1 The reaction of calcium oxide with hydrochloric acid is an exothermic reaction.

$$CaO(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l)$$

In an experiment to investigate this reaction, the following procedure was carried out.

1. 50.0 cm^3 of hydrochloric acid, concentration 2.0 mol dm^{-3} (an excess), was pipetted into a polystyrene cup and the initial temperature measured using a thermometer with 0.5 °C graduations.

2. 1.46 g of calcium oxide powder was weighed out and added to the acid. The mixture was stirred and the maximum temperature measured.

Maximum temperature / °C	35.0
Initial temperature / °C	19.5

(a) Calculate the enthalpy change, in joules, for the quantities in this experiment. Assume that the specific heat capacity of the solution is 4.18 J g^{-1} C^{-1}.

Use the expression:

energy transferred in joules = 50.0 × specific heat capacity × temperature change

(1)

(b) sing your answer from (a), calculate the molar enthalpy change for the reaction between calcium oxide and hydrochloric acid. Include a sign and units in your answer.

(2)

(c) The standard molar enthalpy change for the reaction between calcium oxide and hydrochloric acid is −196.8 kJ mol^{-1}.

(i) Suggest **three** reasons why the calculated value in part (b) is different from this value.

(3)

Reason 1 .....

.....

Reason 2 .....

.....

Reason 3 .....

.....

(ii) Using the standard enthalpy change of −196.8 kJ mol^{-1}, calculate the minimum mass of calcium oxide that would be needed to raise the temperature of 250 cm^3 of hydrochloric acid (an excess) by 25.0 °C.

(3)

(d) The reaction of calcium carbonate with hydrochloric acid has the following standard molar enthalpy change.

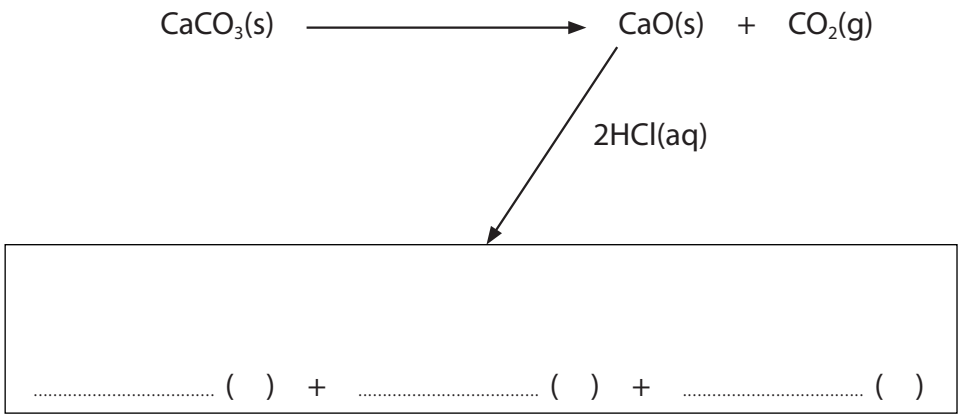
$$\Delta H^{\ominus} = -18.8 \text{ kJ mol}^{-1}$$

This value can be used, with the enthalpy change for the reaction of calcium oxide with hydrochloric acid, to determine the enthalpy change for the thermal decomposition of calcium carbonate. This cannot be measured directly.

(i) Complete the Hess energy cycle below by adding the missing arrow and entities.

Use the cycle, and the standard enthalpy change for the reaction of calcium oxide and hydrochloric acid (−196.8 kJ mol^{-1}), to determine the standard enthalpy change for the decomposition of calcium carbonate.

(4)

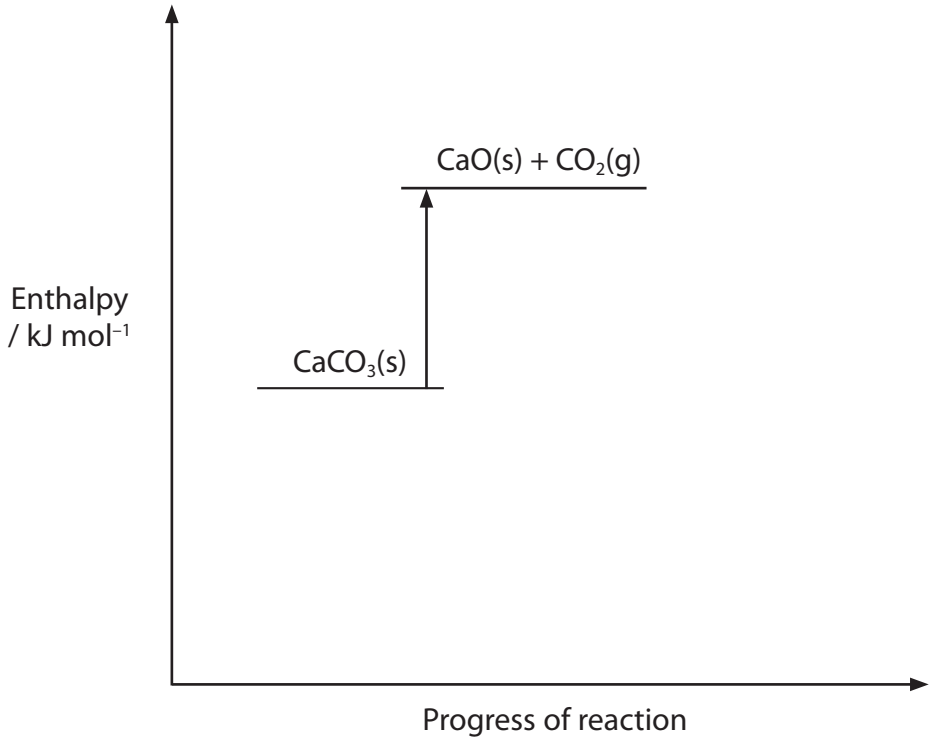


Enthalpy change = ... kJ mol^{-1}

(ii) Complete and label the enthalpy level diagram below, for the series of reactions in (d)(i).

Your diagram does not have to be to scale.

(1)



(Total for Question = 14 marks)

2 Propane is a saturated hydrocarbon with molecular formula C_3H_8.

*(a) Explain the meaning of the terms **saturated** and **hydrocarbon**.

(2)

Saturated .....

.....

Hydrocarbon .....

.....

(b) Propane is sold in small cylinders for use as a fuel in camping stoves. The enthalpy change of combustion of propane can be measured by experiment using one of these cylinders.

A known mass of propane is burned to heat a container of water, and the temperature rise of the water is measured.

The results of the experiment are shown below.

Mass of propane burned	0.33 g
Temperature of water at start	18.0 °C
Final temperature of water	45.1 °C
Mass of water in container	100 g

(i) How would the mass of propane which was burned be measured?

(1)

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.....

(ii) Calculate the energy transferred in the experiment, using the results above and the following expression.

Energy transferred (J) = mass × specific heat capacity × temperature change

The specific heat capacity of water is 4.18 J g^{-1} $°C^{-1}$.

(1)

(iii) Calculate the enthalpy change of combustion of propane, ΔH_c, in kJ mol^{-1}.

Give your answer to **three** significant figures and include a sign.

(3)

(iv) The results of this experiment are inaccurate due to heat loss.

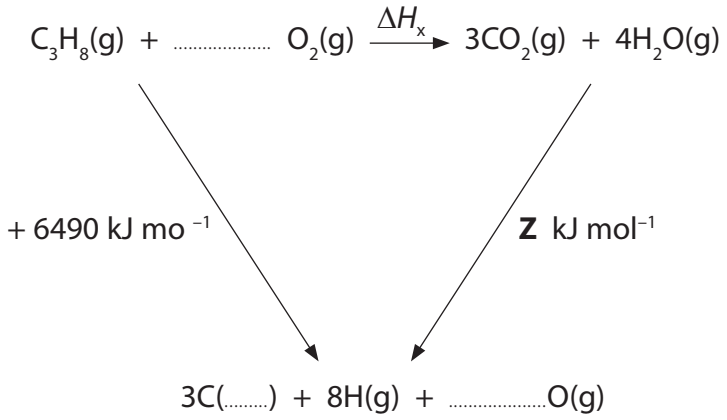
Suggest **one** other source of error, other than measurement errors and limitations of the equipment.

(1)

(c) Another way of calculating the enthalpy change of combustion for propane is to use mean bond enthalpy data.

(i) Complete the equations in the Hess cycle below. The enthalpy change of +6490 kJ mol^{-1} is the total energy required to break the bonds in propane and in oxygen.

(1)



(ii) Use the data in the table to calculate the enthalpy change, **Z**, in kJ mol^{-1}.

Bond	Mean bond enthalpy / kJ mol^{-1}
C═O	805
H—O	464

(1)

(iii) Use the cycle in (c)(i), and your answer to (c)(ii), to calculate the enthalpy change, ΔH_x, in kJ mol^{-1}, for the combustion of propane.

(1)

(iv) The data book value for the standard enthalpy change of combustion, $\Delta H_c^{\ominus}$, for propane is –2219.2 kJ mol^{-1}. This value is more exothermic than that calculated using mean bond enthalpy data. Give **one** reason for this.

(1)

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(Total for Question = 12 marks)

3 Sodium hydrogencarbonate decomposes on heating to form sodium carbonate. It is difficult to measure the enthalpy change of this reaction directly.

$$2NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(l)$$

One method of determining this enthalpy change is to react known amounts of sodium hydrogencarbonate and sodium carbonate, separately, with excess dilute hydrochloric acid.

(a) 0.010 mol of solid sodium hydrogencarbonate was added to 25 cm^3 of dilute hydrochloric acid. A temperature rise of 11 °C was measured using a thermometer graduated at 1 °C intervals.

(i) Calculate the heat energy produced by this reaction using the equation:

Energy transferred in joules = mass × 4.18 × change in temperature

(1)

(ii) Calculate the standard enthalpy change for the reaction when one mole of sodium hydrogencarbonate reacts with hydrochloric acid.

Remember to include a sign and units with your answer which should be given to three significant figures.

(2)

*(b) The standard enthalpy change for the reaction between sodium carbonate and dilute hydrochloric acid is found by a similar method to be

$\Delta H^{\ominus} = -321.6$ kJ mol^{-1}

Complete the Hess energy cycle below by adding the missing arrow and entities. Use it to calculate the standard enthalpy change for the decomposition of two moles of sodium hydrogencarbonate as in the equation below.

Remember to show your reasoning clearly.

(5)

$2NaHCO_3(s) \longrightarrow Na_2CO_3(s) + CO_2(g) + H_2O(l)$

2HCl(aq)

..... ( ) + ... ( ) + ... ( )

(c) The uncertainty for each thermometer reading is ± 0.5 °C.
Calculate the percentage error in the temperature rise of 11 °C.

(1)

(d) Sodium hydrogencarbonate is used in cooking. Suggest what it is used for and how it works.

(2)

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(Total for Question = 11 marks)

4 (a) State Hess's Law.

(1)

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(b) Methane burns in a limited supply of oxygen to give carbon monoxide and water.

$$CH_4(g) + 1\frac{1}{2}O_2(g) \rightarrow CO(g) + 2H_2O(l)$$

The enthalpy change for this reaction cannot be determined directly, but can be found using the standard enthalpy changes of combustion of methane and carbon monoxide, together with Hess's Law.

The standard enthalpy changes of combustion needed are for CH_4, 890 kJ mol ^{1}, and for CO, 283 kJ mol ^{1}.

(i) Draw a Hess's Law diagram which would enable you to calculate the enthalpy change for the combustion of methane to carbon monoxide.

$$CH_4(g) + 1\frac{1}{2}O_2(g) \rightarrow CO(g) + 2H_2O(l)$$

(2)

(ii) Calculate the enthalpy change for this reaction, in kJ mol ^{1}.

(2)

(iii) Explain why the enthalpy change for this reaction cannot be determined directly.

(1)

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.....

(c) Explain why the calculation in part (b)(ii) would give an incorrect result for the enthalpy change for the reaction below.

$$CH_4(g) + 1\frac{1}{2}O_2(g) \rightarrow CO(g) + 2H_2O(g)$$

(2)

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(Total for Question 8 marks)

5 This question is about the solubility of some Group 1 halides.

(a) Potassium fluoride is a soluble, white, crystalline solid used in etching glass. A Hess cycle can be used to calculate its enthalpy of solution, using data including enthalpies of hydration of ions.

Define the term **enthalpy of hydration** of an ion.

(2)

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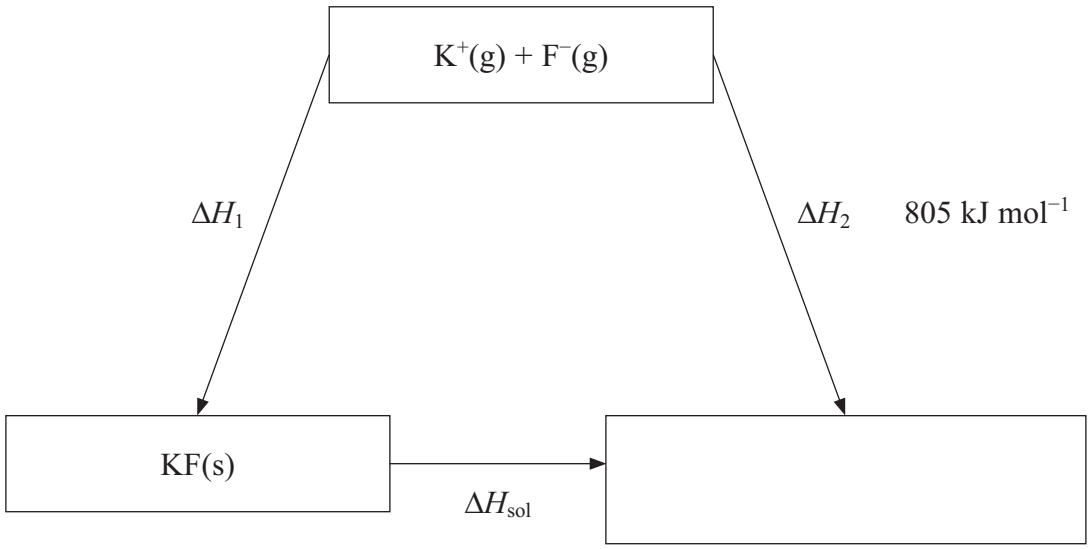
(b) Consider the Hess cycle below.



(i) Complete the cycle by filling in the empty box.

(1)

(ii) Apply Hess's Law to obtain an expression for ΔH_{sol} in terms of ΔH_1 and ΔH_2.

(1)

ΔH_{sol}

(iii) Give the name of the energy change ΔH_1.

(1)

(iv) Referring to page 12 of the data booklet and your answer to (ii), calculate the standard enthalpy of solution of potassium fluoride.

(2)

(c) The standard enthalpy of solution of sodium chloride is + 3 kJ mol^{-1}.

(i) 1 g of sodium chloride was added to 250 cm^3 of water in a beaker and stirred with a thermometer graduated in intervals of 1 °C. Describe and explain what would happen to the reading on the thermometer as the sodium chloride dissolves. No calculation is required.

(3)

*(ii) Explain, in terms of entropy changes, why sodium chloride dissolves in water under standard conditions. No calculation is required.

(4)

*(d) Lithium iodide is generally much more soluble in organic solvents than lithium chloride. Explain this observation using values of lattice energies from your data booklet and your knowledge of the trend in ionic radii down Group 7.

(4)

(Total for Question 18 marks)