



Oxford Cambridge and RSA

Tuesday 21 May 2024 – Morning

AS Level Chemistry A

H032/02 Depth in chemistry

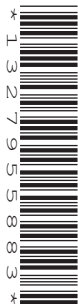
Time allowed: 1 hour 30 minutes

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 **20** pages.

ADVICE

- Read each question carefully before you start your answer.

1 This question is about water, H_2O , and ammonia, NH_3 .

(a) Hydrogen and oxygen have different electronegativities.

What is meant by the term **electronegativity**?

Electronegativity is the ability of an atom to attract the bonding electrons (the shared pair) in a covalent bond.

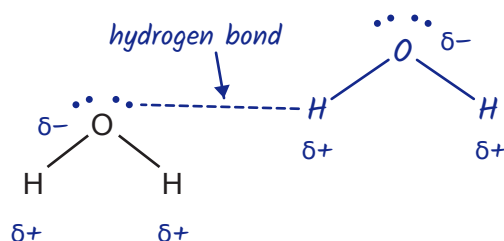
[2]

(b) H_2O is a polar molecule that has hydrogen bonding.

(i) Complete the diagram below to show hydrogen bonding between the H_2O molecule shown and another H_2O molecule.

Include relevant dipoles and lone pairs.

Label the hydrogen bond.



[2]

(ii) Explain why molecules of H_2O are polar.

The O-H bonds are polar and the molecule is bent (non-symmetrical), so the dipoles do not cancel out: H_2O has an overall dipole.

[1]

(iii) One unusual property of H_2O is that ice floats on water.

Explain why ice has a lower density than water.

In ice, the H_2O molecules are held apart by hydrogen bonds in an open lattice, so there are gaps between the molecules.

[1]

(c) Solid ammonia, NH_3 , also contains hydrogen bonds.

(i) Suggest why solid ammonia has a lower melting point than ice.

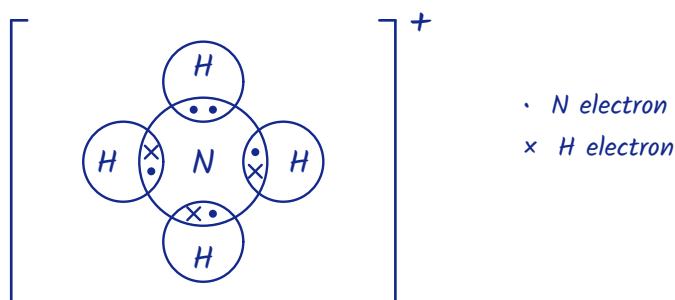
Ammonia has weaker (and fewer) hydrogen bonds than ice, so less energy is needed to break them.

N is less electronegative than O, and N has only one lone pair while O has two lone pairs. [2]

(ii) When ammonia dissolves in water, ammonium ions, NH_4^+ , are formed.

Draw a 'dot-and-cross' diagram to show the bonding in an NH_4^+ ion.

Show outer electrons only.



[2]

(iii) Outline how you would test for the presence of NH_4^+ ions in a solution.

Your answer should include observations.

Warm the solution with aqueous sodium hydroxide, NaOH(aq) (hydroxide ions).

Hold damp red litmus (or pH indicator) paper at the mouth of the tube; it turns

blue because ammonia gas is given off.

[2]

(d) A student heats 11.50 g of hydrated zinc sulfate, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, to remove all the water of crystallisation.

Calculate the mass of anhydrous zinc sulfate that should be obtained.

$$M(\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}) = 65.4 + 32.1 + 4(16.0) + 7(18.0) = 287.5 \text{ g mol}^{-1}$$

$$n(\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}) = 11.50 \div 287.5 = 0.0400 \text{ mol}$$

$$M(\text{ZnSO}_4) = 161.5 \text{ g mol}^{-1}$$

$$\text{mass of ZnSO}_4 = 0.0400 \times 161.5 = 6.46 \text{ g}$$

$$\text{mass} = \dots\dots\dots 6.46 \dots\dots\dots \text{g} \quad [3]$$

Turn over

2 This question is about periodicity and the reaction of some Group 2 metals.

(a) Periodicity is the repeating trend in properties of elements across different periods in the periodic table.

(i) Complete the table below with the electron configurations and blocks.

	Group 2	Group 17 (7)
Period 2	Be 1s ² 2s ²	F 1s ² 2s ² 2p ⁵
Period 3	Mg 1s ² 2s ² 2p ⁶ 3s ²	Cl 1s ² 2s ² 2p ⁶ 3s ² 3p ⁵
Block	s	p

[3]

(ii) Use your answers to (a)(i) to explain why electron configuration is an example of a periodic trend.

Across period 2 the 2s subshell fills first, then the 2p subshell (Be is s², F is s²p⁵).

Across period 3 the same pattern repeats (3s then 3p), so elements in the same group have the same outer electron configuration.

[2]

(iii) Mg forms 2+ ions but Cl usually forms 1- ions in their reactions. Explain why.

Mg loses its two 3s electrons to form Mg²⁺, while Cl gains one electron into its 3p subshell to form Cl⁻.

In both cases the ion has a full outer shell (noble gas configuration, a stable octet).

[2]

(iv) Magnesium reacts with oxygen in the air.

Write the equation for this reaction.

2Mg + O₂ → 2MgO

[1]

- (b) The reaction between calcium and hydrochloric acid is a redox reaction.



- (i) Explain, in terms of electron transfer, why the reaction shown in **equation 2.1** is a redox reaction.

Ca loses 2 electrons ($\text{Ca} \rightarrow \text{Ca}^{2+} + 2\text{e}^-$), so Ca is oxidised.

Each H (in H^+) gains 1 electron ($2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$), so H is reduced.

.....

..... [2]

- (ii) A student plans to add 0.0100 mol of Ca to 120 cm³ of 0.100 mol dm⁻³ HCl(aq).

When the student carries out this reaction, they are surprised that all the calcium reacts, despite being in excess of the HCl(aq).

- Show by calculation that calcium is in excess of the HCl(aq).
- Suggest a reason for this unexpected result.

$n(\text{HCl}) = 0.100 \times 120 \div 1000 = 0.0120 \text{ mol}$

Ca : HCl react in a 1 : 2 ratio, so 0.0120 mol HCl reacts with only $0.0120 \div 2$

$= 0.00600 \text{ mol Ca}$. 0.0100 mol Ca would need 0.0200 mol HCl, so Ca is in excess

(0.00400 mol Ca left over).

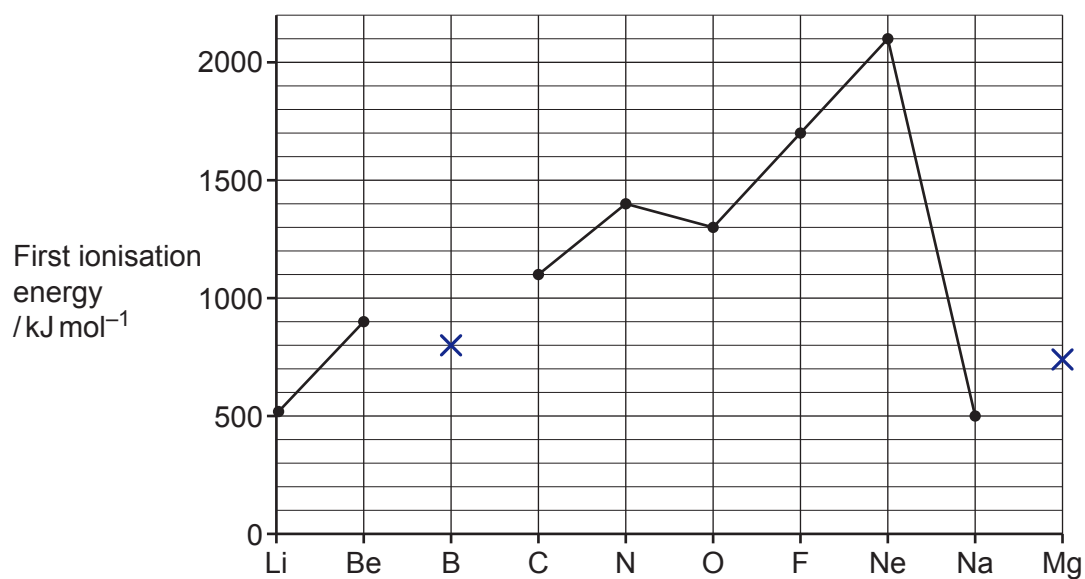
All the calcium reacts because the excess Ca also reacts with the water in the

acid: $\text{Ca} + 2\text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 + \text{H}_2$.

.....

..... [3]

(c) The graph shows the first ionisation energies for the elements Li to Be and for C to Na.



(i) Complete the graph by adding points for the missing values of B and Mg. [2]

(ii) Write an equation, including state symbols, to represent the **second** ionisation energy of B.



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Turn over for the next question

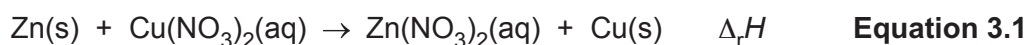
3 Enthalpy changes of reaction can be determined by experiment.

(a) What is meant by the term **enthalpy change of reaction**?

The enthalpy change when the reactants react in the molar quantities shown in the equation.

[1]

(b)* A student carries out an experiment to determine the enthalpy change for the reaction between zinc and copper(II) nitrate solution.



The student follows the method outlined below.

- Add 100 cm³ of 0.500 mol dm⁻³ Cu(NO₃)₂(aq) to a beaker.
- Measure the temperature of the solution.
- Add excess zinc to the beaker.
- Stir the mixture and record the maximum temperature.

The temperature of the solution changes from 19.5 °C to 38.1 °C.

Calculate $\Delta_r H$, in kJ mol⁻¹, for **equation 3.1**.

State any assumptions you have made in your calculation.

Suggest improvements for obtaining a more accurate value for $\Delta_r H$.

[6]

Energy transferred: $q = mc\Delta T = 100 \times 4.18 \times (38.1 - 19.5) = 100 \times 4.18 \times 18.6 = 7774.8 \text{ J} = 7.7748 \text{ kJ}$

Moles: $n(\text{Cu(NO}_3)_2) = 0.500 \times 100 \div 1000 = 0.0500 \text{ mol}$ (zinc is in excess, so $\text{Cu(NO}_3)_2$ reacts completely).

$\Delta H = -q \div n = -7.7748 \div 0.0500 = -155 \text{ kJ mol}^{-1}$ (3 s.f.) It is negative because the temperature rose, so the reaction is exothermic.

Assumptions: the density of the solution is 1.00 g cm⁻³ (the same as water), so 100 cm³ has a mass of 100 g; the specific heat capacity of the solution is the same as water (4.18 J g⁻¹ K⁻¹); the mass and heat capacity of the zinc are ignored; no heat is lost to the surroundings; no water evaporates; the reaction goes to completion.

Improvements: carry out the reaction in an insulated polystyrene cup (or vacuum flask) with a lid to reduce heat loss; use a more precise thermometer (or

temperature probe); measure the volume of solution with a burette or pipette;
 take temperature readings every 30 s and plot a cooling curve, extrapolating back
 to the time of mixing to find the true maximum temperature change.

Extra answer space if required

- (c) The student modifies the experiment using 50 cm^3 instead of 100 cm^3 of 0.500 mol dm^{-3} copper(II) nitrate solution.

The value of $\Delta_r H$ for this modified experiment is the same as in **equation 3.1**.

Explain why.

With 50 cm^3 , half the moles of $\text{Cu}(\text{NO}_3)_2$ react (0.0250 mol) and half the mass
 of solution is heated, so half the energy is released ($q = 3.887\text{ kJ}$).
 The temperature change stays the same ($18.6\text{ }^\circ\text{C}$), so $\Delta H = -3.887 \div 0.0250 =$
 -155 kJ mol^{-1} ; the energy released per mole is unchanged.

[2]

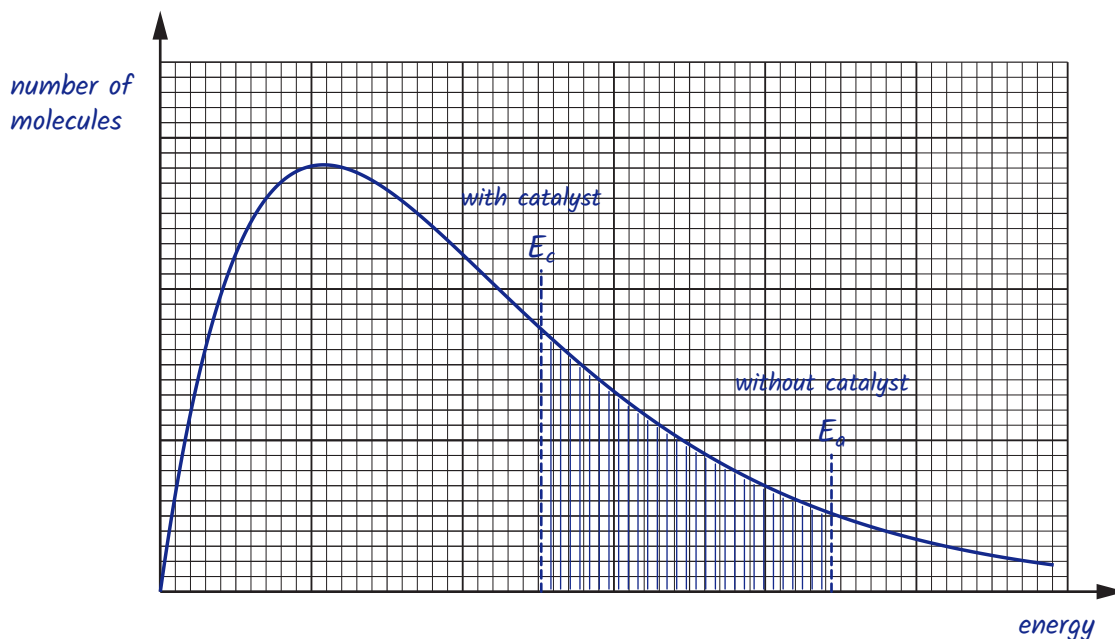
- 4 Aqueous hydrogen peroxide, $\text{H}_2\text{O}_2(\text{aq})$, gradually decomposes to produce water and oxygen.



The rate of decomposition of H_2O_2 can be increased by adding a small amount of manganese(IV) oxide, MnO_2 , which acts as a catalyst.

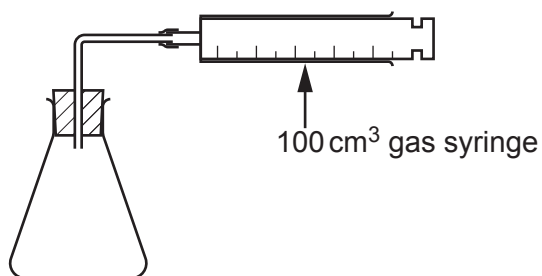
- (a) Explain, using a Boltzmann distribution model, why the rate of a reaction increases in the presence of a catalyst.

You are provided with the axes below, which you should label.



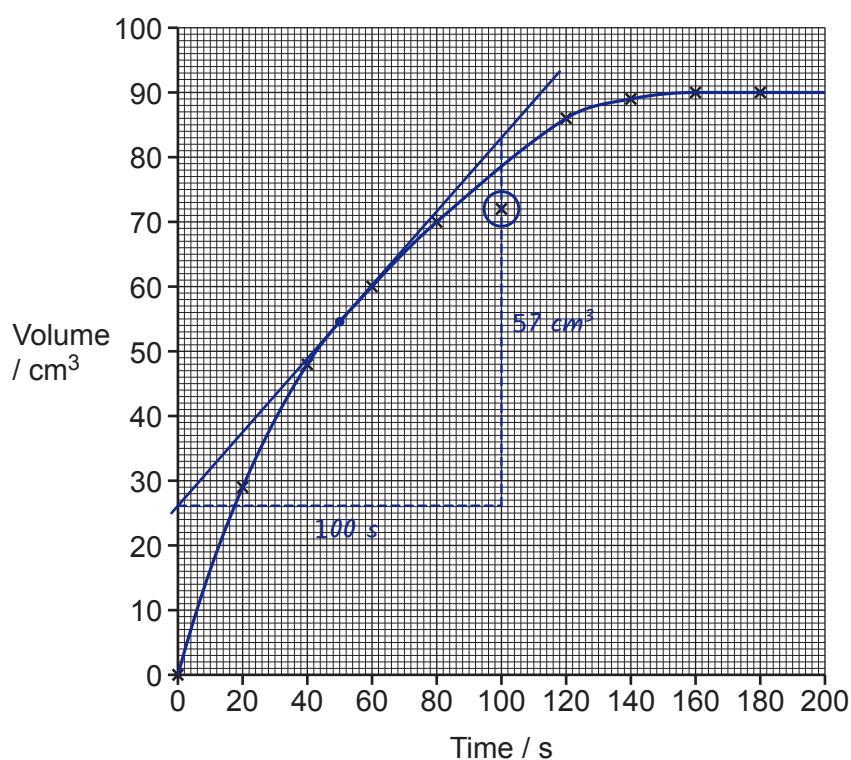
The catalyst provides an alternative reaction pathway with a lower activation energy (E_c is lower than E_a).
 So many more molecules have energy greater than or equal to the activation energy (the shaded extra area under the curve), so more collisions are successful per second and the rate increases. [4]

- (b) A student investigates the rate of decomposition of H_2O_2 , on addition of MnO_2 catalyst, using a gas syringe.



The student obtains the results shown in **graph 4.1**.

Graph 4.1



- (i) On **graph 4.1**, draw a best-fit smooth curve of the results **and** circle the anomalous result. [2]
- (ii) Use your graph to determine the rate of reaction, in cm^3s^{-1} , at 50 s.

Show your working below and on the graph.

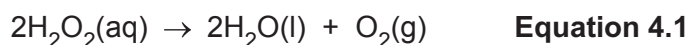
Tangent drawn to the curve at $t = 50$ s.

$$\text{gradient} = (83 - 26) \div (100 - 0) = 57 \div 100$$

$$\text{rate} = 0.57 \text{ cm}^3 \text{ s}^{-1}$$

rate = ...0.57..... cm^3s^{-1} [2]
Turn over

- (iii) The student uses 50.0 cm^3 of H_2O_2 in the experiment. **Equation 4.1** shows the reaction that takes place.



Calculate the concentration of H_2O_2 , in mol dm^{-3} , required to produce 90 cm^3 of $\text{O}_2(\text{g})$ at RTP.

$$n(\text{O}_2) = 90 \div 24000 = 0.00375 \text{ mol}$$

$$n(\text{H}_2\text{O}_2) = 2 \times 0.00375 = 0.00750 \text{ mol}$$

$$\text{concentration} = 0.00750 \div (50.0 \div 1000) = 0.150 \text{ mol dm}^{-3}$$

$$\text{concentration} = \dots\dots\dots 0.150 \dots\dots\dots \text{ mol dm}^{-3} \quad [3]$$

- (c) A student plans to compare the rate of decomposition of H_2O_2 using different metal oxides as the catalyst.

Suggest **two** variables which should be kept constant.

1 ...temperature of the H_2O_2 solution.....

2 ...volume and concentration of H_2O_2 , and the mass of metal oxide.....

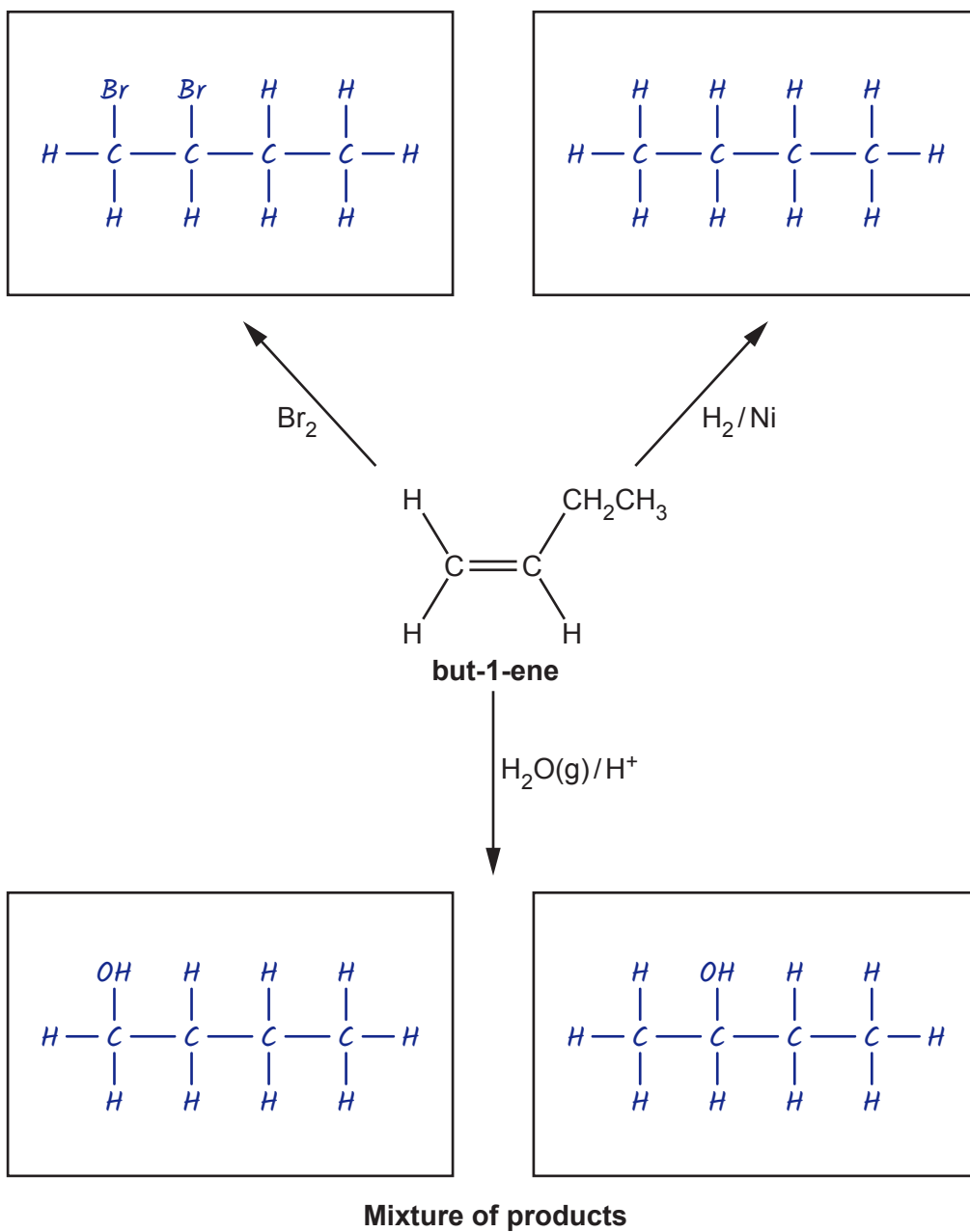
[2]

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Turn over for the next question

5 This question is about some reactions of alkenes.

- (a) Complete the flowchart for the reactions of but-1-ene, by adding the structures of the organic products in each box.

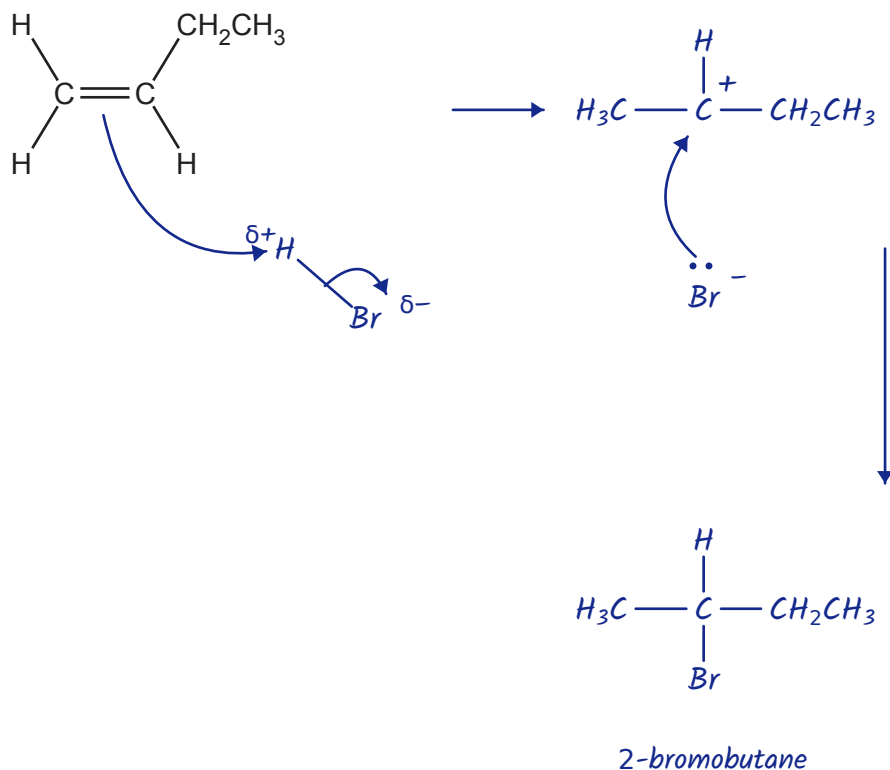


[4]

(b) HBr reacts readily with alkenes.

(i) Outline the mechanism for the reaction of but-1-ene with HBr to form **2-bromobutane**.

Include curly arrows, relevant dipoles and the structure of the product.



[4]

(ii) During this reaction, a small amount of **1-bromobutane** is also produced.

Explain why **2-bromobutane** is the major product.

2-bromobutane forms from a secondary carbocation (the C⁺ is bonded to two alkyl groups), while 1-bromobutane forms from a primary carbocation. The secondary carbocation is more stable, so it forms more readily and gives the major product.

[2]

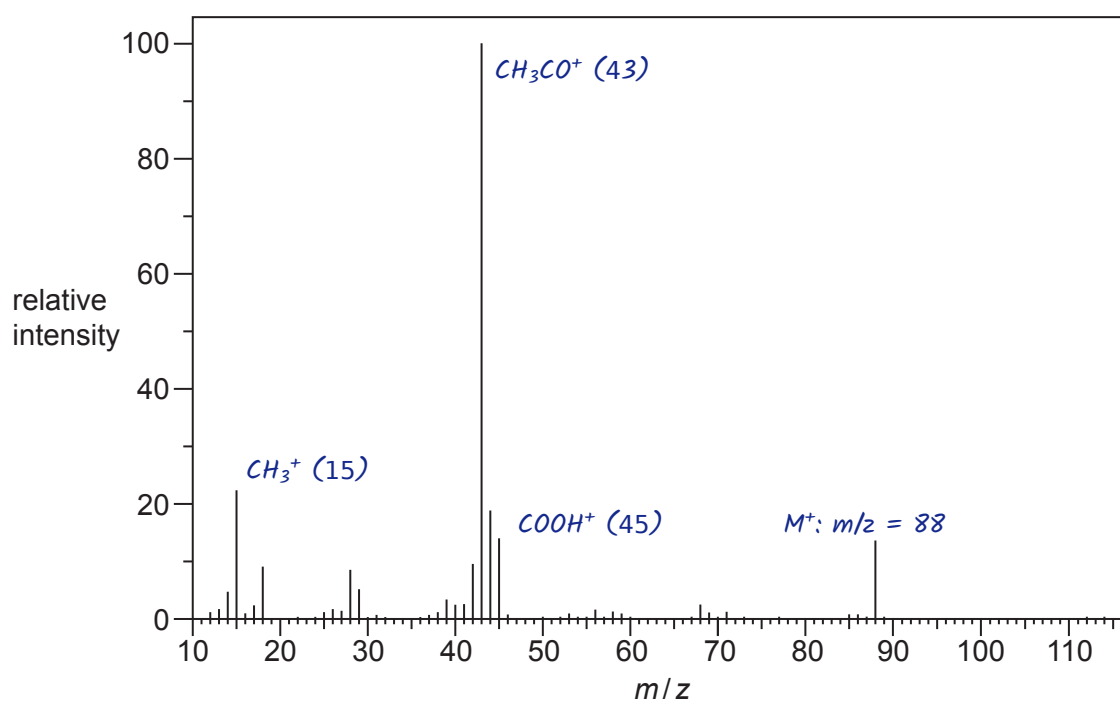
6* Compound **X** is an organic compound with **two** functional groups.

Compound **X** has the percentage composition by mass:
C, 40.91%; H, 4.54%; O, 54.55%.

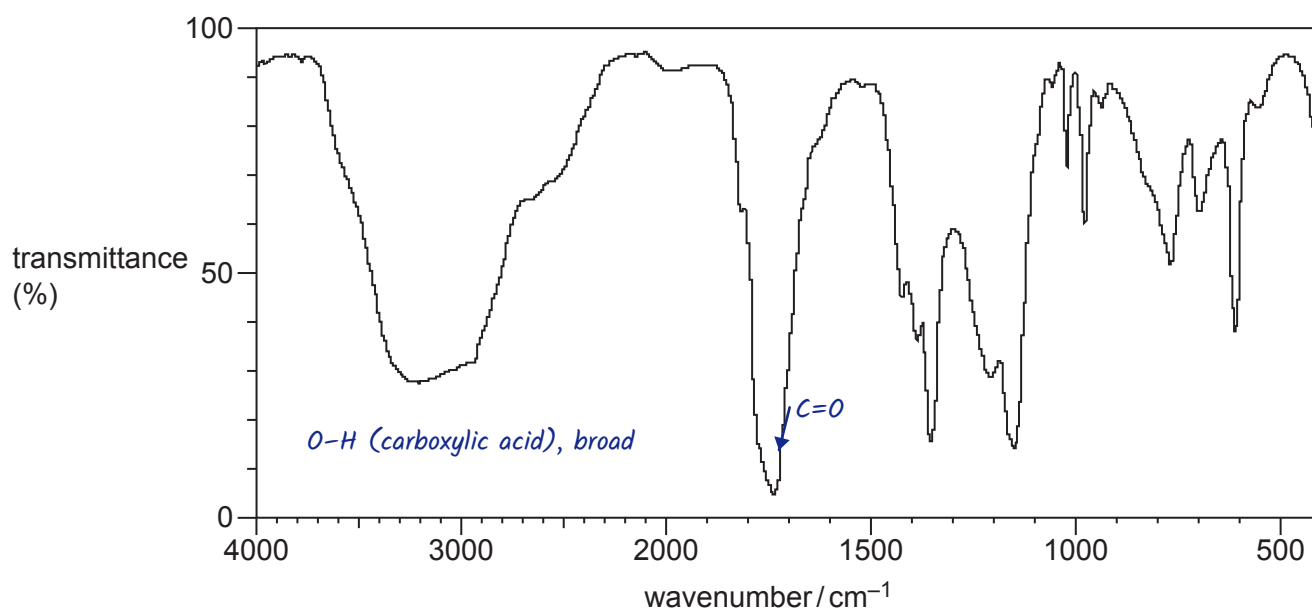
Compound **X** does **not** decolourise bromine water.

A scientist analyses compound **X** using mass spectrometry and infrared spectroscopy.

Mass spectrum of X



IR spectrum of X



Use all the information to determine a possible structure of compound **X**.

In your answer, make it clear how your conclusions are linked to the evidence.

[6]

Empirical formula: $C \ 40.91 \div 12.0 = 3.41$; $H \ 4.54 \div 1.0 = 4.54$; $O \ 54.55 \div 16.0 = 3.41$. Dividing by 3.41 gives $1 : 1.33 : 1 = 3 : 4 : 3$, so the empirical formula is $C_3H_4O_3$ (88.0).

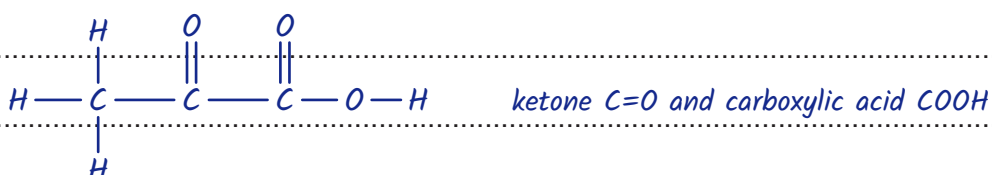
Mass spectrum: the molecular ion peak is at $m/z = 88$, so $M_r = 88$ and the molecular formula is $C_3H_4O_3$ (the same as the empirical formula).

IR: the broad absorption at about 2500 to 3300 cm^{-1} is $O-H$ in a carboxylic acid, and the strong peak at about 1720 cm^{-1} is $C=O$. So **X** contains a $COOH$ group.

X does not decolourise bromine water, so it has no $C=C$ bond. $COOH$ uses two of the three O atoms, so the third O must be in a second $C=O$ group: a ketone.

Fragments: $m/z = 43$ is CH_3CO^+ , $m/z = 15$ is CH_3^+ and $m/z = 45$ is $COOH^+$, which fit a CH_3-CO- group joined to a $COOH$ group.

So **X** is 2-oxopropanoic acid (pyruvic acid), CH_3COCO_2H :



Extra answer space if required

END OF QUESTION PAPER

[illegible]

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