

1 Enthalpy changes of combustion, ΔH_c , are amongst the easiest enthalpy changes to determine directly.

(a) Define the term *enthalpy change of combustion*.

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..... [2]

(b) A student carried out an experiment to determine the enthalpy change of combustion of pentan-1-ol, $\text{CH}_3(\text{CH}_2)_4\text{OH}$.

In the experiment, 1.76 g of pentan-1-ol was burnt. The energy was used to heat 250 cm^3 of water from 24.0°C to 78.0°C .

(i) Calculate the energy released, in kJ, during combustion of 1.76 g pentan-1-ol.

The specific heat capacity of water = $4.18\text{ J g}^{-1}\text{ K}^{-1}$.

Density of water = 1.00 g cm^{-3} .

energy = kJ [1]

(ii) Calculate the amount, in moles, of pentan-1-ol that was burnt.

amount = mol [2]

(iii) Calculate the enthalpy change of combustion of pentan-1-ol.

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

$\Delta H_c = \dots\dots\dots\text{ kJ mol}^{-1}$ [3]

(c) The standard enthalpy change of formation of hexane can be defined as:

The enthalpy change when 1 mol of hexane is formed from its constituent elements in their standard states under standard conditions.

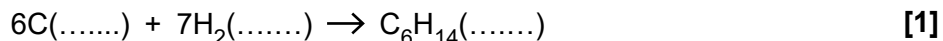
Hexane melts at -95°C and boils at 69°C .

(i) What are *standard conditions*?

..... [1]

(ii) An incomplete equation is shown below for the chemical change that takes place to produce the standard enthalpy change of formation of hexane.

Add state symbols to the equation to show each species in its standard state.



(iii) It is very difficult to determine the standard enthalpy change of formation of hexane directly. Suggest a reason why.

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..... [1]

(iv) The standard enthalpy change of formation of hexane can be determined indirectly.

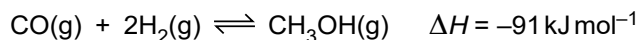
Calculate the standard enthalpy change of formation of hexane using the standard enthalpy changes of combustion below.

substance	$\Delta H_c^{\ominus} / \text{kJ mol}^{-1}$
C	-394
H ₂	-286
C ₆ H ₁₄	-4163

answer = kJ mol⁻¹ [3]

[Total: 14]

- 2 In the chemical industry methanol, CH₃OH, is synthesised by reacting together carbon monoxide and hydrogen in the presence of copper, zinc oxide and alumina which act as a catalyst. This is a reversible reaction.



- (a) High pressures and low temperatures would give the maximum equilibrium yield of methanol. Explain why.

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- (b) Explain why the actual conditions used in the chemical industry might be different from those in (a) above.

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- (c) Catalysts are increasingly being used in chemical processes.

*A catalyst speeds up a reaction without being consumed by the overall reaction.
A catalyst provides an alternative reaction route with a lower activation energy.*

- (i) Chlorine radicals, Cl[•], catalyse some reactions.

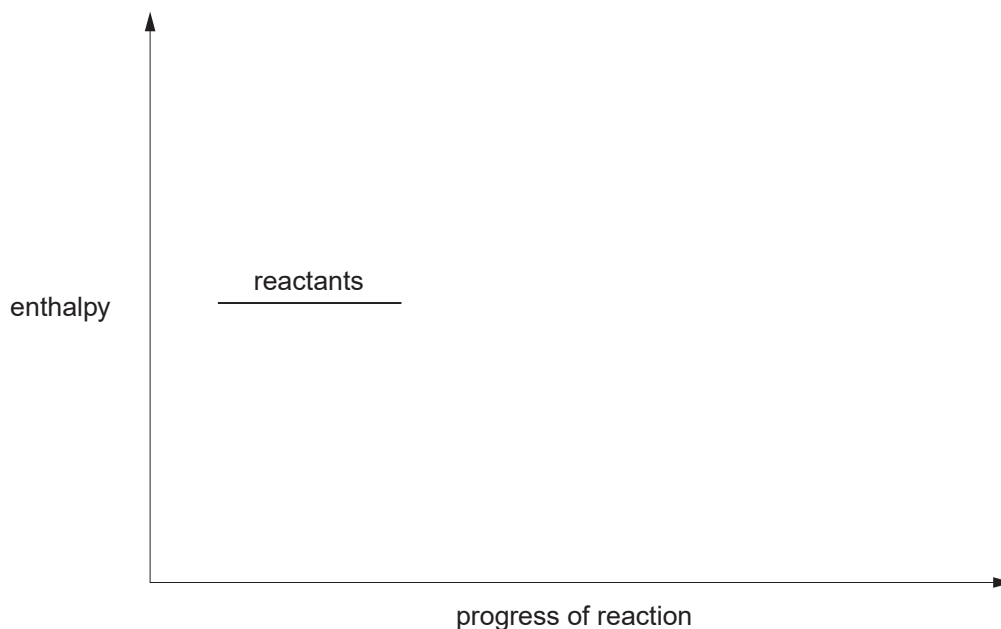
Choose a reaction that you have studied that is catalysed by chlorine radicals.

Write down an equation for the overall reaction and show how chlorine radicals are **not** consumed by the overall reaction.

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(ii) Using the axes below, sketch an enthalpy profile diagram for an exothermic reaction to show how a catalyst provides an alternative reaction route with a lower activation energy. Include on your diagram labels for:

- enthalpy change, ΔH ;
- activation energy for the catalysed route, E_c ;
- activation energy for the uncatalysed route, E_a .



[3]

(d) Chemical companies are using catalysts to develop processes that are more sustainable. These processes reduce costs and are less harmful to the environment.

Suggest **two** ways in which the use of catalysts helps chemical companies to make their processes more sustainable.

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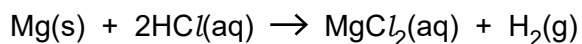
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[4]

[Total: 14]

3 Enthalpy changes can be determined directly or indirectly.

(a) A student investigates the reaction between magnesium and dilute hydrochloric acid.



The student determines the enthalpy change for this reaction.

In her experiment, she reacts 0.486 g of magnesium with 50.0 cm³ of 2.00 mol dm⁻³ HCl(aq). The HCl(aq) is in excess.

The temperature of the solution changes from 19.2 °C to 32.0 °C.

(i) Calculate the energy released, in kJ, during this reaction.

The specific heat capacity of the solution = 4.18 J g⁻¹ K⁻¹.

The density of the solution is 1.00 g cm⁻³.

energy =kJ [2]

(ii) Calculate the amount, in moles, of magnesium used by the student.

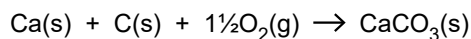
amount = mol [1]

(iii) Calculate the enthalpy change of reaction.

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

enthalpy change of reaction =kJ mol⁻¹ [3]

- (b) The student wants to determine the enthalpy change of formation of calcium carbonate, CaCO₃(s).



- (i) What is meant by the term *standard enthalpy change of formation*?
You should state the standard conditions in your answer.

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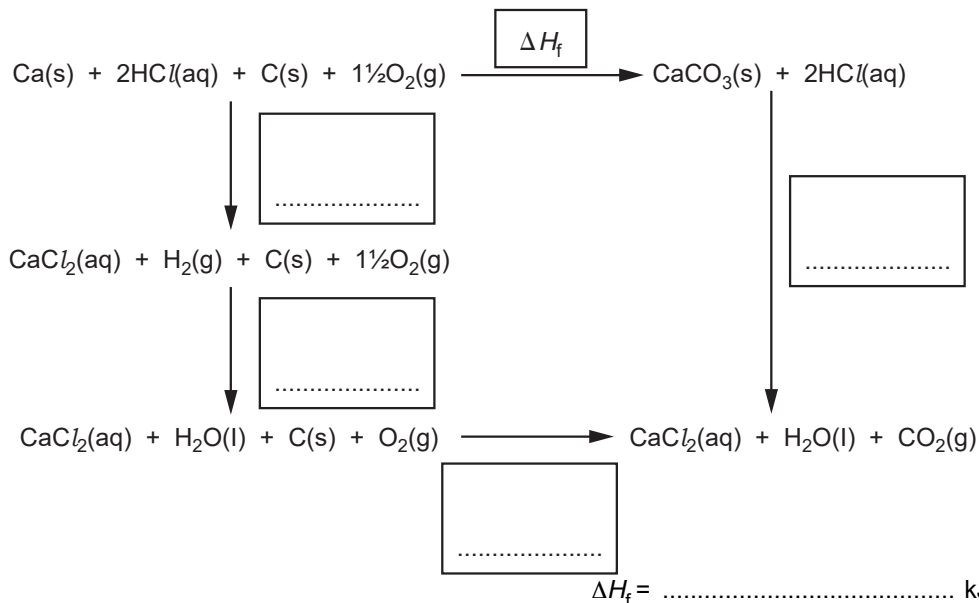
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- (ii) Using the following data and enthalpy cycle,

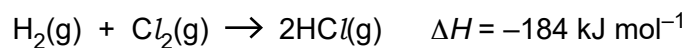
- fill in the boxes on the enthalpy cycle with the correct enthalpy change values
- calculate the enthalpy change of formation, ΔH_f , of CaCO₃(s).

reaction	enthalpy change, $\Delta H / \text{kJ mol}^{-1}$
$\text{C(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$	-393
$\text{H}_2\text{(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{H}_2\text{O(l)}$	-285
$\text{CaCO}_3\text{(s)} + 2\text{HCl(aq)} \rightarrow \text{CaCl}_2\text{(aq)} + \text{H}_2\text{O(l)} + \text{CO}_2\text{(g)}$	-54
$\text{Ca(s)} + 2\text{HCl(aq)} \rightarrow \text{CaCl}_2\text{(aq)} + \text{H}_2\text{(g)}$	-168



[Total: 12]

- 4 Hydrogen and chlorine are reacted together to form hydrogen chloride.



- (a) Calculate the bond enthalpy for the H–Cl bond using the information in the table below.

bond	bond enthalpy / kJ mol^{-1}
H–H	+436
Cl–Cl	+243

bond enthalpy = kJ mol^{-1} [2]

- (b) The reaction is repeated at a **higher** pressure.

Describe and explain what happens to the rate of the reaction between $\text{H}_2(\text{g})$ and $\text{Cl}_2(\text{g})$.

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..... [2]

(c) The reaction is repeated again. This time the temperature is **decreased**.

Describe and explain, by drawing appropriately labelled Boltzmann distributions, what happens to the rate of reaction between $\text{H}_2(\text{g})$ and $\text{Cl}_2(\text{g})$.

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..... [5]

(d) The mechanism of the reaction between $\text{H}_2(\text{g})$ and $\text{Cl}_2(\text{g})$ involves initiation, propagation and termination.

(i) The initiation step is the homolytic fission of the covalent bond in a chlorine molecule.

Write an equation to show this homolytic fission.

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(ii) Complete the following equations which show the propagation steps.



(iii) Suggest equations for **two** termination steps.

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..... [2]

[Total: 14]

5 Enthalpy changes of reaction can be determined by experiment or by using bond enthalpies.

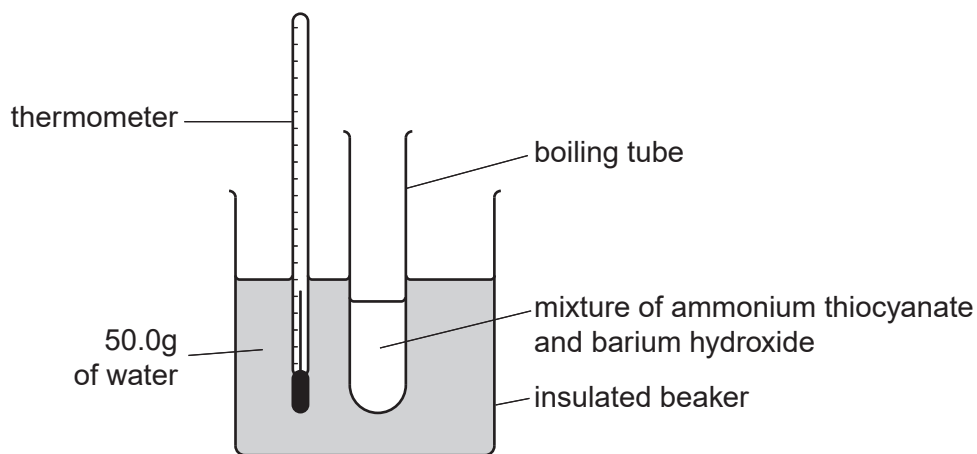
(a) What is meant by the term *enthalpy change of reaction*?

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..... [2]

(b) Solid ammonium thiocyanate, NH_4SCN , reacts with solid barium hydroxide, $\text{Ba}(\text{OH})_2$, as shown in the equation below.



A research chemist carries out an experiment to determine the enthalpy change of this reaction.



In the experiment, 15.22 g of NH_4SCN is reacted with a slight excess of $\text{Ba}(\text{OH})_2$. The reaction absorbs energy, cooling the 50.0 g of water from 21.9 °C to 10.9 °C.

(i) Calculate the energy absorbed, in kJ, during this reaction.

The specific heat capacity of water = $4.2 \text{ J g}^{-1} \text{ K}^{-1}$.

energy =kJ [2]

(ii) Calculate the amount, in moles, of NH_4SCN used by the research chemist.

amount = mol [1]

(iii) Calculate the enthalpy change of reaction.

Include the sign in your answer.

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

$\Delta H_r = \dots\dots\dots \text{kJ mol}^{-1}$ [3]

(c) Standard enthalpy changes of reaction can also be determined using average bond enthalpies.

(i) What is meant by the term *average bond enthalpy*?

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..... [2]

Table 3.1 below shows some average bond enthalpies.

bond	average bond enthalpy / kJ mol ⁻¹
C-H	+
C-C	+
C=C	+611

Table 3.1

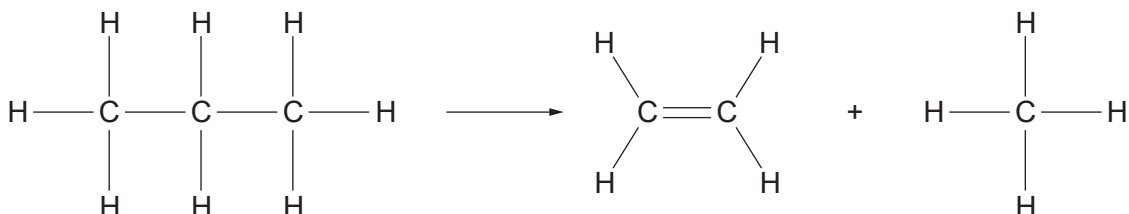
(ii) Explain the bonding in a C=C double bond. Use the orbital overlap model.

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(iii) Suggest why the average bond enthalpy of a C=C bond is **not** twice the bond enthalpy of a C-C bond.

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..... [1]

(iv) Propane can be cracked to make ethene.



Using the average bond enthalpies in **Table 3.1**, calculate the enthalpy change of this reaction.

$$\Delta H_r = \dots\dots\dots \text{kJ mol}^{-1} \text{ [2]}$$

(v) The actual value for the enthalpy change of this reaction is +81 kJ mol⁻¹.

Suggest a reason why the actual value for the enthalpy change of this reaction is different from the calculated value.

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..... [1]

[Total: 16]