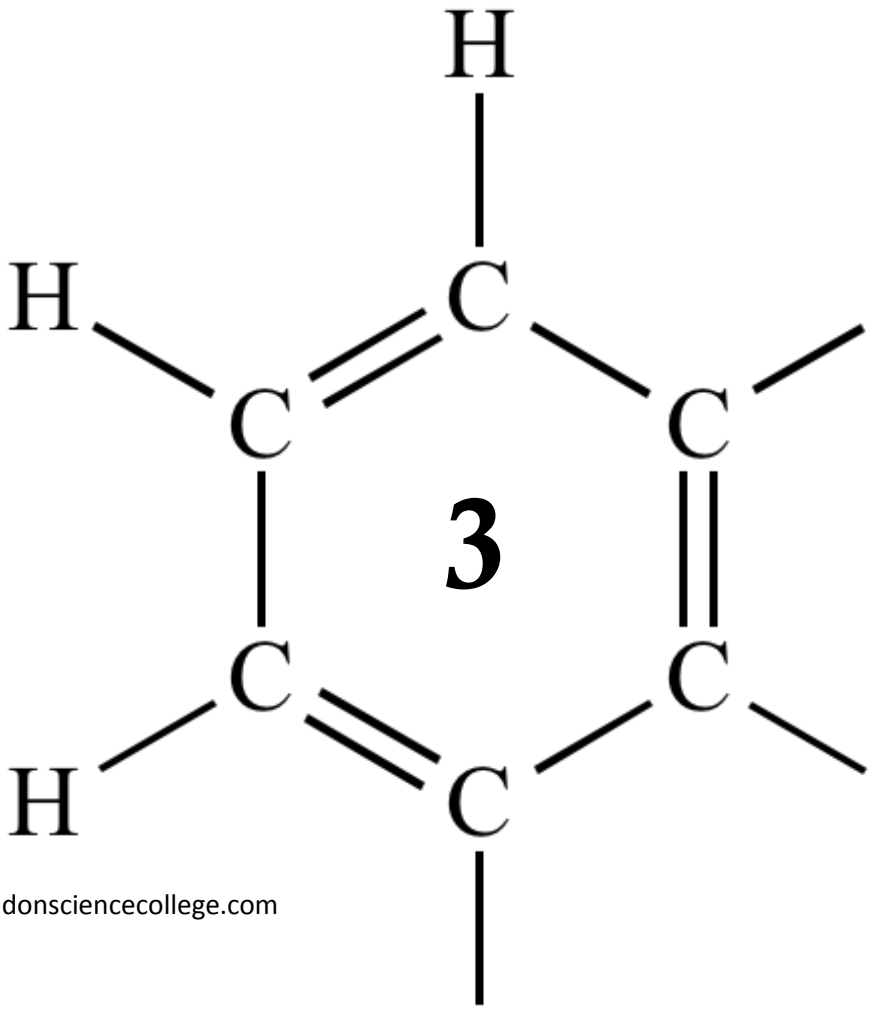
LONDON SCIENCE COLLEGE

OCR AS CHEMISTRY

MODULE 3

ENTHALPY



1 The alcohol 2-methylpropan-2-ol, $(CH_3)_3COH$, 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 / °C	18.1
Final temperature of the water / °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 J K^{-1} 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

$$(CH_3)_3COH(l) + 6O_2(g) \longrightarrow 4CO_2(g) + 5H_2O(l)$$

Table 2 contains some standard enthalpy of formation data.

Table 2

	$(CH_3)_3COH(l)$	$O_2(g)$	$CO_2(g)$	$H_2O(l)$
$\Delta H_f^{\ominus}$ **/ 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 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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(1)

(Total 11 marks)

2 Ethanol is an important industrial compound.

(a) Ethanol can be produced by the hydration of ethene.
The equation for the equilibrium that is established is

$$H_2C{=}CH_2(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g) \qquad \Delta H = -42 \text{ kJ mol}^{-1}$$

The operating conditions for the process are a temperature of 300 °C and a pressure of 7 MPa.
Under these conditions, the conversion of ethene into ethanol is 5%.

(i) Identify the catalyst used in this process.
Deduce how an overall yield of 95% is achieved in this process without changing the operating conditions.

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(ii) Use your knowledge of equilibrium reactions to explain why a manufacturer might consider using an excess of steam in this process, under the same operating conditions.

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(iii) At pressures higher than 7 MPa, some of the ethene reacts to form a solid with a relative molecular mass greater than 5000.

Deduce the identity of this solid.

Give **one** other reason for **not** operating this process at pressures higher than 7 MPa.
Do **not** include safety reasons.

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(2)

(b) Write an equation for the reaction that has an enthalpy change that is the standard enthalpy of formation of ethanol.

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(2)

(c) When ethanol is used as a fuel, it undergoes combustion.

(i) Define the term *standard enthalpy of combustion*.

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(ii) Consider these bond enthalpy data.

	C–H	C–C	C–O	O=O	C=O	O–H
Bond enthalpy / kJ mol^{-1}	412	348	360	496	805	463

Use these data and the equation to calculate a value for the enthalpy of combustion of gaseous ethanol.

$$CH_3CH_2OH(g) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(g)$$

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(d) Gaseous ethanol can be used to convert hot copper(II) oxide into copper.

(i) Deduce the role of ethanol in this reaction.

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(ii) Draw the structure of the organic compound with M_r = 60 that is produced in this reaction.

(1)

(Total 17 marks)

3 Group 2 metals and their compounds are used commercially in a variety of processes.

(a) Strontium is extracted from strontium oxide (SrO) by heating a mixture of powdered strontium oxide and powdered aluminium.

Consider these standard enthalpies of formation.

	SrO(s)	$Al_2O_3(s)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	– 590	– 1669

$$3SrO(s) + 2Al(s) \longrightarrow 3Sr(s) + Al_2O_3(s)$$

Use these data and the equation to calculate the standard enthalpy change for this extraction of strontium.

The use of powdered strontium oxide and powdered aluminium increases the surface area of the reactants.
Suggest **one** reason why this increases the reaction rate.

Suggest **one** major reason why this method of extracting strontium is expensive.

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(b) Explain why calcium has a higher melting point than strontium.

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(c) Magnesium is used in fireworks. It reacts rapidly with oxygen, burning with a bright white light. Magnesium reacts slowly with cold water.

Write an equation for the reaction of magnesium with oxygen.

Write an equation for the reaction of magnesium with cold water.

Give a medical use for the magnesium compound formed in the reaction of magnesium with cold water.

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(Total 10 marks)

4 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 kJ mol^{-1}.

Calculate the enthalpy of solution for potassium bromide.

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(2)

(c) The enthalpy of solution for potassium chloride is +17.2 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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(Extra space) .....

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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 J K^{-1} g^{-1}.

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(Total 13 marks)

5 This question is about the extraction of metals.

(a) Manganese can be extracted from Mn_2O_3 by reduction with carbon monoxide at high temperature.

(i) Use the standard enthalpy of formation data from the table and the equation for the extraction of manganese to calculate a value for the standard enthalpy change of this extraction.

	$Mn_2O_3(s)$	$CO(g)$	$Mn(s)$	$CO_2(g)$
$\Delta H_f^{\ominus}$/ kJ mol^{-1}	−971	−111	0	−394

$$Mn_2O_3(s) + 3CO(g) \longrightarrow 2Mn(s) + 3CO_2(g)$$

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(ii) State why the value for the standard enthalpy of formation of Mn(s) is zero.

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(b) Titanium is extracted in industry from titanium(IV) oxide in a two-stage process.

(i) Write an equation for the first stage of this extraction in which titanium(IV) oxide is converted into titanium(IV) chloride.

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(2)

(ii) Write an equation for the second stage of this extraction in which titanium(IV) chloride is converted into titanium.

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(2)

(c) Chromium is extracted in industry from chromite ($FeCr_2O_4$).

(i) In the first stage of this extraction, the $FeCr_2O_4$ is converted into Na_2CrO_4 Balance the equation for this reaction.

.....$FeCr_2O_4$ + ...Na_2CO_3 + ...O_2 ⟶ .....Na_2CrO_4 + 2Fe_2O_3 + 8CO_2

(1)

(ii) In the final stage, chromium is extracted from Cr_2O_3 by reduction with aluminium.

Write an equation for this reaction.

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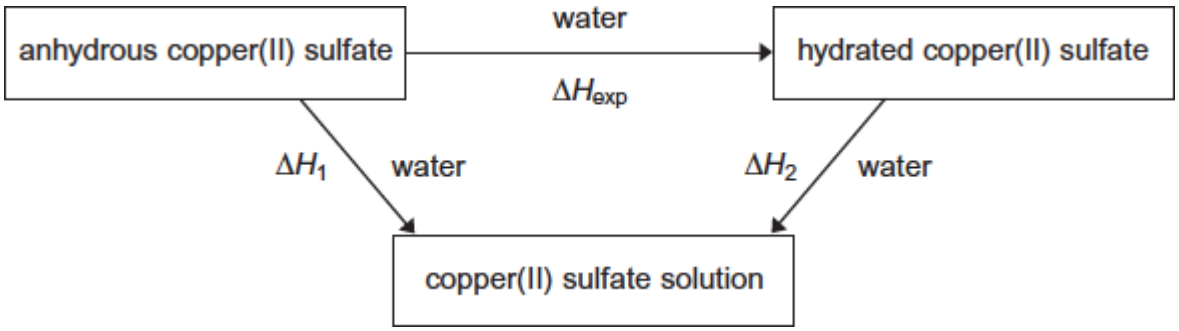
(1)

(Total 10 marks)

6 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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(1)

(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}

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

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

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(d) The student added 0.0210 mol of pure anhydrous copper(II) sulfate to 25.0 cm^3 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_1 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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(1)
(Total 8 marks)

7 Hydrazine (N_2H_4) decomposes in an exothermic reaction. Hydrazine also reacts exothermically with hydrogen peroxide when used as a rocket fuel.

(a) Write an equation for the decomposition of hydrazine into ammonia and nitrogen only.

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(b) State the meaning of the term *mean bond enthalpy*.

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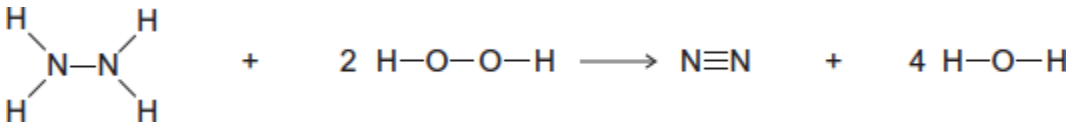
(2)

(c) Some mean bond enthalpies are given in the table.

	N–H	N–N	N≡N	O–H	O–O
Mean bond enthalpy / kJ mol^{-1}	388	163	944	463	146

Use these data to calculate the enthalpy change for the gas-phase reaction between hydrazine and hydrogen peroxide.



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(Total 6 marks)

8 This question is about bond dissociation enthalpies and their use in the calculation of enthalpy changes.

(a) Define *bond dissociation enthalpy* as applied to chlorine.

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(b) Explain why the enthalpy of atomisation of chlorine is exactly half the bond dissociation enthalpy of chlorine.

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(c) The bond dissociation enthalpy for chlorine is +242 kJ mol^{-1} and that for fluorine is +158 kJ mol^{-1}. The standard enthalpy of formation of ClF(g) is −56 kJ mol^{-1}.

(i) Write an equation, including state symbols, for the reaction that has an enthalpy change equal to the standard enthalpy of formation of gaseous ClF

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(ii) Calculate a value for the bond enthalpy of the Cl – F bond.

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(iii) Calculate the enthalpy of formation of gaseous chlorine trifluoride, $ClF_3(g)$. Use the bond enthalpy value that you obtained in part (c)(ii).

(If you have been unable to obtain an answer to part (c)(ii), you may assume that the Cl – F bond enthalpy is +223 kJ mol^{-1}. This is **not** the correct value.)

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(iv) Explain why the enthalpy of formation of $ClF_3(g)$ that you calculated in part (c)(iii) is likely to be different from a data book value.

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(d) Suggest why a value for the Na – Cl bond enthalpy is **not** found in any data book.

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(1)

(Total 11 marks)

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

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

	$CO_2(g)$	$H_2(g)$	$CH_3OH(g)$	$H_2O(g)$
$\Delta H_f^{\ominus}$/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.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

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

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(1)

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

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Effect on yield .....

Explanation .....

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(3)

(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.

$$CH_4(g) + H_2O(g) \rightleftharpoons C0(g) + 3H_2(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

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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(1)

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

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(1)

(iii) The equation for the synthesis of methanol is shown below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Use this equation and your answer to part (d)(ii) to deduce an equation to represent the overall chemical change that occurs when methanol behaves as a carbon-neutral fuel.

Equation .....

(1)

(e) A student carried out an experiment to determine the enthalpy change when a sample of methanol was burned.

The student found that the temperature of 140 g of water increased by 7.5 °C when 0.011 mol of methanol was burned in air and the heat produced was used to warm the water.

Use the student's results to calculate a value, in kJ mol $^{-1}$, for the enthalpy change when one mole of methanol was burned.

(The specific heat capacity of water is 4.18 J K^{-1} g^{-1}).

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(Total 16 marks)