



Oxford Cambridge and RSA

**Tuesday 20 May 2025 – Morning**

**AS Level Chemistry A**

**H032/02 Depth in chemistry**

**Time allowed: 1 hour 30 minutes**



**You must have:**

- the Data Sheet for Chemistry A

**You can use:**

- a scientific or graphical calculator
- an HB pencil



Please write clearly in black ink. **Do not write in the barcodes.**

Centre number

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Candidate number

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First name(s)

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Last name

*StemUp Model Solution*

### INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

### INFORMATION

- The total mark for this paper is **70**.
- The marks for each question are shown in brackets [ ].
- Quality of extended response will be assessed in questions marked with an asterisk (\*).
- This document has **24** pages.

### ADVICE

- Read each question carefully before you start your answer.

- 1 A student is investigating the enthalpy change of neutralisation for a strong acid and a strong alkali.

(a) Explain what is meant by an **alkali**.

*An alkali is a soluble base: it dissolves in water and releases  $\text{OH}^-$  (hydroxide) ions in aqueous solution.* [1]

(b) Write the ionic equation for the neutralisation reaction between an acid and an alkali.

*$\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$*  [1]

(c) The student mixes  $40.0\text{ cm}^3$  of  $1.40\text{ mol dm}^{-3}$   $\text{HCl}$  and  $40.0\text{ cm}^3$  of  $1.40\text{ mol dm}^{-3}$   $\text{NaOH}$ .

The temperature rises by  $9.40^\circ\text{C}$

(i) Calculate the enthalpy change of neutralisation, in  $\text{kJ mol}^{-1}$ .

Give your answer to **3** significant figures.

Assume that the density of all solutions and the specific heat capacity,  $c$ , of the reaction mixture is the same as for water.

$$\begin{aligned}\text{Energy released: } q &= mc\Delta T = 80.0 \times 4.18 \times 9.40 \\ &= 3143.36 \text{ J} = 3.14336 \text{ kJ}\end{aligned}$$

$$n(\text{HCl}) = n(\text{NaOH}) = n(\text{H}_2\text{O}) = 40.0 \times 1.40 \div 1000 = 0.0560 \text{ mol}$$

$$\begin{aligned}\Delta H \text{ per mole of } \text{H}_2\text{O} &= -3.14336 \div 0.0560 \\ &= -56.131... \text{ kJ mol}^{-1}\end{aligned}$$

$$\Delta H_{\text{neut}} = -56.1 \text{ kJ mol}^{-1} \text{ (3 s.f., negative as exothermic)}$$

Enthalpy change of neutralisation = .....*-56.1*.....  $\text{kJ mol}^{-1}$  [4]

- (ii) The student repeats the experiment using the same volume and concentration of NaOH but using  $20.0\text{ cm}^3$  of  $2.80\text{ mol dm}^{-3}\text{ HCl}$  instead of  $40.0\text{ cm}^3$  of  $1.40\text{ mol dm}^{-3}\text{ HCl}$ .

The temperature rise is greater than  $9.4\text{ }^{\circ}\text{C}$ .

Explain why.

*The number of moles of HCl is the same:  $20.0 \times 2.80 \div 1000 = 0.0560\text{ mol}$ , so the same amount of water forms and the same quantity of heat energy ( $q$ ) is released.*

*But this same energy is spread over a smaller total volume / mass of solution:  $60.0\text{ cm}^3$  ( $60.0\text{ g}$ ) instead of  $80.0\text{ cm}^3$ , so  $\Delta T = q \div mc$  is larger ( $3143 \div (60.0 \times 4.18) = 12.5\text{ }^{\circ}\text{C}$ ).*

[2]

2 This question is about reactions of some Group 2 elements and their compounds.

(a) The table below shows the first and second ionisation energies of magnesium and calcium.

| Group 2 element | 1st Ionisation energy<br>/kJ mol <sup>-1</sup> | 2nd Ionisation energy<br>/kJ mol <sup>-1</sup> |
|-----------------|------------------------------------------------|------------------------------------------------|
| Mg              | 738                                            | 1451                                           |
| Ca              | 590                                            | 1145                                           |

(i) Write an equation to represent the **second** ionisation energy of calcium.

Include state symbols.



(ii)\* Magnesium and calcium differ in their reactivity.

Give a balanced equation for the reaction of **calcium** with water and describe what would be observed. Explain why this is a redox reaction.

Explain the difference in reactivity of magnesium and calcium.



*Observations: effervescence (fizzing) of  $\text{H}_2$  gas; the calcium dissolves; a white precipitate of  $\text{Ca}(\text{OH})_2$  forms (cloudy).* .....

*Redox: calcium is oxidised, as its oxidation number increases from 0 in Ca to +2 in  $\text{Ca}(\text{OH})_2$  (each Ca atom loses 2 electrons to form  $\text{Ca}^{2+}$ ). Hydrogen is reduced, as its oxidation number decreases from +1 in  $\text{H}_2\text{O}$  to 0 in  $\text{H}_2$  (each H gains 1 electron). Both oxidation and reduction take place, so it is a redox reaction.* .....

*Reactivity: calcium is more reactive than magnesium. A Ca atom has a larger atomic radius than a Mg atom, as it has one more electron shell, so there is more shielding of its outer electrons. Its outer 4s electrons are further from the nucleus, so they feel a weaker nuclear attraction than the 3s electrons of Mg.* .....

*So less energy is needed to remove the two outer electrons of Ca: its first and second ionisation energies (590 and 1145 kJ mol<sup>-1</sup>) are lower than those of Mg (738 and 1451 kJ mol<sup>-1</sup>). So Ca loses its outer electrons more easily and reacts more vigorously.* .....

[6]

Extra answer space if required.

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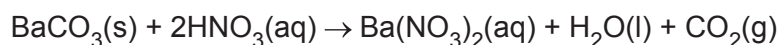
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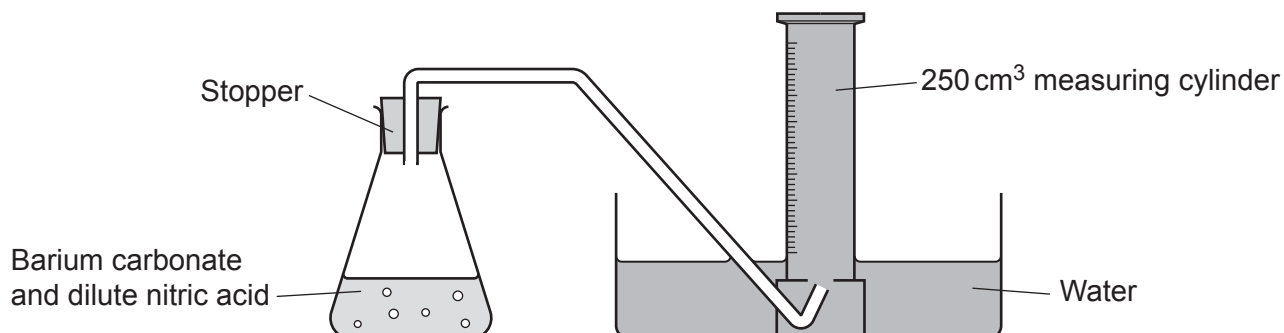
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- (b) A student adds 1.51 g of barium carbonate,  $\text{BaCO}_3$  (molar mass  $197.3 \text{ g mol}^{-1}$ ), to an excess of dilute nitric acid. The equation is shown below.



The student uses the following apparatus.



- (i) Calculate the volume, in  $\text{cm}^3$ , of gas the student expects to be produced at room temperature and pressure (RTP).

Give your answer to **3** significant figures.

$$n(\text{BaCO}_3) = n(\text{CO}_2) = 1.51 \div 197.3 = 7.653 \times 10^{-3} \text{ mol}$$

$$V(\text{CO}_2) = 7.653 \times 10^{-3} \times 24\,000 \text{ cm}^3 = 183.7 \text{ cm}^3$$

Volume of gas ..... 184 .....  $\text{cm}^3$  [2]

- (ii) The volume of gas collected is less than the calculated volume.

Suggest **two** reasons for this difference.

- 1 Some  $\text{CO}_2$  escapes before the stopper is replaced after adding the  $\text{BaCO}_3$  to the acid.
- 2 Some  $\text{CO}_2$  dissolves in the water ( $\text{CO}_2$  is slightly soluble).  
The room conditions may not be exactly at RTP.

[2]

- (iii) Suggest **one** way in which the student could modify the apparatus to produce a volume closer to the calculated volume.

Collect the gas in a gas syringe instead of the measuring cylinder over water.

[1]

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**Turn over for the next question**

### 3 Malic acid tablets are sold as a health supplement.

A student carries out a titration to determine the mass of malic acid,  $\text{C}_4\text{H}_6\text{O}_5$ , in **one** tablet.

The student follows the method below:

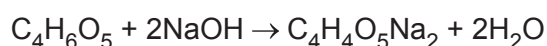
**Step 1** Crush **three** tablets, transfer the powder into a beaker and dissolve in distilled water.

**Step 2** Transfer the solution into a  $250.0\text{ cm}^3$  volumetric flask and make up to the mark with distilled water.

**Step 3** Pipette  $25.0\text{ cm}^3$  of the solution from **Step 2** into a conical flask and add a few drops of indicator.

**Step 4** Titrate this solution with  $0.0800\text{ mol dm}^{-3}$  sodium hydroxide, NaOH, in the burette.

The equation for the neutralisation reaction is:



(a) The student takes burette readings to the nearest  $0.05\text{ cm}^3$ .

The student's readings are shown in the table.

**The rough titre has been omitted.**

(i) Complete the table below.

| Titration                       | 1               | 2               | 3               |
|---------------------------------|-----------------|-----------------|-----------------|
| Final reading / $\text{cm}^3$   | 23.60           | 46.70           | 25.65           |
| Initial reading / $\text{cm}^3$ | 0.30            | 23.65           | 2.50            |
| Titre / $\text{cm}^3$           | .....23.30..... | .....23.05..... | .....23.15..... |

[1]

(ii) Calculate the mean titre of NaOH that the student should use to analyse the results.

*Titres 2 and 3 are concordant (within  $0.10\text{ cm}^3$ ):*

*mean titre =  $(23.05 + 23.15) \div 2 = 23.10\text{ cm}^3$*

Mean titre = .....23.10.....  $\text{cm}^3$  [1]

(iii) Calculate the mass, in mg, of malic acid in **one** tablet.

Assume that malic acid (molar mass  $134.0 \text{ g mol}^{-1}$ ) is the only acid in the tablets.

Give your answer to **3** significant figures.

$$n(\text{NaOH}) = 23.10 \times 0.0800 \div 1000 = 1.848 \times 10^{-3} \text{ mol}$$

$$n(\text{C}_4\text{H}_6\text{O}_5) \text{ in } 25.0 \text{ cm}^3 = 1.848 \times 10^{-3} \div 2 = 9.24 \times 10^{-4} \text{ mol}$$

$$n(\text{C}_4\text{H}_6\text{O}_5) \text{ in } 250.0 \text{ cm}^3 \text{ (3 tablets)} = 9.24 \times 10^{-4} \times 10 = 9.24 \times 10^{-3} \text{ mol}$$

$$\text{mass in 3 tablets} = 9.24 \times 10^{-3} \times 134.0 = 1.23816 \text{ g}$$

$$\text{mass in one tablet} = 1.23816 \div 3 = 0.41272 \text{ g}$$

$$= 0.41272 \times 1000 = 413 \text{ mg}$$

Mass of malic acid ..... **413** ..... mg [5]

(b) Another student carries out the same experiment.

Instead of rinsing the burette used in **Step 4** with  $0.0800 \text{ mol dm}^{-3}$  NaOH, the student rinses with water before filling it up with  $0.0800 \text{ mol dm}^{-3}$  NaOH.

State and explain how this error would affect the titre.

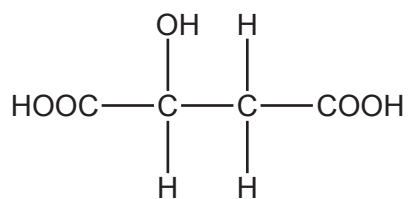
*The titre would be greater (larger volume of NaOH needed).*

*The water left in the burette dilutes the NaOH, so it is less concentrated than*

*$0.0800 \text{ mol dm}^{-3}$  and a bigger volume is needed to neutralise the same amount*

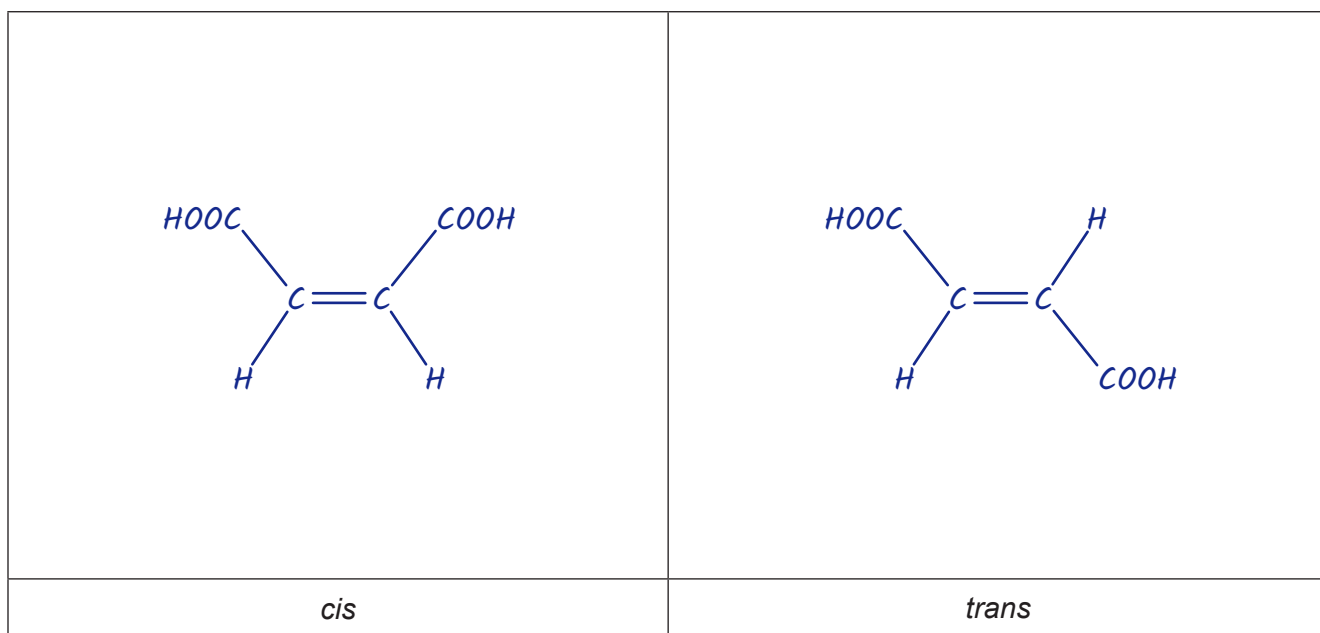
*of acid.* [2]

(c) The structure of malic acid is shown below.



When malic acid is heated with an acid catalyst, a mixture of *cis* and *trans* stereoisomers is produced.

Draw the structures of the *cis* and *trans* isomers.



[2]

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- 4 The alkanes belong to a homologous series of hydrocarbons.

Table 4.1 shows information about some straight chain alkanes.

Table 4.1

| Alkane  | Molecular formula              | Boiling point / °C | Enthalpy change of combustion / kJ mol <sup>-1</sup> |
|---------|--------------------------------|--------------------|------------------------------------------------------|
| Propane | C <sub>3</sub> H <sub>8</sub>  | -42                | -2219                                                |
| Butane  | C <sub>4</sub> H <sub>10</sub> | 0                  | To estimate in part (b)(iv)                          |
| Pentane | C <sub>5</sub> H <sub>12</sub> | 36                 | -3509                                                |
| Hexane  | C <sub>6</sub> H <sub>14</sub> | 69                 | -4163                                                |

- (a) State and explain the trend in boiling points of the straight chain alkanes in Table 4.1.

*Trend: the boiling point increases from propane to hexane as the chain length increases (more carbon atoms in the chain).*

*Explanation: longer alkane molecules have more electrons and a larger surface area, so there is more surface contact between neighbouring molecules.*

*So there are more / stronger induced dipole-dipole interactions (London forces) between the molecules.*

*So more energy is needed to overcome (break) the London forces (intermolecular forces) between the molecules, giving a higher boiling point.*

[4]

(b) When alkanes undergo complete combustion carbon dioxide and water are produced.

(i) Write the balanced equation for the complete combustion of **one** mole of pentane.



(ii) Use the information in **Table 4.1** to calculate the mass of carbon dioxide formed when 1.00 kJ of energy is released during the complete combustion of pentane.

$1 \text{ mol } C_5H_{12} \text{ releases } 3509 \text{ kJ and forms } 5 \text{ mol } CO_2$

$\text{mass of } CO_2 \text{ per mole of pentane} = 5 \times 44.0 = 220 \text{ g}$

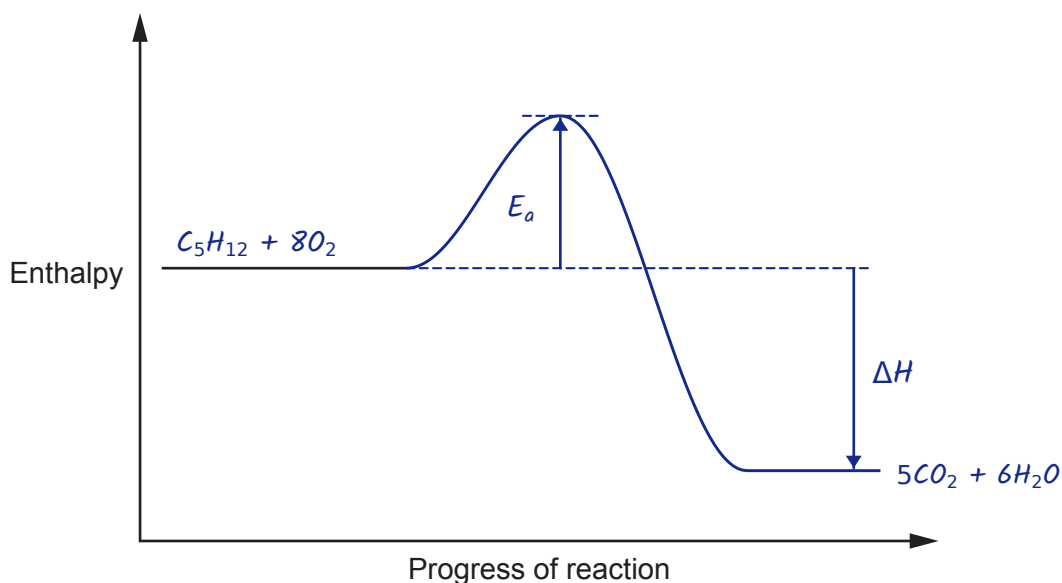
$\text{mass of } CO_2 \text{ per } 1.00 \text{ kJ} = 220 \div 3509 = 0.0627 \text{ g}$

Mass of carbon dioxide .....  $0.0627$  ..... g [2]

(iii) Complete the enthalpy profile diagram for the complete combustion of pentane.

On your diagram:

- Label the enthalpy change as  $\Delta H$ .
- Include the formulae of the reactants and products.
- Label the activation energy as  $E_a$ .



[2]

(iv) Use the data in **Table 4.1** to estimate a value for the enthalpy change of combustion of butane.

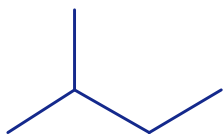
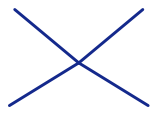
Give your answer to **2** significant figures.

$\text{Each extra } CH_2 \text{ adds about } 650 \text{ kJ mol}^{-1}; (-2219 + -3509) \div 2 = -2864$

Estimated enthalpy change of combustion of butane .....  $-2900$  .....  $\text{kJ mol}^{-1}$  [1]

- (c) Besides pentane, there are two other structural isomers of  $C_5H_{12}$ .

Draw the **skeletal** formulae of these two other structural isomers and state the systematic name of each.

|                  | Isomer 1                                                                          | Isomer 2                                                                            |
|------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Skeletal formula |  |  |
| Systematic name  | <i>2-methylbutane</i>                                                             | <i>2,2-dimethylpropane</i>                                                          |

[2]

- (d) In the presence of ultraviolet radiation, propane reacts with bromine to form a mixture of products.

Two of these products are structural isomers of  $C_3H_7Br$ .

- (i) Write an equation, using molecular formulae, for the formation of  $C_3H_7Br$  from propane.



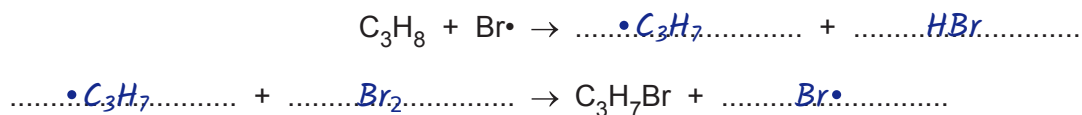
- (ii) The first step in the mechanism of the reaction is the homolytic fission of a Br–Br bond.

Explain what is meant by **homolytic fission**.

*A covalent bond breaks and each atom (Br) takes one electron from the bonding (shared) pair, forming two radicals.*..... [1]

- (iii) Complete the equations for the propagation steps in the mechanism.

Use molecular formulae for organic species and dots (•) for unpaired electrons on radicals.



[2]

- (iv) Explain why two structural isomers of  $C_3H_7Br$  are formed.

*Br can substitute at different positions along the carbon chain: an H on an end carbon (1-bromopropane) or an H on the middle carbon (2-bromopropane), as two different propyl radicals can form.*..... [1]

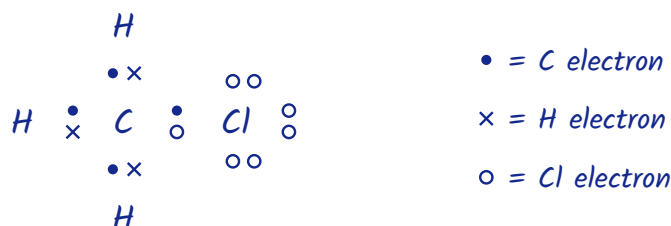
5 This question is about haloalkanes.

(a) Chloromethane,  $\text{CH}_3\text{Cl}$  is a covalent molecule.

(i) Draw a 'dot-and-cross' diagram for  $\text{CH}_3\text{Cl}$ .

Show outer electrons only.

Use a different symbol for the electrons of each element.



[1]

(ii) Name the shape of the chloromethane molecule and predict the value of the  $\text{H}-\text{C}-\text{Cl}$  bond angle.

Name of shape.....*Tetrahedral*.....

Bond angle.....*109.5°*.....

[2]

(b) Chloroethene,  $\text{H}_2\text{C}=\text{CHCl}$ , is a covalent molecule with a double bond.

The bond angles in  $\text{H}_2\text{C}=\text{CHCl}$  are different from those in  $\text{CH}_3\text{Cl}$ .

Predict the  $\text{H}-\text{C}-\text{Cl}$  bond angle in  $\text{H}_2\text{C}=\text{CHCl}$  and explain why it is different from the  $\text{H}-\text{C}-\text{Cl}$  bond angle in  $\text{CH}_3\text{Cl}$ .

Bond angle .....*120°*.....

Explanation ..... *$\text{CH}_3\text{Cl}$ : the C atom has 4 bonded pairs of*.....

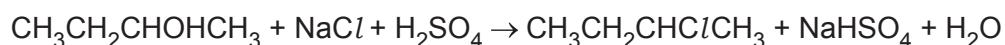
*electrons.  $\text{H}_2\text{C}=\text{CHCl}$ : the C atom has 3 bonded regions (2 single bonds and 1 double bond) and no lone pairs.*

*Electron pairs (bonded regions) repel each other as far apart as possible, so 3 regions give 120° (trigonal planar) instead of 109.5°.*

[3]

(c)\* 2-Chlorobutane,  $\text{CH}_3\text{CH}_2\text{CHClCH}_3$ , is an organic liquid with a boiling point of  $70^\circ\text{C}$ .

A student prepares 2-chlorobutane from butan-2-ol,  $\text{CH}_3\text{CH}_2\text{CHOHCH}_3$ , as shown in the equation below.



The student's method is outlined below.

- Add 9.25 g  $\text{CH}_3\text{CH}_2\text{CHOHCH}_3$  to an excess of  $\text{NaCl(aq)}$  in a pear-shaped flask.
- Add an excess of concentrated sulfuric acid.
- Heat the flask under reflux for about 45 minutes.

The student obtains a reaction mixture containing an organic layer (density =  $0.87 \text{ g cm}^{-3}$ ) and an aqueous layer (density =  $1.00 \text{ g cm}^{-3}$ ).

After purification, the percentage yield of  $\text{CH}_3\text{CH}_2\text{CHClCH}_3$  is 65.0 %.

Describe how the student could obtain a pure, dry sample of  $\text{CH}_3\text{CH}_2\text{CHClCH}_3$  from the reaction mixture and explain the reason for carrying out each purification step.

Calculate the mass of pure  $\text{CH}_3\text{CH}_2\text{CHClCH}_3$  that would be expected from this preparation.

*Separation: pour the reaction mixture into a separating funnel and allow the layers*

*to separate. The organic layer (density  $0.87 \text{ g cm}^{-3}$ ) is less dense than the*

*aqueous layer ( $1.00 \text{ g cm}^{-3}$ ), so it is the top layer. Run off and discard the*

*lower aqueous layer, keeping the organic layer containing the 2-chlorobutane.*

*Drying: transfer the organic layer to a dry conical flask and add an anhydrous*

*salt, e.g. anhydrous  $\text{MgSO}_4$  or  $\text{CaCl}_2$ . This removes water from the organic layer.*

*Decant or filter off the drying agent.*

*Distillation: redistil the dry organic liquid and collect the fraction that boils at*

*about  $70^\circ\text{C}$  (the boiling point of 2-chlorobutane). This separates the pure*

*product from unreacted butan-2-ol and other side products, which have different*

*boiling points.*

*Calculation:  $M_r(\text{CH}_3\text{CH}_2\text{CHOHCH}_3) = 74.0$  and  $M_r(\text{CH}_3\text{CH}_2\text{CHClCH}_3) = 92.5$ .*

*$n(\text{butan-2-ol}) = 9.25 \div 74.0 = 0.125 \text{ mol}$ . Mole ratio 1 : 1, so 100% yield*

*gives  $0.125 \text{ mol}$  of 2-chlorobutane.*

*At 65.0% yield:  $n(\text{CH}_3\text{CH}_2\text{CHClCH}_3) = 0.125 \times 0.650 = 0.08125 \text{ mol}$*

*mass =  $0.08125 \times 92.5 = 7.52 \text{ g}$  (3 s.f.)*

[6]

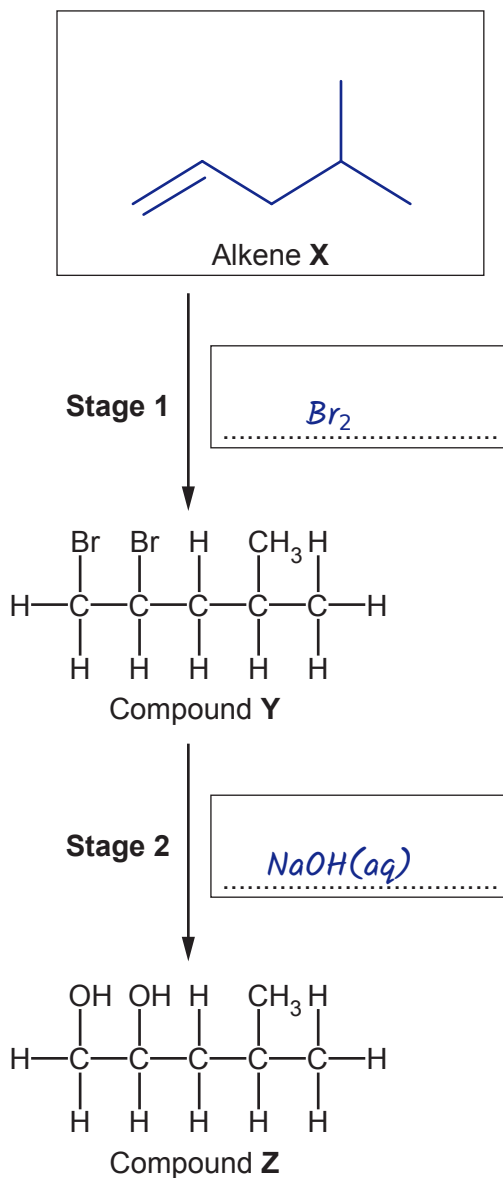
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[illegible]

(d) Haloalkanes are important intermediates in organic synthesis.

A student plans a two-stage synthesis to prepare compound **Z** from a hydrocarbon alkene **X**.

(i) Draw the structure of the hydrocarbon alkene **X** in the box and write down the reagents for each stage on the dotted lines.



[3]

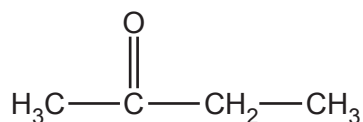
(ii) State the name of the mechanism of the reaction in **Stage 2**.

Nucleophilic substitution..... [1]

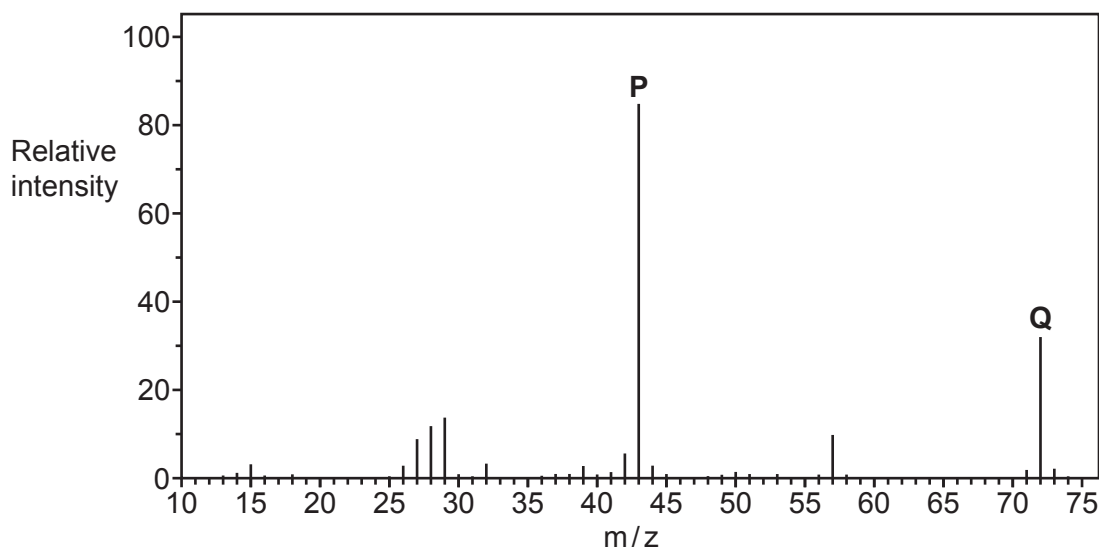
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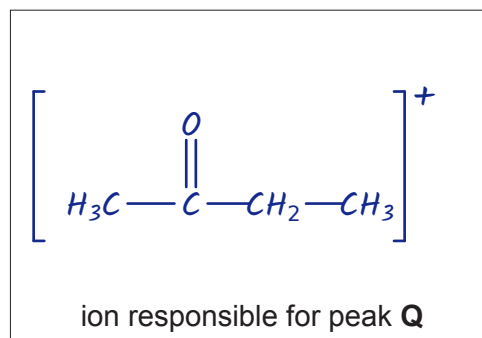
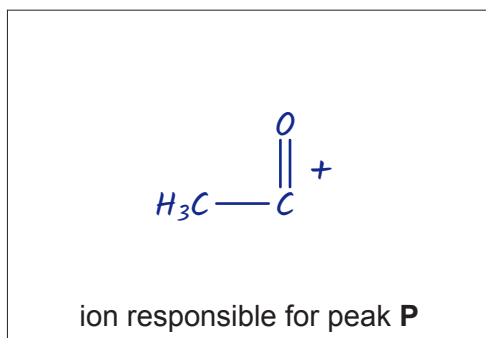
- 6 Compound **A** is a ketone. It has the following structure.



- (a) The mass spectrum of compound **A** is shown below.



- (i) Draw structures for the ions responsible for peak **P** and peak **Q**.



[2]

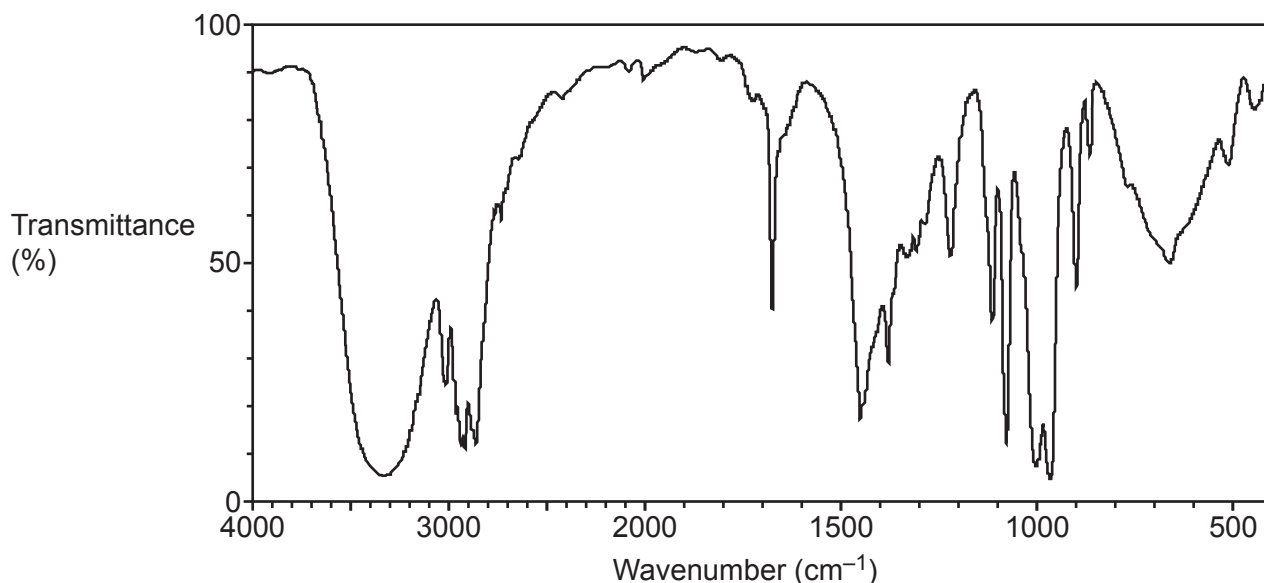
- (ii) Explain why there is a small peak at  $m/z = 73$

*It is the M+1 peak, caused by the small proportion of molecules that contain a carbon-13 ( $^{13}\text{C}$ ) atom.*

[1]

- (b) Compound **B** is a non-cyclic structural isomer of Compound **A**.

The infrared spectrum of Compound **B** is shown below.



- (i) State the effect infrared radiation has on covalent bonds.

*Infrared radiation makes covalent bonds vibrate more (bend and stretch), as the bonds absorb the energy.* [1]

- (ii) Identify **two** functional groups which are likely to be present in Compound **B** but are not present in Compound **A**.

Explain your answers.

Functional group *Alcohol and alkene*  
*Alcohol: contains the O-H group; alkene: contains the C=C bond.*  
*Compound A (a ketone) has C=O but no O-H and no C=C.*

Explanation *O-H (alcohol): broad absorption at 3200 to 3600 cm⁻¹ (about 3350).*  
*C=C (alkene): sharp peak at 1620 to 1680 cm⁻¹ (about 1650 cm⁻¹).*

[2]

END OF QUESTION PAPER

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