

Chemistry
Higher level
Paper 2

Specimen paper

Candidate session number

2 hours 30 minutes

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Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.



Answer **all** questions. Answers must be written within the answer boxes provided.

1. A monoprotic acid, HX, is found to have the following composition by mass:

C = 39.99 %

H = 6.73 %

O = 53.28 %

- (a) Determine the empirical formula of the compound HX. [2]

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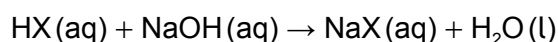
- (b) 25.00 cm³ of a solution, containing 1.51 g of HX is titrated with a 0.750 mol dm⁻³ solution of NaOH(aq). The HX(aq) solution is exactly neutralized by 22.30 cm³ of the NaOH(aq) solution. Determine the molar mass (*M*) of HX. [2]

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- (c) State the molecular formula of HX. [1]

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- (d) HX reacts with aqueous sodium hydroxide according to the equation:



- Identify a functional group present in HX. [1]

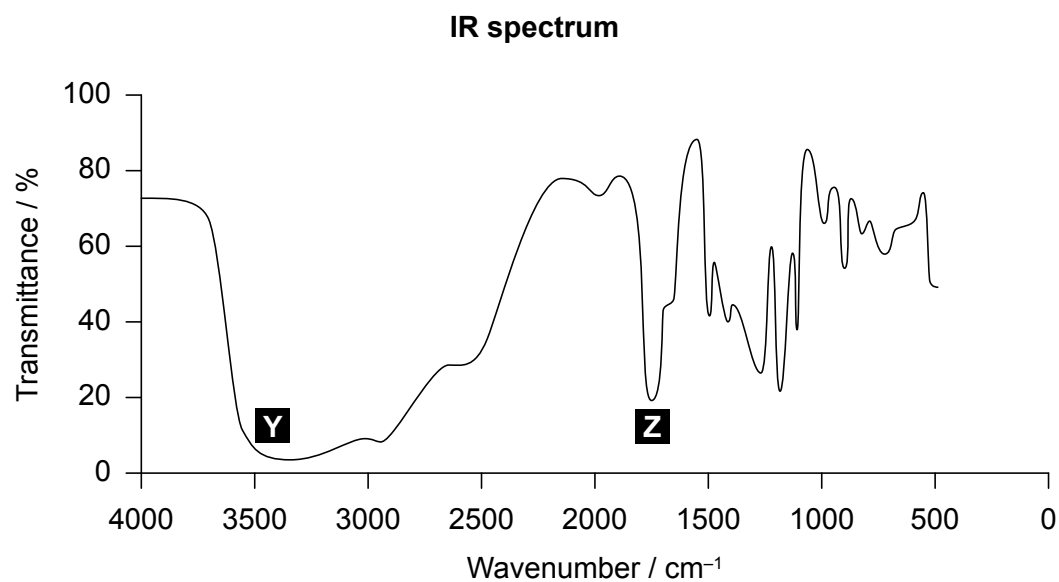
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(Question 1 continued)

- (e) The IR spectrum of HX is shown.



- (i) Identify the functional groups responsible for the absorption bands shown at **Y** and **Z** using section 20 of the data booklet.

[1]

Y:

Z:

- (ii) Draw a structural formula of HX that is consistent with all the evidence.

[1]

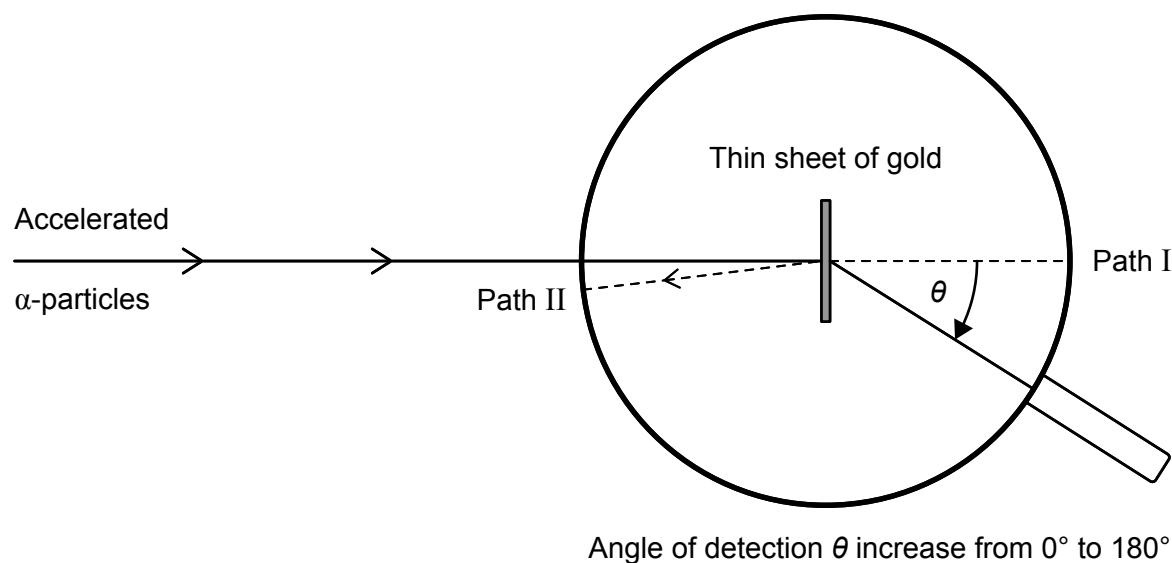


28EP03

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2. Scientific models are used to explain the structure of matter.

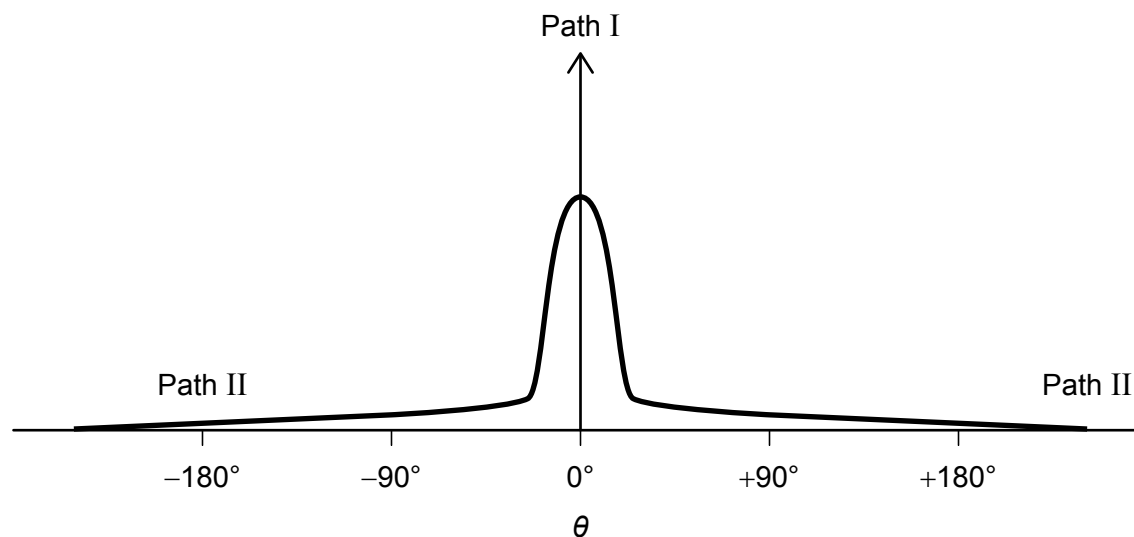
- (a) An α -particle is a helium-4 nucleus. In an experiment, α -particles are accelerated towards a thin sheet of gold and their resulting paths are detected, giving evidence of the positive charge of the nucleus.



The number of α -particles detected at different angles of deflection θ are shown.

Key:

— Number of α -particles detected



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(Question 2 continued)

- (i) Explain why some α -particles follow path II, rebounding from the gold sheet. [1]

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- (ii) Most of the α -particles follow path I and pass straight through undeflected ($\theta = 0^\circ$). Suggest a conclusion that can be made about the structure of the atom based on this evidence. [1]

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28EP05

Turn over

(Question 2 continued)

(b) Helium was first identified by analysing spectra of solar radiation.

(i) Outline the appearance of the emission spectrum of helium.

[1]

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Emission spectra of one-electron systems can be explained using a model with the electron attracted to the nucleus by an electrostatic force.

This model predicts that the electron occupies discrete energy levels. Some energy levels for the He^+ ion are shown.



(ii) Explain how the frequencies observed in emission spectra support the idea of the electron occupying discrete energy levels.

[2]

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(Question 2 continued)

- (iii) Deduce the ionization energy of the He^+ ion from the energy levels shown. [1]

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- (iv) Suggest **two** reasons why the ionization energy of the hydrogen atom is significantly smaller than the ionization energy of the He^+ ion. [2]

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- (v) Suggest why the model outlined in (b)(ii) can predict the emission spectrum of He^+ but not He. [1]

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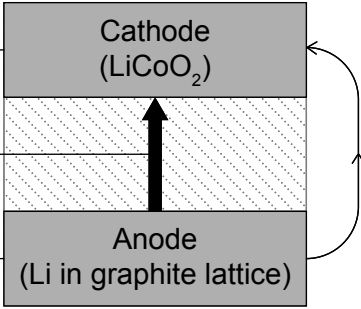
- (c) Outline why models of the atom have evolved over time. [1]

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3. The development of the lithium-ion battery won the 2019 chemistry Nobel Prize.

- (a) The diagram represents a cell in such a battery delivering a current. Complete the half-equations on the diagram and identify the species moving between the electrodes. [3]

$\text{Li}(\text{CoO}_2)_2 + \dots \rightarrow 2\text{LiCoO}_2$	—		
Species moving:	—		
.....	—		

- (b) The discharge of the lithium-ion battery is a spontaneous chemical reaction producing a potential difference and an increase in temperature.

- (i) Deduce the signs of the following: [1]

$\Delta H_{\text{discharge}}$	
E_{cell}	
$\Delta G_{\text{discharge}}$	

- (ii) The lithium-ion battery can be recharged by reversing the reactions at each electrode. Compare the absolute value of $\Delta G_{\text{recharge}}$ and $\Delta G_{\text{discharge}}$. [1]

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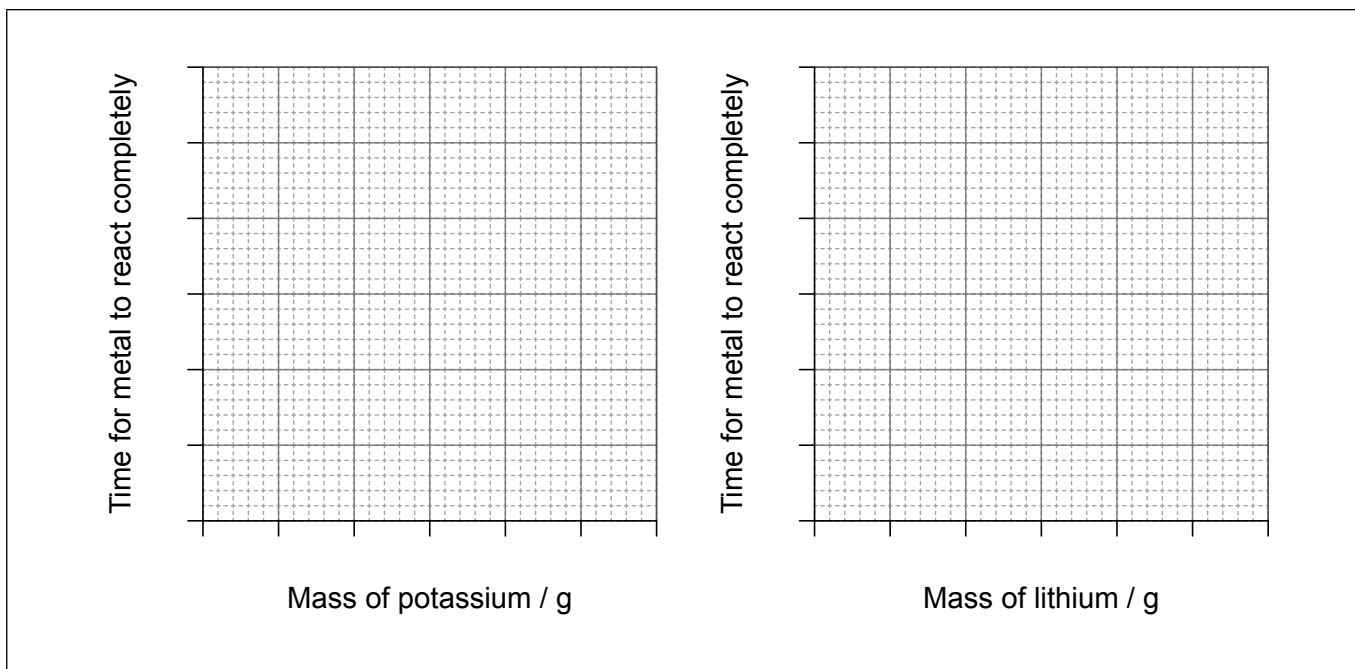
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(Question 3 continued)

- (c) In a simulation, equal masses of potassium and lithium are added to water and the time taken for the metals to fully react is recorded. Five different increasing masses of each metal are used, and the reaction is timed.

- (i) Sketch the graphs on the axes to show the expected results of this experiment. [2]



- (ii) Suggest a reason why comparing the time for complete reaction of equal masses is not a valid measure of reactivity. [1]

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- (iii) Lithium carbide, Li_2C_2 , is one of many compounds of lithium and carbon. Determine the percentage covalent character and bonding type in this compound by using sections 9 and 17 of the data booklet. [2]

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28EP10

(Question 3 continued)

- (iv) Calculate the Gibbs energy of formation, $\Delta G_f^\ominus$, in kJ mol^{-1} , for Li_2C_2 at 298.15 K. Use the data provided and section 1 of the data booklet. [1]

$$\Delta H_f^\ominus \text{Li}_2\text{C}_{2\text{solid}} = -62 \text{ kJ mol}^{-1}$$

$$\Delta S_f^\ominus \text{Li}_2\text{C}_{2\text{solid}} = -11 \text{ J mol}^{-1} \text{ K}^{-1}$$

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- (v) Draw the Lewis formula of the anion in the salt Li_2C_2 . [2]

- (vi) State the type of hybridization shown by the carbon atoms in the anion. [1]

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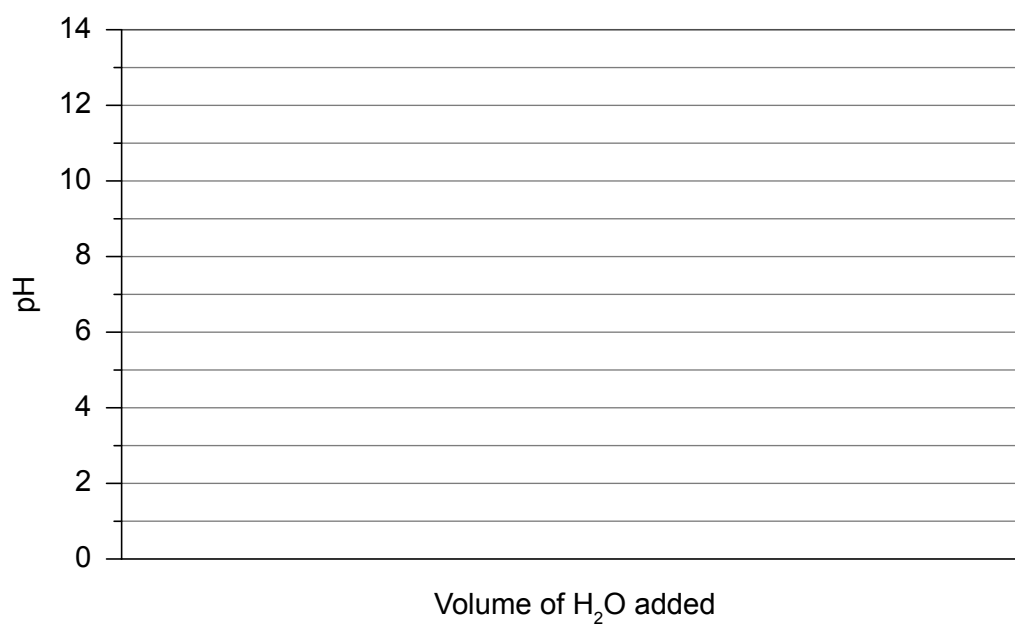


4. Hydrochloric acid is an important chemical reactant and industrial chemical.

- (a) A pH probe is placed in a small volume of 0.10 mol dm^{-3} solution of hydrochloric acid. The pH is recorded while a steady stream of distilled water is added to the acid at constant temperature.

(i) On the axes, sketch the graph of pH against volume of water added.

[3]



- (ii) The experiment is repeated using 0.10 mol dm^{-3} ethanoic acid at the same temperature. Calculate the initial pH of the ethanoic acid.

[2]

$$pK_a \text{ ethanoic acid} = 4.76$$

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(Question 4 continued)

- (b) Chloride ions can form complex ions with some transition metals. The formulas and colours of three compounds of cobalt are:

Compound	Colour
$[\text{Co}(\text{NH}_3)_6]\text{Cl}_3$	orange–yellow
$[\text{Co}(\text{NH}_3)_5\text{Cl}]\text{Cl}_2$	purple
$[\text{Co}(\text{NH}_3)_4\text{Cl}_2]\text{Cl}$	green

- (i) Deduce the oxidation state of cobalt in $[\text{Co}(\text{NH}_3)_5\text{Cl}]\text{Cl}_2$ and the charge of the complex ion.

[2]

Oxidation state:

Charge of complex ion:

- (ii) Describe the bonding of chloride ions in $[\text{Co}(\text{NH}_3)_4\text{Cl}_2]\text{Cl}$.

[2]

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- (iii) Explain why these complex ions are coloured.

[3]

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(This question continues on the following page)



(Question 4 continued)

- (iv) State and explain, in which of the complex ions, the electron transitions responsible for the colour require the highest energy. Use the colour wheel and the electromagnetic spectrum in sections 5 and 15 of the data booklet.

[2]

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28EP15

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5. Heptadecane, $C_{17}H_{36}$, can be extracted from crude oil or cactus plants.

(a) Write an equation for the complete combustion of $C_{17}H_{36}$.

[1]

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(b) The enthalpy of combustion of $C_{17}H_{36}$ is $-11\,350\text{ kJ mol}^{-1}$.

(i) Calculate the maximum energy produced when 2.00 g of $C_{17}H_{36}$ is combusted.

[2]

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(ii) Determine the maximum temperature change when 500.0 cm^3 of water is heated by a 2.00 g sample of $C_{17}H_{36}$.

[2]

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(iii) Outline **two** assumptions made in the calculation in (b)(ii).

[2]

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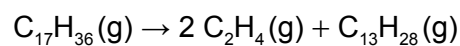


(Question 5 continued)

- (c) Explain why biofuels contribute less to climate change than fossil fuels. [1]

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- (d) Heptadecane can be broken down into smaller molecules. Consider the reaction:



- (i) Determine the standard enthalpy change, $\Delta H^\ominus$, for the reaction stated, using section 12 of the data booklet. [3]

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- (ii) Determine the enthalpy change of reaction. Use the data provided and section 13 of the data booklet. [2]

$$\Delta H_f(\text{C}_{17}\text{H}_{36}) = -393.9 \text{ kJ mol}^{-1}$$

$$\Delta H_f(\text{C}_{13}\text{H}_{28}) = -311.5 \text{ kJ mol}^{-1}$$

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(Question 5 continued)

- (iii) Comment on the difference between the two values calculated in (d)(i) and (d)(ii). [1]

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- (iv) Predict the sign of the entropy change of the reaction, giving a reason. [1]

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- (v) Discuss, with reference to (d)(ii) and (d)(iv), how temperature affects the spontaneity of the reaction. [2]

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- (e) Ethene can be converted to ethanol in one reaction. State the equation for this reaction. [1]

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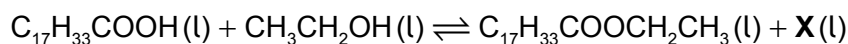
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(Question 5 continued)

- (f) Ethanol reacts with oleic acid to produce ethyl oleate.



- (i) Identify the type of reaction and the side product **X**(l). [1]

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- (ii) Calculate the atom economy of the reaction. [1]

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- (iii) Discuss why the atom economy of a reaction is an important consideration when evaluating the impact of a reaction in an industrial process. [2]

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- (iv) Deduce the equilibrium constant expression, K_c , for the reaction. Assume that the reaction is homogeneous. [1]

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(Question 5 continued)

(g) The equilibrium constant, K_c , is 9.3×10^{-5} at 75°C .

- (i) Determine the amount of ethyl oleate present in the reaction mixture at equilibrium when 0.10 mol dm^{-3} of oleic acid reacts with 0.10 mol dm^{-3} of ethanol at 75°C and state any assumptions you have made in your calculation. [2]

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- (ii) State **one** method of increasing the yield. [1]

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6. Halogens are important reactants in the laboratory and in the environment.

- (a) (i) Write an equation for the homolytic fission of chlorine under UV light, showing the movement of electrons. [2]

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- (ii) Under different conditions, chlorine molecules can break down by heterolytic fission. Write an equation showing the movement of electrons. [1]

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- (iii) Identify, giving a reason, which one of the three species produced in (a)(i) and (a)(ii) is an electrophile. [1]

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- (iv) Draw the full structural formula of the most stable carbocation formed in the reaction between hydrogen chloride and propene. [1]

- (v) Outline why this intermediate is the most stable. [1]

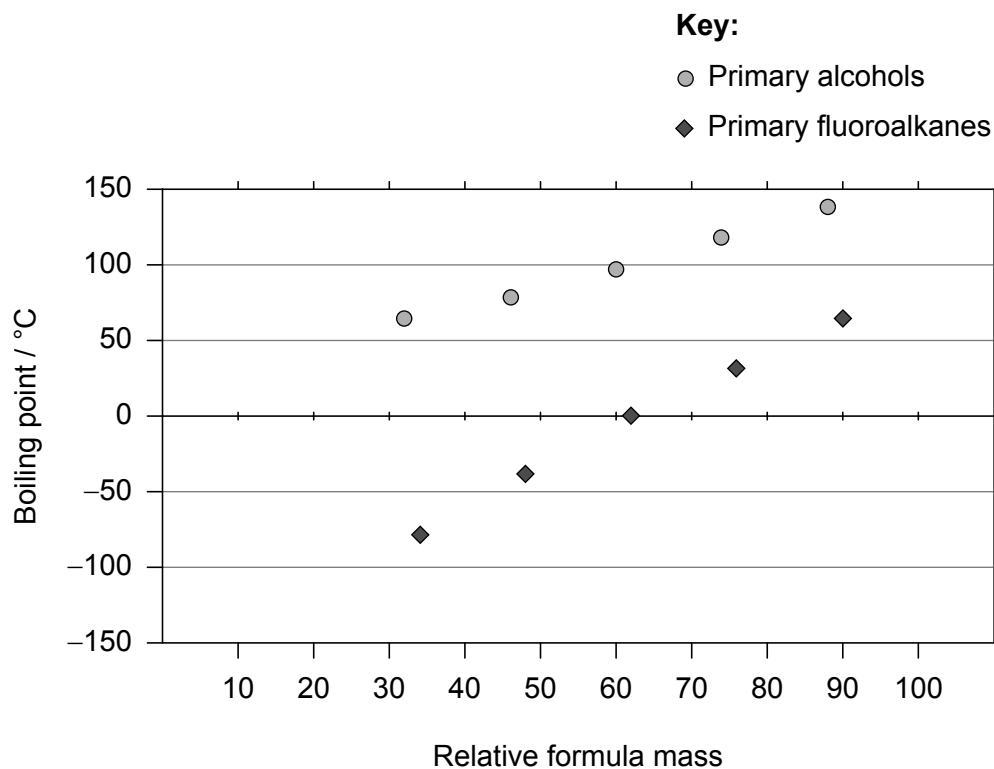
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(Question 6 continued)

- (b) The graph shows the boiling points of the first five straight-chain primary alcohols and fluoroalkanes.



- (i) Outline why the alcohols have higher boiling points than fluoroalkanes of similar relative formula mass.

[1]

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- (ii) Explain the general trend in the boiling points shown for the alcohols.

[2]

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(This question continues on the following page)



(Question 6 continued)

- (iii) Predict, giving a reason, how the boiling points of branched fluoroalkanes compare to their straight-chain isomers.

[1]

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- (iv) Explain why primary bromoalkanes have higher boiling points compared to the corresponding fluoroalkanes.

[1]

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- (c) (i) Draw the structures of 2-bromobutane and its tertiary isomer.

[2]

- (ii) One of the isomers in (c)(i) exists as enantiomers. Draw their stereochemical formulas.

[1]

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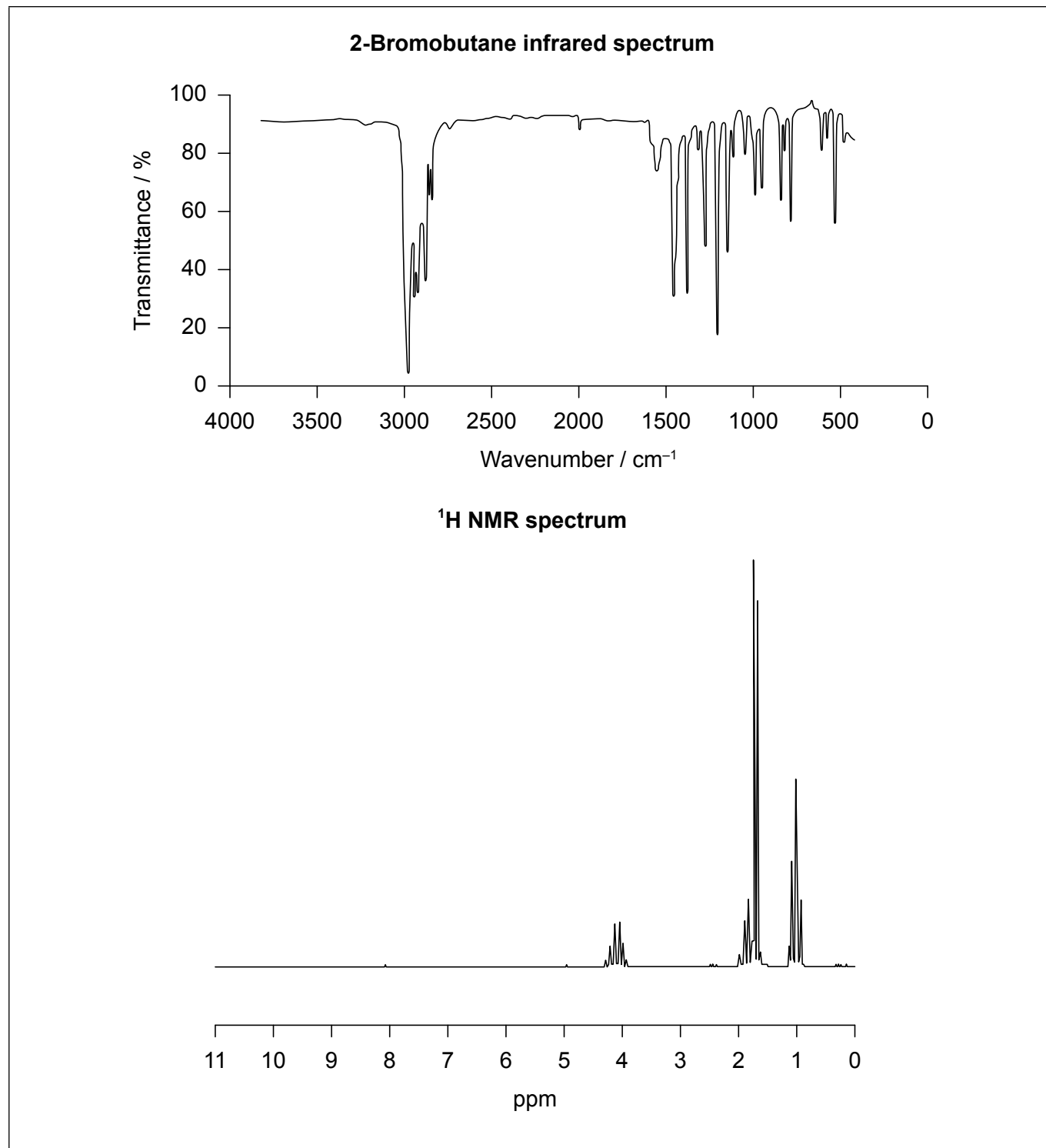
28EP25

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(Question 6 continued)

- (iii) The IR and ^1H NMR spectra of 2-bromobutane are shown. Circle the regions which indicate the presence of the bromine atoms. Use sections 20 and 21 of the data booklet.

[2]



(This question continues on the following page)



(Question 6 continued)

- (iv) Explain whether the IR and ^1H NMR spectra can be used to distinguish the tertiary isomer from 2-bromobutane.

[2]

IR:

^1H NMR:



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References:

6. (c)(iii) [2-Bromobutane infrared spectrum] NIST, 1960. Butane, 2-bromo-. *NIST Chemistry WebBook*. [online]
Available at: <<https://webbook.nist.gov/cgi/cbook.cgi?ID=C78762&Units=SI&Type=IR-SPEC&Index=1#IR-SPEC>>
[Accessed 1 February 2021].
- [¹H NMR spectrum] ChemicalBook, n.d. *2-Bromobutane (78-76-2) 1H NMR*. [CAS DataBase List>78-76-2More
Spectrum> 2-Bromobutane (78-76-2) 1H NMR] ChemicalBook [online]
Available through: <https://www.chemicalbook.com/SpectrumEN_78-76-2_1HNMR.htm>
[Accessed 1 February 2021].



28EP28