not a liquid, so it cannot go in a spirit burner.

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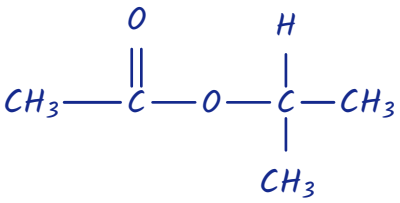
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(c) Propan-2-ol can react with ethanoic acid in the presence of concentrated sulfuric acid to form an ester and water. This reaction is reversible so an equilibrium mixture is produced and the ester is removed by distillation.

(i) Write the equation for the reaction between propan-2-ol and ethanoic acid.

Clearly show the structure of the ester formed. [2]

$CH_3CH(OH)CH_3 + CH_3COOH \rightleftharpoons$



(1-methylethyl ethanoate)

$+ \quad H_2O$

(ii) Explain fully why the ester can be separated from the equilibrium mixture by distillation. [2]

The ester has a lower boiling temperature (than the alcohol and acid). The alcohol and acid form hydrogen bonds between molecules, stronger than the van der Waals forces between ester molecules (esters do not hydrogen bond).

(iii) I. Explain why the yield of ester in the equilibrium mixture is increased by removing the ester. [1]

Removing the ester decreases its concentration, so the position of equilibrium moves to the right to form more ester.

II. Concentrated sulfuric acid is a dehydrating agent.

Suggest why the yield of ester in the equilibrium mixture is increased by adding concentrated sulfuric acid. [1]

It removes the water formed, decreasing its concentration, so the equilibrium position moves to the right, forming more ester.

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8. (a) Alkanes and alkenes are hydrocarbons. Alkanes can be obtained from fossil fuels such as petroleum.

Alkenes can be obtained by cracking long-chain hydrocarbons. They are more reactive than alkanes.

(i) The use of fossil fuels to meet our energy needs has many disadvantages, but there are some benefits.

Give one advantage of the use of fossil fuels. [1]

Fossil fuels release a large amount of energy when burned and are available at all times (reliable supply).

(ii) Name a **solid** pollutant that may form if a fossil fuel is burned incompletely in air. [1]

carbon (soot)

(iii) Explain why alkenes are more reactive than alkanes. [2]

Alkenes contain a C=C double bond: the π bond is a region of high electron density, so alkenes are easily attacked by electrophiles, and the π bond is weaker and easily broken.

Alkanes contain only single (σ) C–C and C–H bonds, with no double bond, so they are unreactive.

(iv) One molecule of decane, $C_{10}H_{22}$, can be cracked to give one molecule of pentane and two other products.

Write an equation for this reaction. [1]

$C_{10}H_{22} \rightarrow C_5H_{12} + C_2H_4 + C_3H_6$

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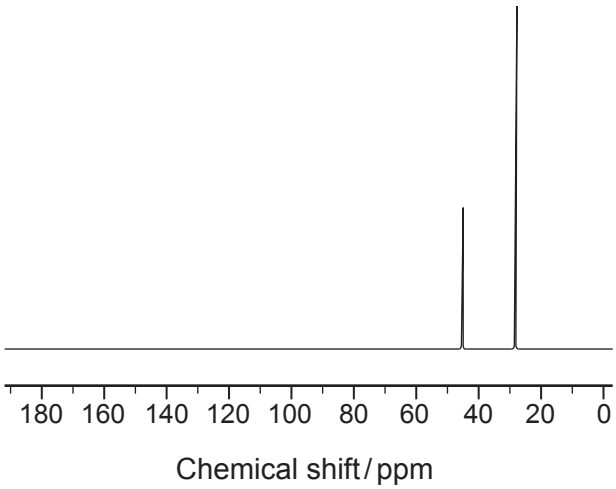
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(b) The information given below relates to liquid **X**.

Quantitative analysis shows that it contains 29.2% carbon and 5.8% hydrogen by mass. The remainder is bromine.

The mass spectrum shows two molecular ion signals at m/z 122 and m/z 124 in the ratio of 1:1.

Its ^{13}C NMR spectrum is shown below.



(i) Use **all** the information to identify liquid **X**. [5]

$C : H : Br = 29.2/12.0 : 5.8/1.01 : 65.0/79.9$

$= 2.43 : 5.74 : 0.814 = 3 : 7 : 1$

empirical formula = C_3H_7Br

M_r of $C_3H_7{}^{79}Br = 36 + 7 + 79 = 122$, so molecular formula = C_3H_7Br

m/z 122 and 124 (1 : 1) are the molecular ions $C_3H_7{}^{79}Br^+$ and $C_3H_7{}^{81}Br^+$ (two Br isotopes in equal amounts).

^{13}C NMR: only two peaks, so two carbon environments: about 30 ppm (two equivalent CH_3) and 45 ppm (CHBr).

X is 2-bromopropane, $CH_3CHBrCH_3$.

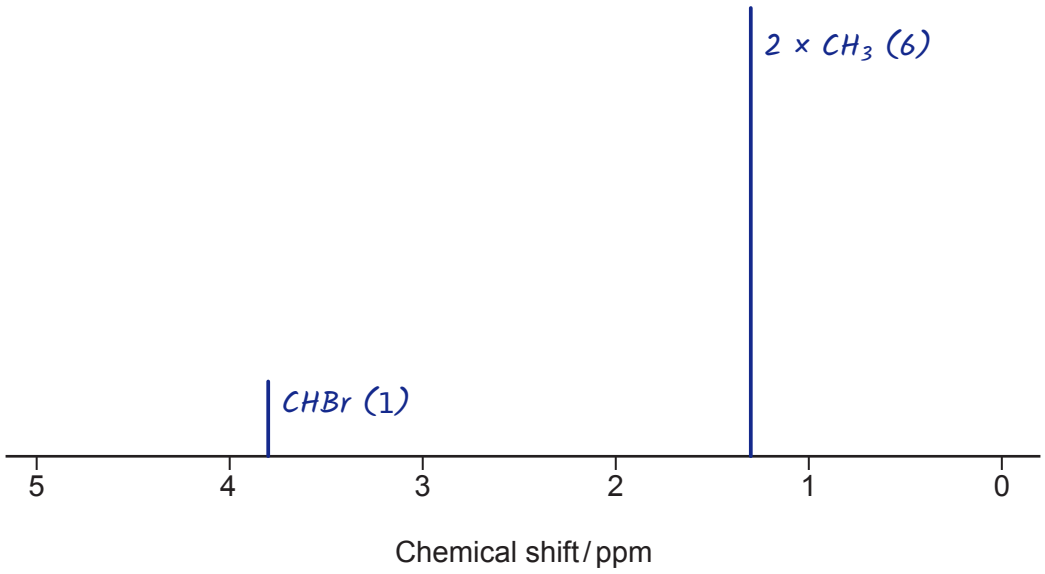
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(ii) Sketch the low resolution ^{1}H NMR spectrum of liquid **X**.

Identify which protons are responsible for each peak giving the approximate chemical shift (ppm) and the relative area of each peak. [2]



CHBr: δ 3.8 ppm, relative area 1

CH_3 (6 H): δ 1.3 ppm, relative area 6

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9. (a) A student is provided with unlabelled samples of the three liquids listed below.

1-chloropropane hex-1-ene propanoic acid

Describe chemical tests, apart from the use of an indicator, that the student should carry out to positively identify each of the three liquids.

You should include balanced equations for any reactions that occur. [6 QER]

Test 1, 1-chloropropane: warm a sample with aqueous sodium hydroxide, then acidify with dilute nitric acid and add aqueous silver nitrate. A white precipitate of AgCl forms with 1-chloropropane only.

$C_3H_7Cl + OH^- \rightarrow C_3H_7OH + Cl^-$ $Ag^+ + Cl^- \rightarrow AgCl$

Test 2, hex-1-ene: add bromine water and shake well. The colour changes from orange to colourless with hex-1-ene only, as Br_2 adds across the C=C bond.

$C_6H_{12} + Br_2 \rightarrow C_6H_{12}Br_2$

Test 3, propanoic acid: add aqueous sodium carbonate, Na_2CO_3. Effervescence is seen with propanoic acid only (the CO_2 turns limewater milky).

$2C_2H_5COOH + Na_2CO_3 \rightarrow 2C_2H_5COONa + CO_2 + H_2O$

The other two liquids give no visible change in each test, so each test positively identifies one liquid.

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(b) 1-Chloropropane, C_3H_7Cl, can be converted into propylamine, $C_3H_7NH_2$.

If the percentage yield of the reaction is 34.5%, calculate the mass of propylamine made from 8.93 g of 1-chloropropane.

Give your answer to an **appropriate** number of significant figures. [3]

$M_r(C_3H_7Cl) = 78.6$ $M_r(C_3H_7NH_2) = 59.1$

moles of 1-chloropropane = 8.93 ÷ 78.6 = 0.114 mol

1 : 1, so theoretical moles of propylamine = 0.114 mol

theoretical mass = 0.114 × 59.1 = 6.74 g

actual mass = 6.74 × 34.5 ÷ 100 = 2.33 g (3 s.f.)

Mass of propylamine = *2.33* g

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10. A student carried out an experiment to study the rate of the reaction between barium carbonate and hydrochloric acid.

$$BaCO_3 + 2HCl \longrightarrow BaCl_2 + H_2O + CO_2$$

M_r 197

He started with 1.50 g of barium carbonate and 30.0 cm^3 of 0.400 mol dm^{-3} hydrochloric acid. The experiment was carried out at 25 °C and 1 atm.

He determined the rate by following the loss in mass over 5 minutes.

(a) State which reactant is in excess. Use the data given to justify your answer. [2]

moles $BaCO_3$ = 1.50 ÷ 197 = 7.61×10^{-3} mol

moles HCl = 0.400 × 30.0 ÷ 1000 = 1.20×10^{-2} mol

$BaCO_3$: HCl = 1 : 2, so 1.20×10^{-2} mol HCl reacts with only 6.00×10^{-3} mol $BaCO_3$

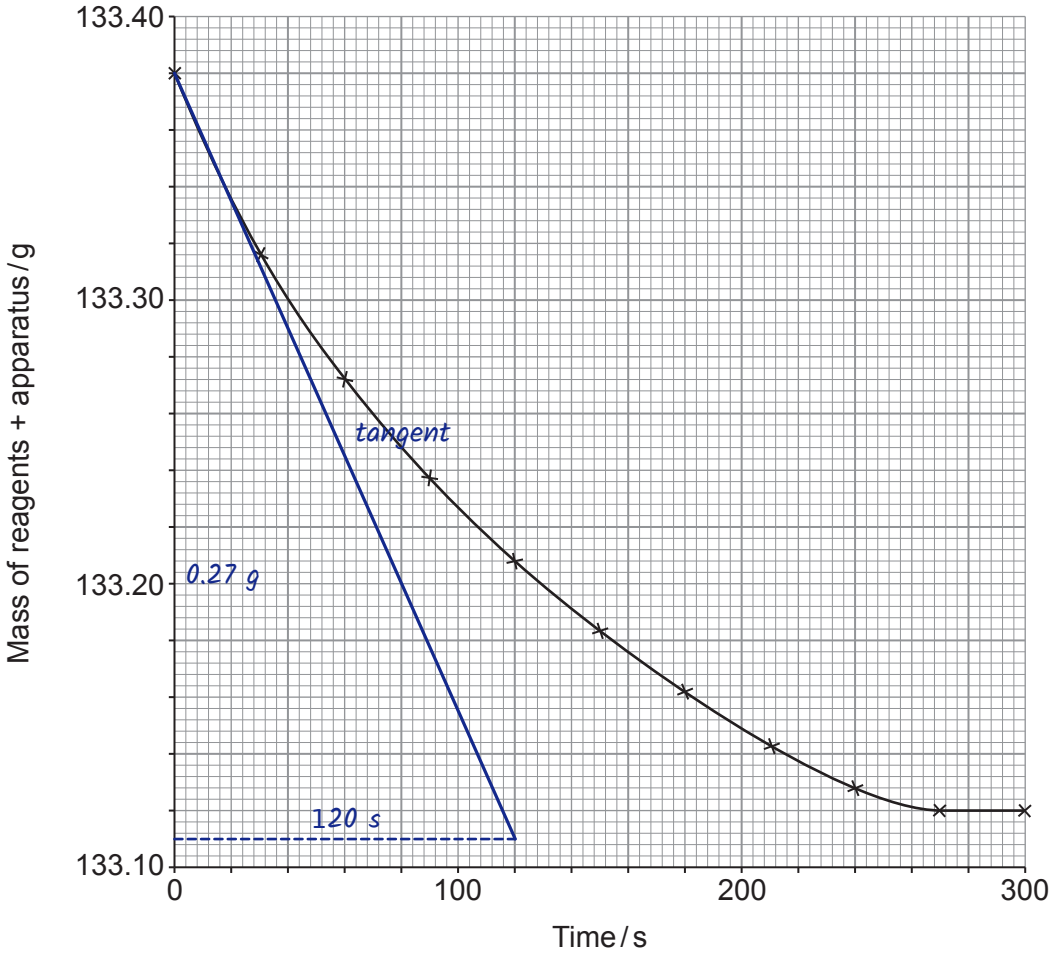
Barium carbonate is in excess (7.61×10^{-3} mol present but only 6.00×10^{-3} mol needed).

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The student plotted his results as follows.



(b) (i) Use the graph to calculate the **mean** rate of the reaction, in $g\,s^{-1}$. [1]

mass lost = 133.38 − 133.12 = 0.26 g in 270 s

mean rate = 0.26 ÷ 270

Mean rate = *9.63×10^{-4}* $g\,s^{-1}$

(ii) Use the graph to calculate the **initial** rate of the reaction, in $g\,s^{-1}$. [2]

gradient of tangent at t = 0 = 0.27 ÷ 120

(133.38 − 133.11 = 0.27 g over 0 to 120 s)

Initial rate = *2.25×10^{-3}* $g\,s^{-1}$

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(c) (i) Use the graph to describe how the rate of the reaction changes over the 5 minutes. [1]

The rate is fastest at the start, then decreases (the reaction slows down) and reaches zero (stops) after about 270 s.

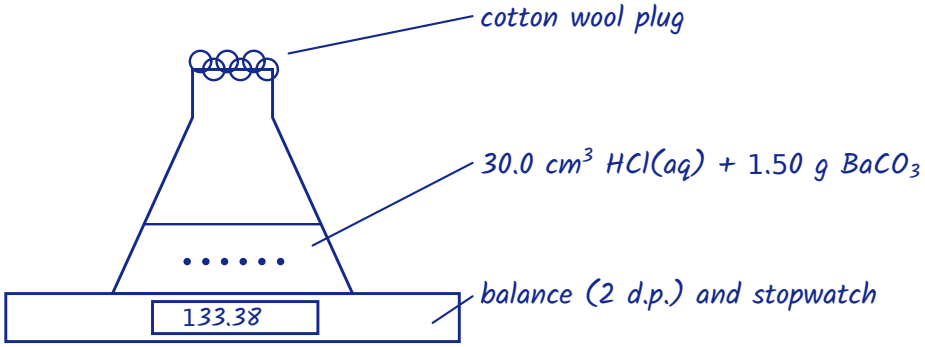
(ii) Use collision theory to explain why the rate of this reaction changes as the reaction proceeds. [2]

As the reaction proceeds the concentration of hydrochloric acid decreases (fewer moles of HCl left to react).

So there are fewer successful collisions per unit time, and the rate decreases.

(d) Outline the method the student used to carry out this experiment.

A diagram may be used in support of your answer. [3]



Record the total mass of the flask containing 30.0 cm^3 of the acid and 1.50 g of $BaCO_3$ (in a weighing boat) on the balance before mixing.

Tip the $BaCO_3$ into the acid, put the cotton wool plug in the neck and start the stopwatch at the same time.

Record the mass every 30 s for 5 minutes.

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(e) Another method to follow this reaction is by measuring the volume of carbon dioxide produced over time.

Name the apparatus you would use to collect the carbon dioxide. [1]

gas syringe

(f) Use the graph to calculate the volume (in cm^3) of carbon dioxide formed during this reaction at 25 °C.

You **must** show your working. [2]

mass of CO_2 = 133.38 − 133.12 = 0.26 g

moles CO_2 = 0.26 ÷ 44.0 = 5.91×10^{-3} mol

volume = $5.91 \times 10^{-3} \times 24.5$ = 0.145 dm^3

= 145 cm^3

Volume = 145 cm^3

(g) Another student said that if you used the same mass of calcium carbonate instead of barium carbonate, the volume of carbon dioxide formed would be less because the relative formula mass of calcium carbonate is less.

Is she correct? Justify your answer. [2]

No. HCl is the limiting reagent: 1.50 g of $CaCO_3$ is 0.0150 mol, more than the 0.00600 mol that reacts, so the carbonate is still in excess.

Only 0.00600 mol $CaCO_3$ reacts, so the same volume of CO_2 would form; she is incorrect.

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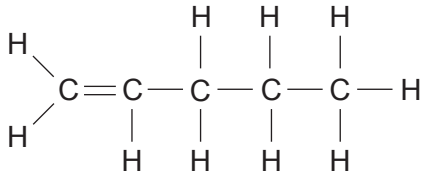
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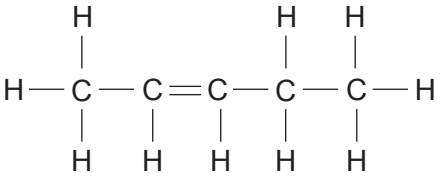
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11. Five non-cyclic structural isomers have the molecular formula C_5H_{10}.

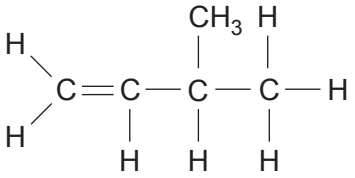
Three of these are shown below.



pent-1-ene



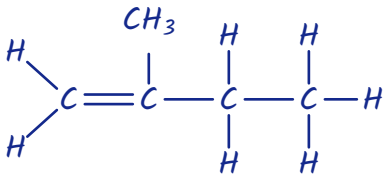
pent-2-ene



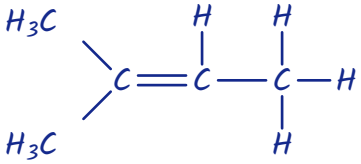
3-methylbut-1-ene

(a) Draw the structures of the other **two** isomers.

Do **not** include both the *E* and the *Z* isomer of the same structure. [2]



2-methylbut-1-ene



2-methylbut-2-ene

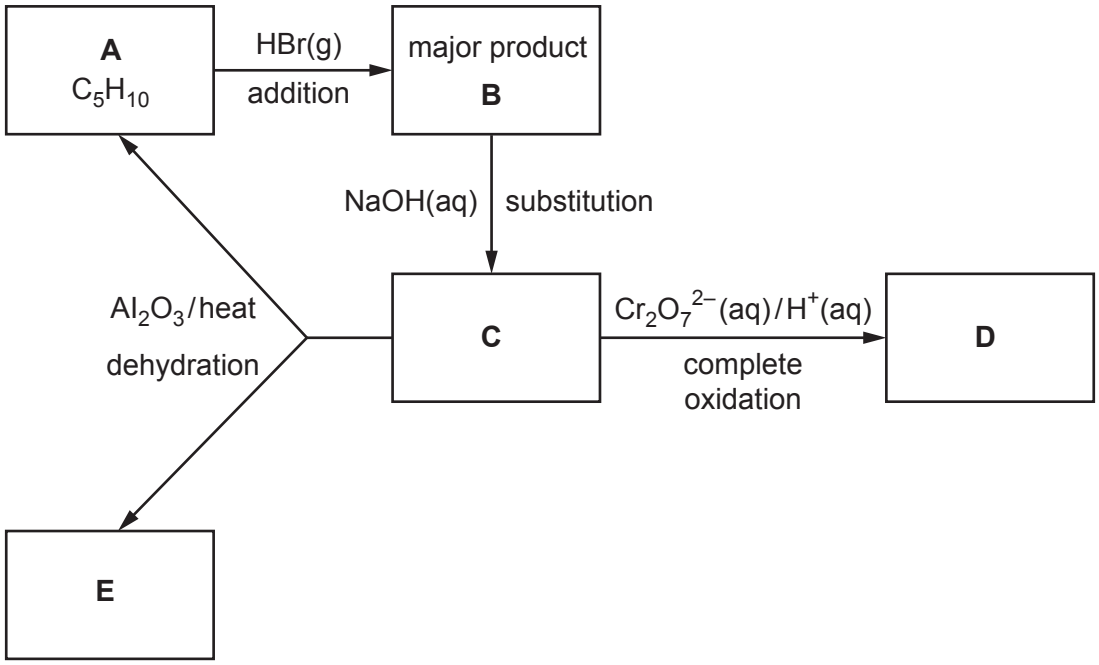
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(b) Compound **A** is one of the five isomers on the previous page.

Study the reaction scheme and the information below.



Compound **D** does **not** react with aqueous sodium carbonate.

Compound **E** does **not** show *E-Z* isomerism.

(i) Use the information to name the homologous series to which compounds **B**–**E** belong. Give your reasoning. [6]

A is an alkene, so addition of HBr gives B, a bromoalkane; B is a secondary bromoalkane since the secondary carbocation is more stable.

Bromoalkanes undergo substitution with aqueous NaOH, so C is an alcohol, and it is a secondary alcohol.

C is not primary: complete oxidation of a primary alcohol by acidified dichromate(VI) forms a carboxylic acid, which reacts with Na_2CO_3. C is not tertiary, as tertiary alcohols are not oxidised.

D is a ketone, since it does not react with aqueous Na_2CO_3 and forms from a secondary alcohol; D is not an aldehyde, as complete oxidation would form a carboxylic acid.

E is an alkene, since alcohols are dehydrated to alkenes.

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(ii) State what you would observe when compound **C** is oxidised to compound **D**. [1]

Colour change from orange to green.

(iii) Compound **B** can also undergo an elimination reaction.

State the reagent(s) and conditions needed for this reaction. [1]

NaOH (KOH) in ethanol, heat under reflux.

(iv) Compound **A** can **only** be 3-methylbut-1-ene.

It cannot be pent-2-ene because its reaction with HBr would give two products in significant quantities.

I. Explain why compound **A** cannot be pent-1-ene. [2]

Pent-1-ene would form 2-bromopentane as the only major product with HBr, which would then form pentan-2-ol by substitution. The alkene E formed on dehydration of pentan-2-ol would be pent-2-ene, but this has E-Z isomers, so A cannot be pent-1-ene.

II. Explain why compound **A** cannot be either of the two isomers drawn in part (a). [2]

2-methylbut-1-ene and 2-methylbut-2-ene would both form a tertiary bromoalkane (2-bromo-2-methylbutane) as the major product on addition of HBr. After substitution this would become a tertiary alcohol, which cannot be oxidised by acidified dichromate(VI), so D could not form.

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END OF PAPER

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CHEMISTRY – AS component 2
Data Booklet

Avogadro constant	N_A	$= 6.02 \times 10^{23}\ \text{mol}^{-1}$
molar gas constant	R	$= 8.31\ \text{J mol}^{-1}\ \text{K}^{-1}$
molar gas volume at 273 K and 1 atm	V_m	$= 22.4\ \text{dm}^3\ \text{mol}^{-1}$
molar gas volume at 298 K and 1 atm	V_m	$= 24.5\ \text{dm}^3\ \text{mol}^{-1}$
Planck constant	h	$= 6.63 \times 10^{-34}\ \text{J s}$
speed of light	c	$= 3.00 \times 10^{8}\ \text{m s}^{-1}$
density of water	d	$= 1.00\ \text{g cm}^{-3}$
specific heat capacity of water	c	$= 4.18\ \text{J g}^{-1}\ \text{K}^{-1}$
ionic product of water at 298 K	K_w	$= 1.00 \times 10^{-14}\ \text{mol}^2\ \text{dm}^{-6}$
fundamental electronic charge	e	$= 1.60 \times 10^{-19}\ \text{C}$

temperature (K) = temperature (°C) + 273

$1\ \text{dm}^3 = 1000\ \text{cm}^3$
$1\ \text{m}^3 = 1000\ \text{dm}^3$
1 tonne = 1000 kg
1 atm = 1.01×10^5 Pa

Multiple	Prefix	Symbol
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m

Multiple	Prefix	Symbol
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G

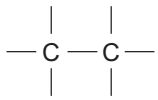
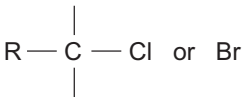
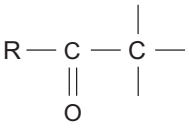
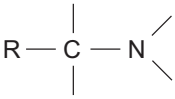
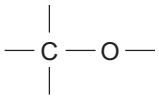
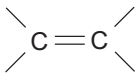
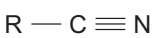
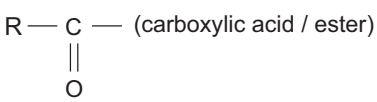
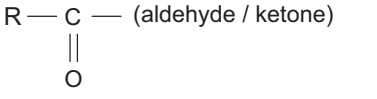
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Infrared absorption values

Bond	Wavenumber / cm^{-1}
C — Br	500 to 600
C — Cl	650 to 800
C — O	1000 to 1300
C = C	1620 to 1670
C = O	1650 to 1750
C ≡ N	2100 to 2250
C — H	2800 to 3100
O — H (carboxylic acid)	2500 to 3200 (very broad)
O — H (alcohol / phenol)	3200 to 3550 (broad)
N — H	3300 to 3500

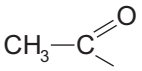
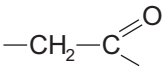
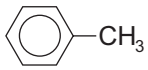
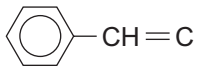
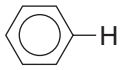
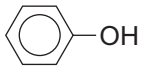
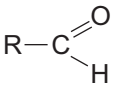
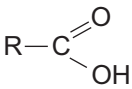
^{13}C NMR chemical shifts relative to TMS = 0

Type of carbon	Chemical shift, δ (ppm)
	5 to 40
	10 to 70
	20 to 50
	25 to 60
	50 to 90
	90 to 150
	110 to 125
	110 to 160
	160 to 185
	190 to 220

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^{1}H NMR chemical shifts relative to TMS = 0

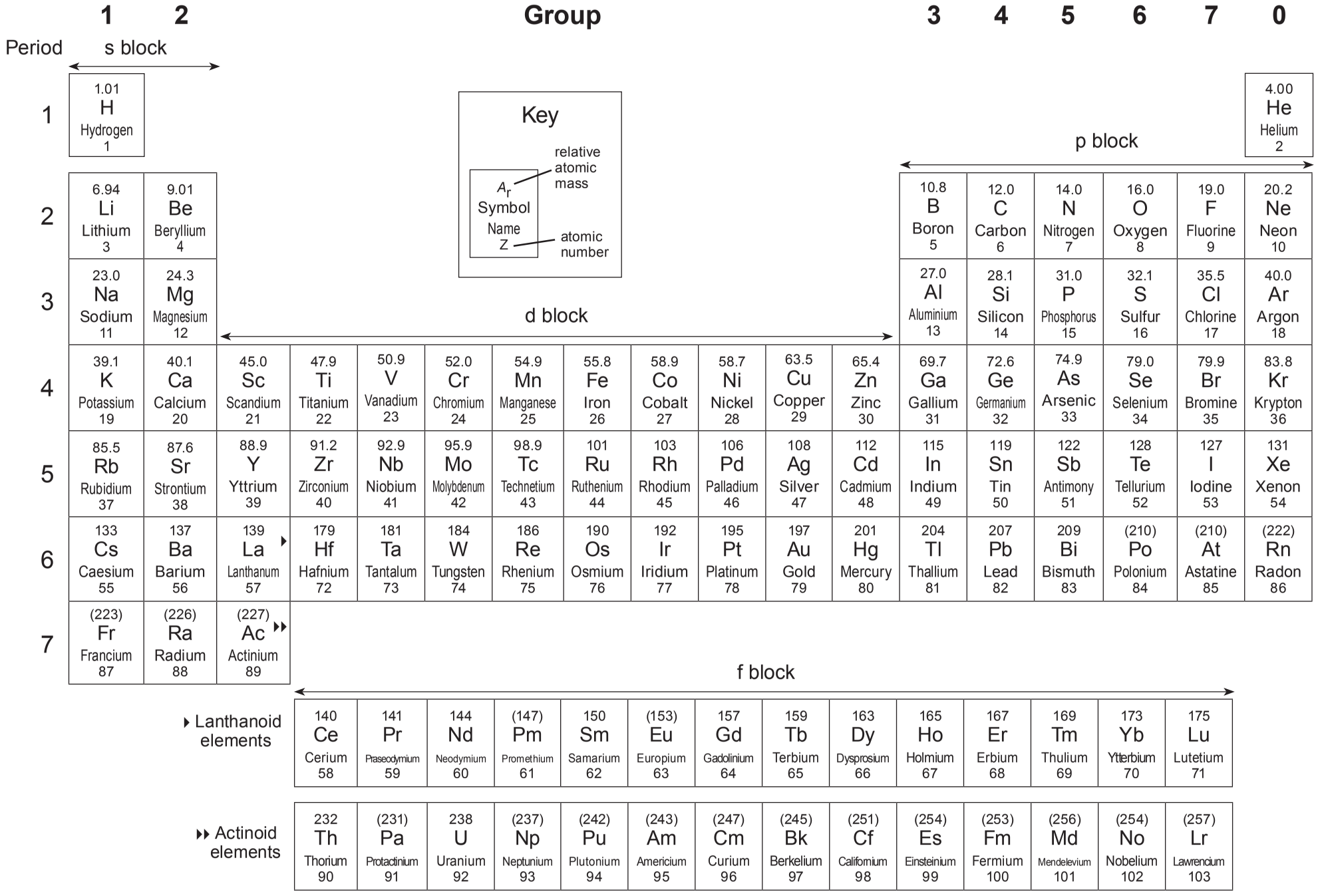
Type of proton	Chemical shift, δ (ppm)
$-CH_3$	0.1 to 2.0
$R-CH_3$	0.9
$R-CH_2-R$	1.3
$CH_3-C\equiv N$	2.0
	2.0 to 2.5
	2.0 to 2.0
	2.2 to 2.3
HC—Cl or HC—Br	3.1 to 4.3
HC—O	3.3 to 4.3
R—OH	4.5 *
—C═CH	4.5 to 6.3
—C═CH—CO	5.8 to 6.5
	6.5 to 7.5
	6.5 to 8.0
	7.0 *
	9.8 *
	11.0 *

*variable figure dependent on concentration and solvent

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THE PERIODIC TABLE



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