

Q1. The alcohol 2-methylpropan-2-ol, $(\text{CH}_3)_3\text{COH}$, reacts to form esters that are used as flavourings by the food industry. The alcohol can be oxidised to produce carbon dioxide and water.

A student carried out an experiment on a pure sample of 2-methylpropan-2-ol to determine its enthalpy of combustion. A sample of the alcohol was placed into a spirit burner and positioned under a beaker containing 50 cm^3 of water. The spirit burner was ignited and allowed to burn for several minutes before it was extinguished.

The results for the experiment are shown in **Table 1**.

Table 1

Initial temperature of the water / $^{\circ}\text{C}$	18.1
Final temperature of the water / $^{\circ}\text{C}$	45.4
Initial mass of spirit burner and alcohol / g	208.80
Final mass of spirit burner and alcohol / g	208.58

- (a) Use the results from **Table 1** to calculate a value for the heat energy released from the combustion of this sample of 2-methylpropan-2-ol. The specific heat capacity of water is $4.18 \text{ J K}^{-1} \text{ g}^{-1}$. Show your working.

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(2)

- (b) Calculate the amount, in moles, of 2-methylpropan-2-ol burned in the experiment. Hence calculate a value, in kJ mol^{-1} , for the enthalpy of combustion of 2-methylpropan-2-ol. Show your working.

(If you were unable to calculate an answer to part (a), you should assume that the heat energy released was 5580 J . This is **not** the correct value.)

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- (c) An equation for the combustion of 2-methylpropan-2-ol is



Table 2 contains some standard enthalpy of formation data.

Table 2

	$(\text{CH}_3)_3\text{COH}(\text{l})$	$\text{O}_2(\text{g})$	$\text{CO}_2(\text{g})$	$\text{H}_2\text{O}(\text{l})$
$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	-360	0	-393	-286

Use the data from **Table 2** to calculate a value for the standard enthalpy of combustion of 2-methylpropan-2-ol. Show your working.

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- (d) An accurate value for the enthalpy of combustion of 2-methylpropan-2-ol in which water is formed as a gas is $-2422 \text{ kJ mol}^{-1}$.

Use this value and your answer from part (b) to calculate the overall percentage error in the student's experimental value for the enthalpy of combustion of 2-methylpropan-2-ol.

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- (e) Suggest **one** improvement that would reduce errors due to heat loss in the student's experiment.

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- (f) Suggest **one** other source of error in the student's experiment. Do **not** include heat loss, apparatus error or student error.

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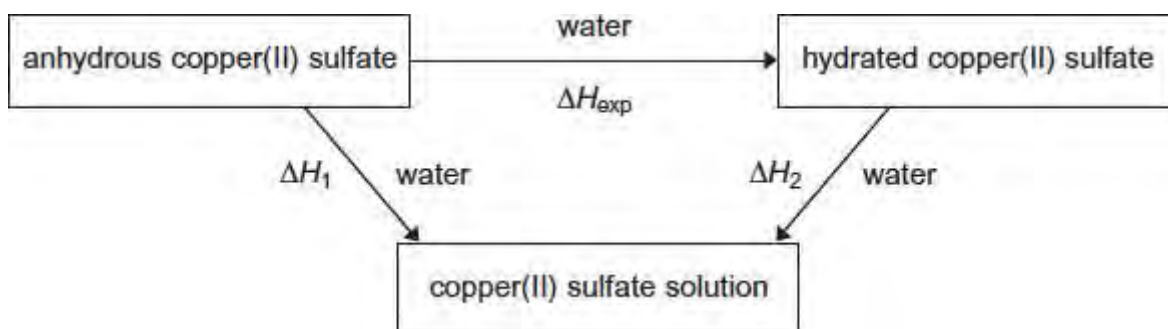
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(Total 11 marks)

Q2.A student used Hess's Law to determine a value for the enthalpy change that occurs when anhydrous copper(II) sulfate is hydrated. This enthalpy change was labelled ΔH_{exp} by the student in a scheme of reactions.



- (a) State Hess's Law.

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- (b) Write a mathematical expression to show how ΔH_{exp} , ΔH_1 and ΔH_2 are related to each other by Hess's Law.

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- (c) Use the mathematical expression that you have written in part (b), and the data book values for the two enthalpy changes ΔH_1 and ΔH_2 shown, to calculate a value for ΔH_{exp}

$$\Delta H_1 = -156 \text{ kJ mol}^{-1}$$

$$\Delta H_2 = +12 \text{ kJ mol}^{-1}$$

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- (d) The student added 0.0210 mol of pure anhydrous copper(II) sulfate to 25.0 cm³ of deionised water in an open polystyrene cup. An exothermic reaction occurred and the temperature of the water increased by 14.0 °C.

- (i) Use these data to calculate the enthalpy change, in kJ mol⁻¹, for this reaction of copper(II) sulfate. This is the student value for ΔH_1

In this experiment, you should assume that all of the heat released is used to raise the temperature of the 25.0 g of water. The specific heat capacity of water is 4.18 J K⁻¹ g⁻¹.

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- (ii) Suggest **one** reason why the student value for ΔH_f calculated in part (d)(i) is less accurate than the data book value given in part (c).

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- (e) Suggest **one** reason why the value for ΔH_{exp} **cannot** be measured directly.

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(Total 8 marks)

Q3. Methanol (CH_3OH) is an important fuel that can be synthesised from carbon dioxide.

- (a) The table shows some standard enthalpies of formation.

	$\text{CO}_2(\text{g})$	$\text{H}_2(\text{g})$	$\text{CH}_3\text{OH}(\text{g})$	$\text{H}_2\text{O}(\text{g})$
$\Delta H_f^\ominus/\text{kJ mol}^{-1}$	- 394	0	- 201	- 242

- (i) Use these standard enthalpies of formation to calculate a value for the standard enthalpy change of this synthesis.



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(ii) State why the standard enthalpy of formation for hydrogen gas is zero.

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(b) State and explain what happens to the yield of methanol when the total pressure is increased in this synthesis.



Effect on yield

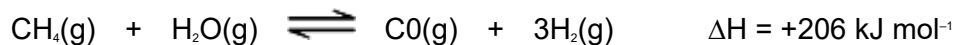
Explanation

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(c) The hydrogen required for this synthesis is formed from methane and steam in a reversible reaction. The equation for this reaction is shown below.



State and explain what happens to the yield of hydrogen in this reaction when the temperature is increased.

Effect on yield

Explanation

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(d) The methanol produced by this synthesis has been described as a carbon-neutral fuel.

(i) State the meaning of the term *carbon-neutral*.

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(ii) Write an equation for the complete combustion of methanol.

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Q4. The enthalpy of hydration for the chloride ion is -364 kJ mol^{-1} and that for the bromide ion is -335 kJ mol^{-1} .

- (a) By describing the nature of the attractive forces involved, explain why the value for the enthalpy of hydration for the chloride ion is more negative than that for the bromide ion.

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- (b) The enthalpy of hydration for the potassium ion is -322 kJ mol^{-1} . The lattice enthalpy of dissociation for potassium bromide is $+670 \text{ kJ mol}^{-1}$.

Calculate the enthalpy of solution for potassium bromide.

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(c) The enthalpy of solution for potassium chloride is $+17.2 \text{ kJ mol}^{-1}$.

(i) Explain why the free-energy change for the dissolving of potassium chloride in water is negative, even though the enthalpy change is positive.

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(ii) A solution is formed when 5.00 g of potassium chloride are dissolved in 20.0 g of water. The initial temperature of the water is 298 K.

Calculate the final temperature of the solution.

In your calculation, assume that only the 20.0 g of water changes in temperature and that the specific heat capacity of water is $4.18 \text{ J K}^{-1} \text{ g}^{-1}$.

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(Total 13 marks)