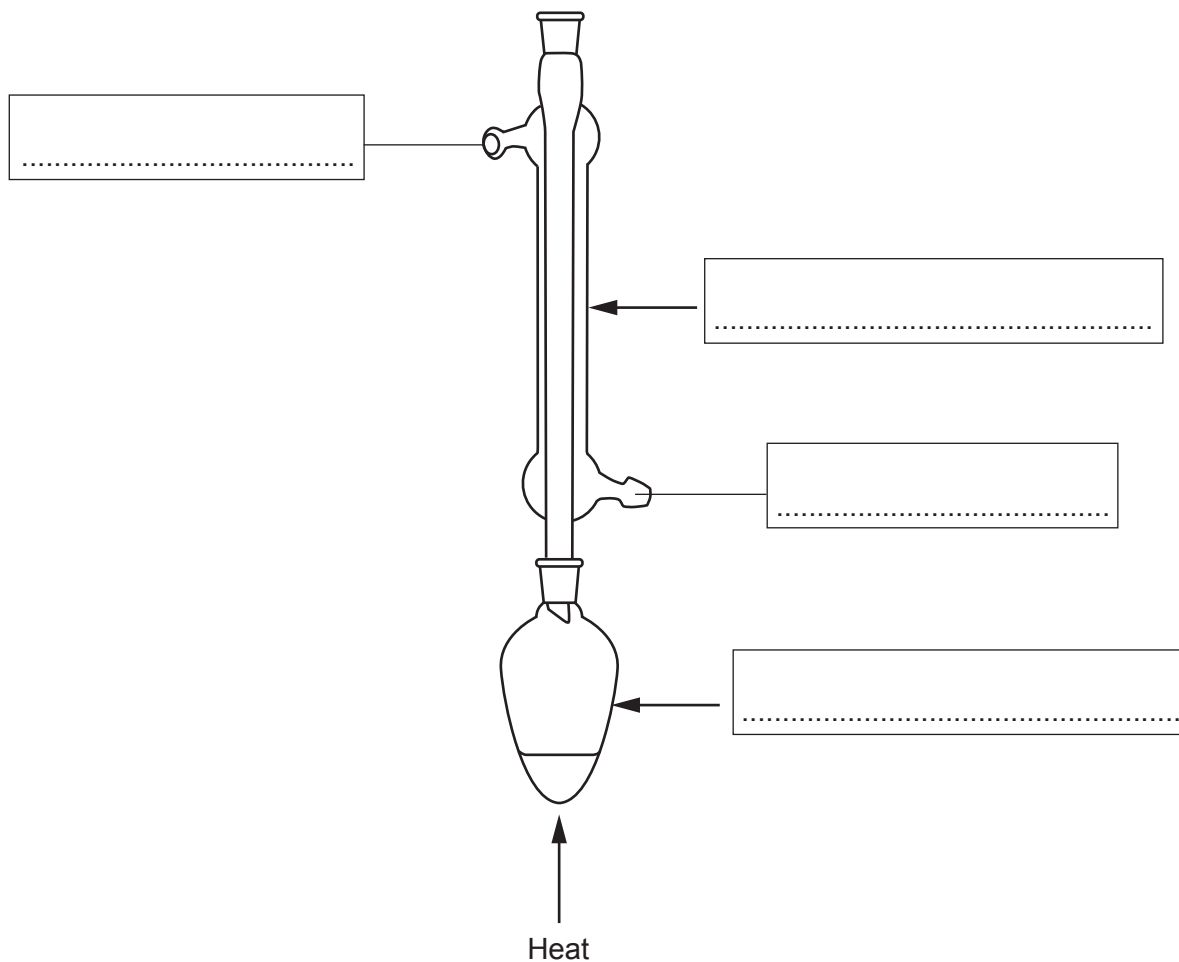


Answer **all** the questions.

1 This question is about organic chemistry.

(a) This part is about two practical techniques used in organic preparations.

(i) Complete the missing labels on the diagram and name the technique.



Name of technique: [2]

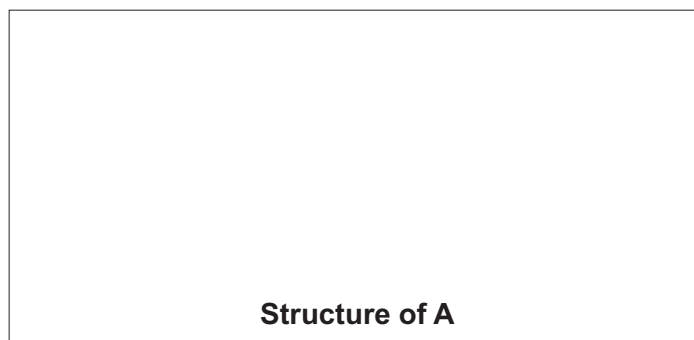
(ii) Draw a labelled diagram to show apparatus set up for filtration under reduced pressure (vacuum filtration).

(ii) Amine **A** is a liquid at room temperature and pressure.

When vaporised, 0.202 g of the amine produces 72.0 cm³ of gas at 1.00 × 10⁵ Pa and 100 °C. The ¹³C NMR spectrum of amine **A** has 3 peaks.

Determine the molecular formula of **A** and suggest a possible structure for amine **A**.

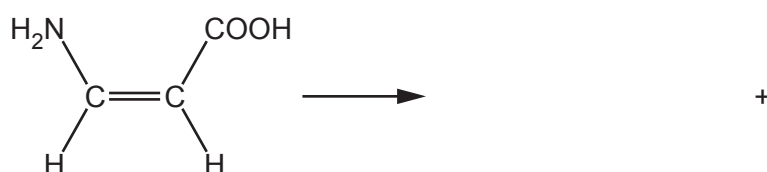
Molecular formula of **A**



[6]

(c) The amino acid Z-H₂NCH=CHCOOH can react to form a cyclic compound with the molecular formula C₃H₃NO and one other product.

Complete the equation for this reaction.



[2]

2* Transition metal ions can bond to ligands to form complex ions with different shapes.

Explain what is meant by the terms **ligand**, **coordination number** and **ligand substitution**, using suitable examples of complex ions with different shapes, limited to monodentate ligands.

Your answer should include diagrams and equations where appropriate. [6]

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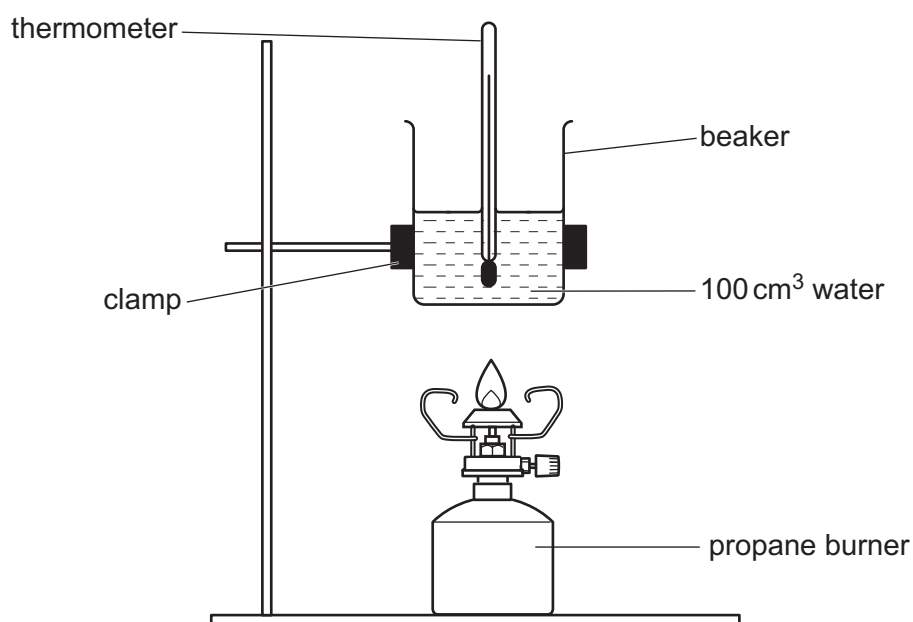
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- 3 Propane, C_3H_8 , (boiling point $-42^\circ C$) is used as 'camping gas'. A student plans to determine the enthalpy change of combustion of propane, $\Delta_c H(C_3H_8)$, by two methods.

(a) The student first carries out an experiment using the apparatus below.



Results

Mass of propane burner before burning/g	99.218
Mass of propane burner after burning/g	98.976
Initial temperature/ $^\circ C$	21.60
Maximum temperature reached/ $^\circ C$	46.10

- (i) Determine the enthalpy change of combustion of propane, in kJ mol^{-1} .

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

$$\Delta_c H(C_3H_8) = \dots\dots\dots \text{kJ mol}^{-1} \quad [3]$$

- (ii) The student finds that the experimental enthalpy change $\Delta_c H$ (C_3H_8) is much less exothermic than the accurate standard enthalpy change $\Delta_c H$ (C_3H_8) in databases.

One reason could be that the student's experiment had not been carried out under standard conditions.

Suggest **two** other reasons for this difference in enthalpy change.

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2

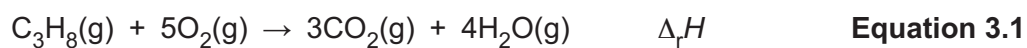
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[1]

(b)* The student determines the standard enthalpy change of combustion of propane using the bond enthalpies in the table. An experiment is not needed.

Bond	Bond enthalpy /kJ mol ⁻¹
C-H	+413
C-C	+347
C=O	+805
O=O	+498
O-H	+464

The bond enthalpies can be used to determine the standard enthalpy change of reaction, $\Delta_r H$, for **equation 3.1**:



Enthalpy change of vaporisation, $\Delta_{\text{vap}} H$

The standard enthalpy change of vaporisation of water, $\Delta_{\text{vap}} H$, is the enthalpy change for the conversion of 1 mol of $\text{H}_2\text{O}(\text{l})$ into 1 mol of $\text{H}_2\text{O}(\text{g})$ under standard conditions:



Determine the standard enthalpy change of combustion of propane (boiling point -42°C) using the $\Delta_r H$ value for **equation 3.1** and $\Delta_{\text{vap}} H$ for water. **[6]**

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4 A student carries out an investigation to identify two metals, **M** and **X**, by two different methods.

(a) The student is provided with a sample of metal **M**.

The student analyses metal **M** using a 'back-titration' technique:

- The metal is reacted with excess acid.
- The resulting solution is titrated to determine the amount of acid remaining after the reaction.

Stage 1

The student adds 100 cm³ of 2.10 mol dm⁻³ HCl(aq) to 6.90 g of **M**.

An excess of HCl(aq) has been used to ensure that all of metal **M** reacts.

A redox reaction occurs, forming a solution containing **M** in the +2 oxidation state.

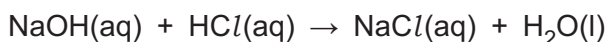
Stage 2

The resulting solution from **Stage 1** is made up to 250.0 cm³ with distilled water.

Stage 3

A 25.00 cm³ sample of the diluted solution from **Stage 2** is titrated with 0.320 mol dm⁻³ NaOH(aq).

The NaOH(aq) reacts with excess HCl(aq) that remains in **Stage 1**:



The student repeats the titration to obtain concordant titres.

Titration results (The trial titre has been omitted.)

The burette readings have been recorded to the nearest 0.05 cm³.

	1	2	3
Final reading / cm³	27.80	37.55	32.20
Initial reading / cm³	0.50	10.00	5.00

(i) In **Stage 1**, a redox reaction takes place between **M** and HCl(aq), forming hydrogen and a solution containing **M** in the +2 oxidation state.

Write an overall equation, with state symbols, for this reaction. Write half-equations for the oxidation and reduction processes.

Overall equation

Oxidation half-equation

Reduction half-equation

[3]

(ii) In **Stage 1**, suggest **two** observations that would confirm that all of metal **M** has reacted.

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2

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[2]

(iii) In **Stage 3**, write the ionic equation for the reaction taking place in the titration.

..... [1]

(iv) Metal **M** can be identified following the steps below.

1. The amount, in mol, of excess $\text{HCl}(\text{aq})$ that remains after the reaction of **M** with $\text{HCl}(\text{aq})$.
2. The amount, in mol, of $\text{HCl}(\text{aq})$ that reacted with **M**.
3. The identity of metal **M**.

Analyse the results to identify metal **M**.

Metal **M** = [6]

- (b) The student is provided with the carbonate of an unknown metal, X_2CO_3 .

The student measures the mass loss when the X_2CO_3 is reacted with an **excess** of hydrochloric acid. The equation is shown below.



The reaction is carried out using this method:

- Step 1** Add 100 cm³ HCl(aq) to a conical flask and weigh.
- Step 2** Add X_2CO_3 to the conical flask and immediately reweigh.
- Step 3** After 5 minutes, reweigh the conical flask and contents.

Results

Mass of conical flask + HCl(aq)	172.93 g
Mass of conical flask + X_2CO_3 + HCl(aq) before reaction	187.50 g
Mass of conical flask + contents after 5 minutes	184.75 g

- (i) Calculate the amount, in mol, of CO_2 released in the reaction.

Amount of CO_2 = mol [1]

- (ii) Calculate the molar mass of X_2CO_3 and identify metal **X**.

Molar mass of X_2CO_3 = g mol⁻¹ Metal **X** = [3]

(c) After analysing the results, the student was told that their molar mass of X_2CO_3 was incorrect.

The student evaluated the experiment for possible reasons for the incorrect result.

(i) The student wondered whether the reaction was complete when the mass was recorded after 5 minutes (**Step 3**).

How could the student modify the experimental procedure to be confident that the reaction was complete?

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..... [1]

(ii) The student finds out that carbon dioxide is slightly soluble in water.

State and explain how the solubility of CO_2 would affect the calculated molar mass of X_2CO_3 .

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..... [2]

- 5 The equilibrium constant K_p and temperature T (in K) are linked by the mathematical relationship shown in **equation 5.1** (R = Gas constant in $\text{J mol}^{-1} \text{K}^{-1}$ and ΔH is enthalpy change in J mol^{-1}).

$$\ln K_p = -\frac{\Delta H}{R} \times \frac{1}{T} + \frac{\Delta S}{R} \quad \text{Equation 5.1}$$

- (a) The table shows the values of K_p at different temperatures for an equilibrium.

Complete the table by adding the missing values of $\frac{1}{T}$ and $\ln K_p$.

Temperature, T/K	400	500	600	700	800
K_p	3.00×10^{58}	5.86×10^{45}	1.83×10^{37}	1.46×10^{31}	1.14×10^{26}
$\frac{1}{T} / \text{K}^{-1}$	2.50×10^{-3}
$\ln K_p$	135

[2]

- (b) State and explain how increasing the temperature affects the position of this equilibrium and whether the forward reaction is exothermic or endothermic.

.....

 [1]

- (c) Plot a graph of $\ln K_p$ against $\frac{1}{T}$ using the axes provided on the opposite page.

Use your graph and **equation 5.1** to determine ΔH , in kJ mol^{-1} , for this equilibrium.

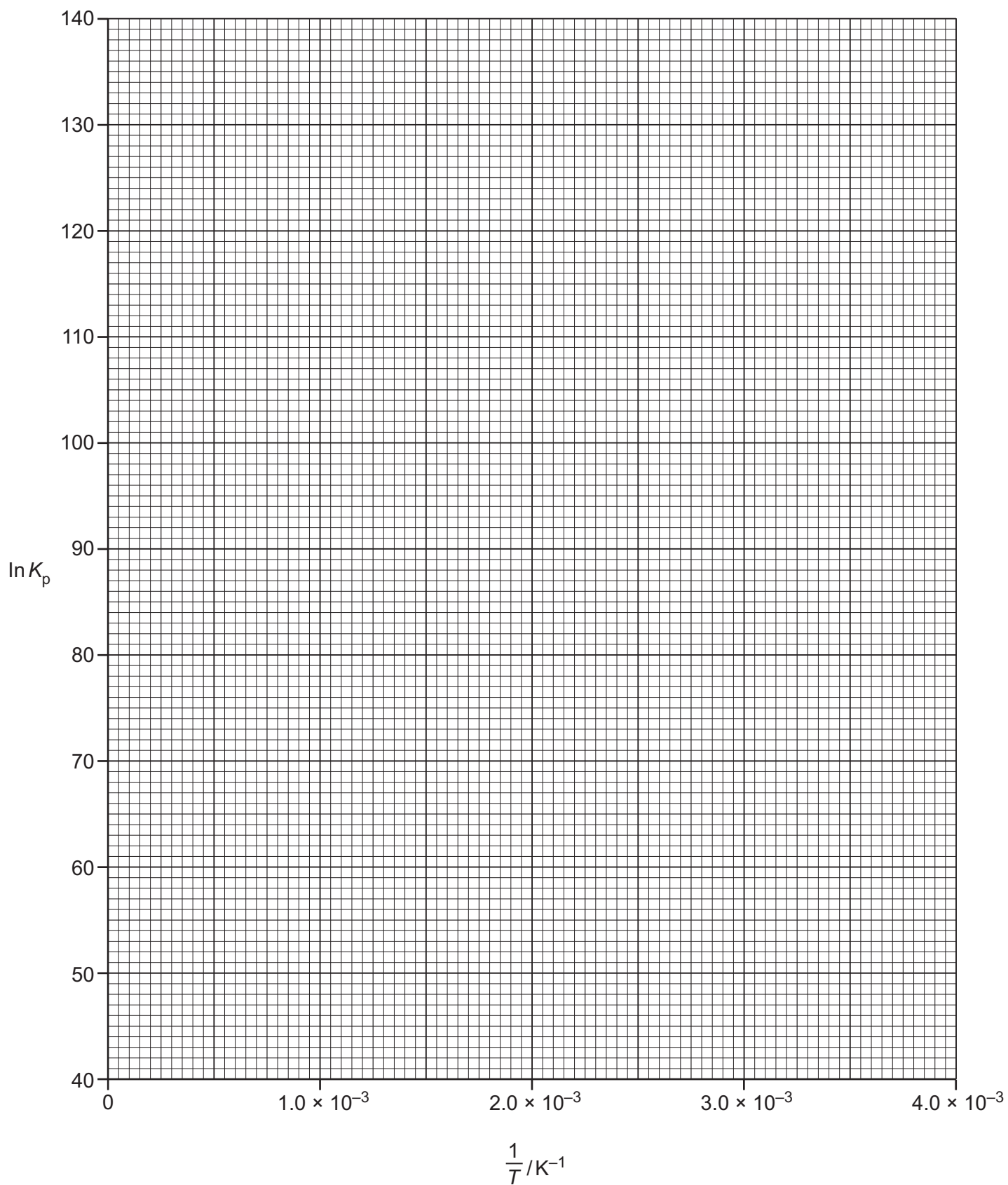
Give your answer to **3** significant figures.

$$\Delta H = \dots\dots\dots \text{kJ mol}^{-1} \quad [4]$$

- (d) Explain how ΔS could be calculated from a graph of $\ln K_p$ against $\frac{1}{T}$.

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 [2]



- 6 This question is about two different types of acid found in organic compounds, carboxylic acids and sulfonic acids, as shown in **Fig. 6.1**.

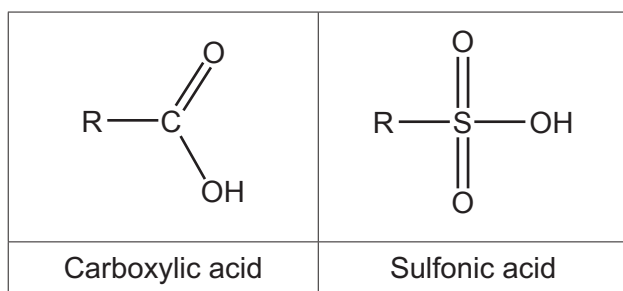


Fig. 6.1

- (a) Complete **Table 6.1** to predict bond angles **a** and **b** and name the shapes which makes these bond angles in the functional groups of carboxylic acids and sulfonic acids.

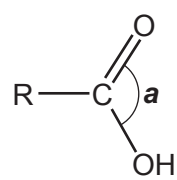
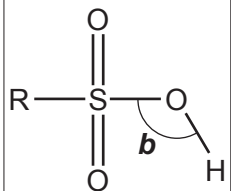
Type of acid	Acid	Bond angle	Name of shape
Carboxylic acid	
Sulfonic acid	

Table 6.1

[2]

- (b) Ethanoic acid, CH_3COOH , and methanesulfonic acid, $\text{CH}_3\text{SO}_2\text{OH}$, are both monobasic acids. The $\text{p}K_{\text{a}}$ values are shown in the table.

Acid		$\text{p}K_{\text{a}}$
Ethanoic acid	CH_3COOH	4.76
Methanesulfonic acid	$\text{CH}_3\text{SO}_2\text{OH}$	-1.90

A student suggests that 1.0 mol dm^{-3} $\text{CH}_3\text{SO}_2\text{OH}$ should have a lower pH value than 1.0 mol dm^{-3} CH_3COOH .

Write an equation, showing conjugate acid–base pairs, for the equilibrium of $\text{CH}_3\text{SO}_2\text{OH}$ with water and explain, with reasons, whether the student is correct.

Label the conjugate acid–base pairs: **A1**, **B1** and **A2**, **B2**.

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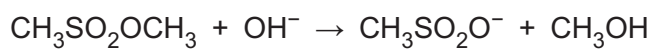
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..... [4]

(c) Carboxylic acids and sulfonic acids both form esters.

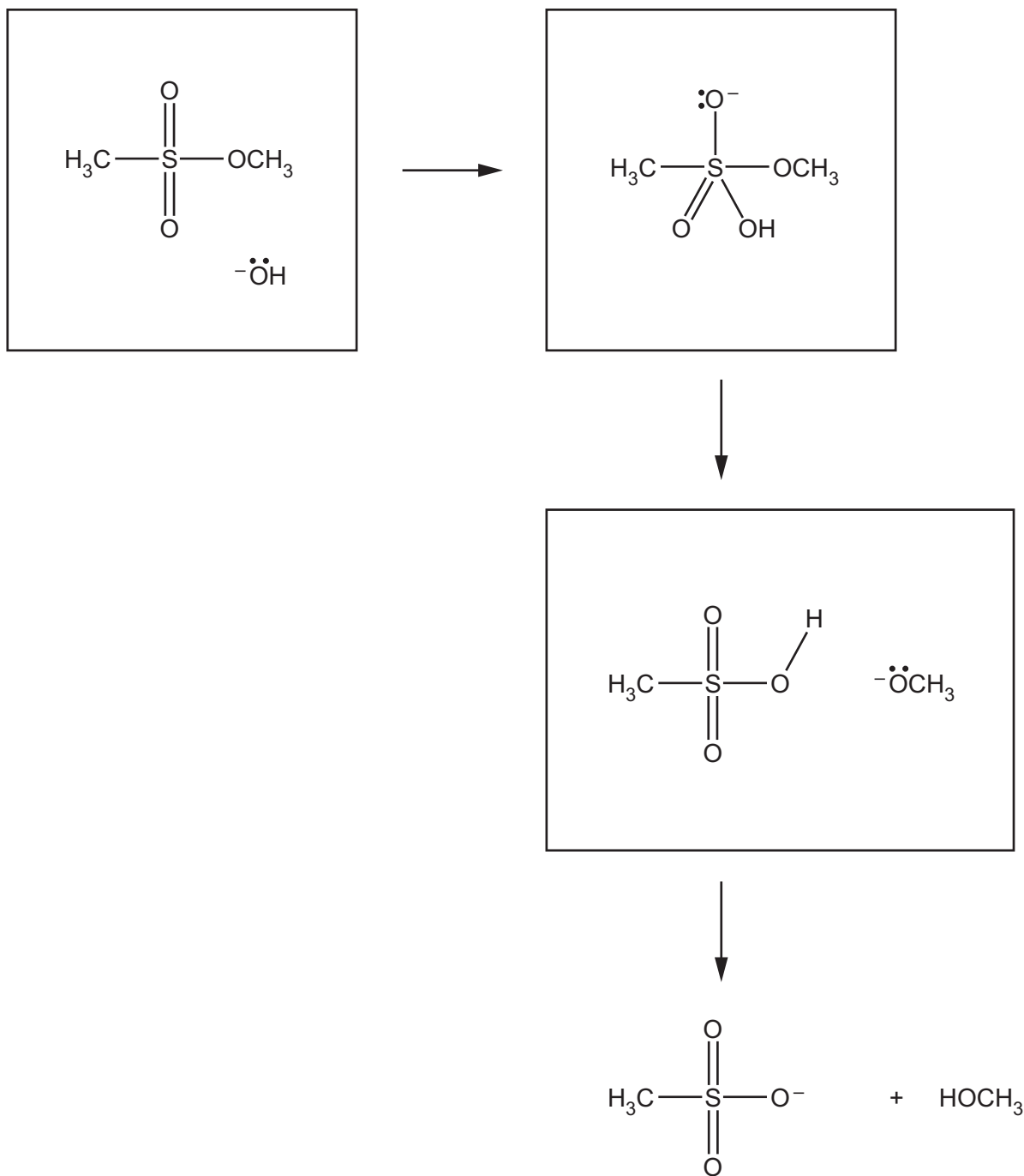
Sulfonic acid esters can be hydrolysed by aqueous alkali.

The equation shows the alkaline hydrolysis of a sulfonic acid ester.



In the **3 boxes below**, add curly arrows to show the mechanism for this reaction.

In the first box, the hydroxide ion acts as a nucleophile.



[4]

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).

A large area of lined paper for writing. It consists of horizontal dotted lines spaced evenly down the page. A vertical solid line runs down the left side of the page, creating a margin. The entire area is intended for providing additional answer space for a question.

A large area of the page is reserved for writing, featuring a vertical solid line on the left side and horizontal dotted lines extending across the page.



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