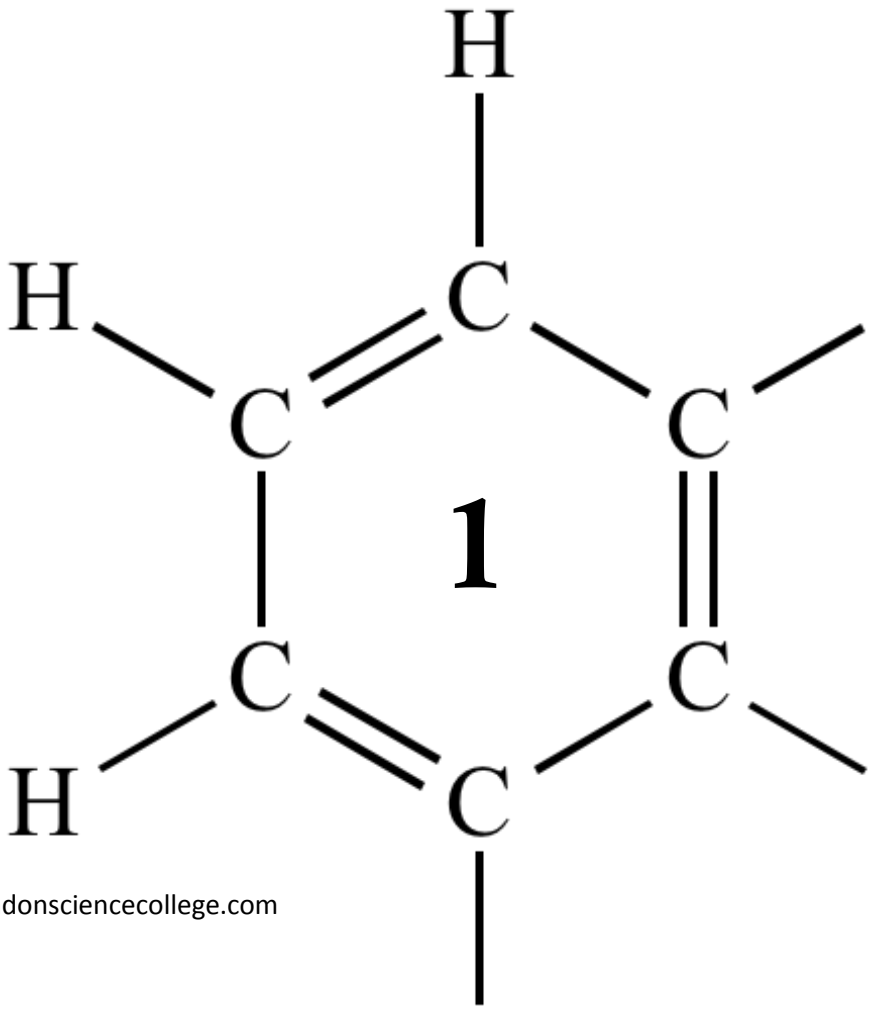
LONDON SCIENCE COLLEGE

OCR AS CHEMISTRY

MODULE 3

ENTHALPY



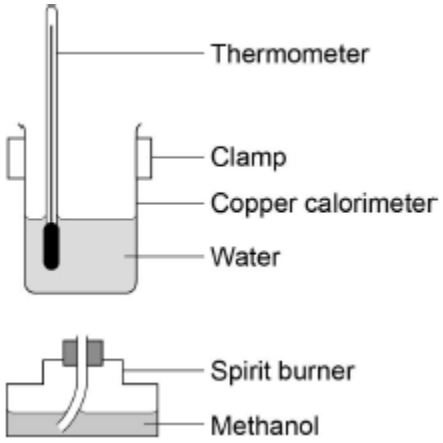
1 Alcohols such as methanol (CH_3OH), ethanol (CH_3CH_2OH) and propan-1-ol ($CH_3CH_2CH_2OH$) are good fuels.

(a) A student carried out an experiment to determine the enthalpy of combustion of methanol.

Methanol was placed in a spirit burner and the mass of the spirit burner measured. The student placed 100 g of water in a copper calorimeter and clamped it above the spirit burner. The burner was lit and allowed to burn for a few minutes. The flame was then extinguished and the new mass of the spirit burner found.

The measured temperature rise was 38.0 °C. The specific heat capacity of water is 4.18 J K^{-1} g^{-1}.

A diagram of the apparatus is shown alongside a table which shows the measurements the student recorded.



Mass of burner containing methanol before experiment	214.02 g
Mass of burner containing methanol after experiment	212.37 g

Use the student's data to calculate an experimental value for the enthalpy of combustion of methanol in kJ mol^{-1}.

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(4)

(b) Suggest **one** reason, other than incomplete combustion or heat transfer to the atmosphere, why the student's value for the enthalpy of combustion of methanol is different from that in a Data Book.

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(1)

(c) The uncertainty in each of the temperature readings from the thermometer in this experiment was ±0.25 °C. This gave an overall uncertainty in the temperature rise of ±0.5 °C.

Calculate the percentage uncertainty for the use of the thermometer in this experiment.

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(1)

(d) The student said correctly that using a thermometer with an overall uncertainty for the rise in temperature of ±0.5 °C was adequate for this experiment.

Explain why this thermometer was adequate for this experiment.

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(1)

(e) The enthalpy of combustion of ethanol is −1371 kJ mol^{-1}. The density of ethanol is 0.789 g cm^{-3}.

Calculate the heat energy released in kJ when 0.500 dm^3 of ethanol is burned. Give your answer to an appropriate number of significant figures.

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(3)

(Total 10 marks)

2 Hydrogen is produced by the reaction of methane with steam. The reaction mixture reaches a state of dynamic equilibrium.

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

Some enthalpy data is given in the table.

Bond	C–H	O–H	H–H	C≡H
Bond enthalpy / kJ mol^{-1}	413	463	436	To be calculated

Use the information in the table and the stated enthalpy change to calculate the missing bond enthalpy.

A 234 ⬭

B 1064 ⬭

C 1476 ⬭

D 1936 ⬭

(Total 1 mark)

3 Standard enthalpy of combustion data can be used to calculate enthalpies of formation.

(a) State the meaning of the term standard enthalpy of combustion.

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(3)

(b) The equation corresponding to the enthalpy of formation of propan-1-ol is shown.

$$3C(s) + 4H_2(g) + \tfrac{1}{2}O_2(g) \longrightarrow CH_3CH_2CH_2OH(l)$$

Table 1 contains some standard enthalpy of combustion data.

Table 1

	C(s)	**$H_2(g)$**	**$CH_3CH_2CH_2OH(l)$**
$\Delta H_c^{\ominus}$ / kJ mol^{-1}	–394	–286	–2010

Use data from **Table 1** to calculate a value for the standard enthalpy of formation of propan-1-ol. Show your working.

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(3)

(c) An equation for the complete combustion of gaseous propan-1-ol is shown.

$$CH_3CH_2CH_2OH(g) + 4\tfrac{1}{2}O_2(g) \longrightarrow 3CO_2(g) + 4H_2O(g) \quad \Delta H = -1893 \text{ kJ mol}^{-1}$$

Table 2 shows some bond enthalpy data.

Table 2

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

Use data from **Table 2** and the enthalpy change for this reaction to calculate a value for the bond enthalpy of a C–C bond in propan-1-ol.

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(3)
(Total 9 marks)

4 (a) Write an equation, including state symbols, for the reaction with enthalpy change equal to the standard enthalpy of formation for $CF_4(g)$.

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(1)

(b) Explain why CF_4 has a bond angle of 109.5°.

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(2)

(c) **Table 1** gives some values of standard enthalpies of formation ($\Delta_f H^\ominus$).

Table 1

Substance	$F_2(g)$	$CF_4(g)$	HF(g)
$\Delta_f H^\ominus$ / kJ mol^{-1}	0	−680	−269

The enthalpy change for the following reaction is −2889 kJ mol^{-1}.

$$C_2H_6(g) + 7F_2(g) \longrightarrow 2CF_4(g) + 6HF(g)$$

Use this value and the standard enthalpies of formation in **Table 1** to calculate the standard enthalpy of formation of $C_2H_6(g)$.

Standard enthalpy of formation of $C_2H_6(g)$ = ... kJ mol^{-1}

(3)

(d) Methane reacts violently with fluorine according to the following equation.

$$CH_4(g) + 4F_2(g) \longrightarrow CF_4(g) + 4HF(g) \quad \Delta H = -1904 \text{ kJ mol}^{-1}$$

Some mean bond enthalpies are given in **Table 2**.

Table 2

Bond	C−H	C−F	H−F
Mean bond enthalpy / kJ mol^{-1}	412	484	562

A student suggested that one reason for the high reactivity of fluorine is a weak F−F bond.

Is the student correct? Justify your answer with a calculation using these data.

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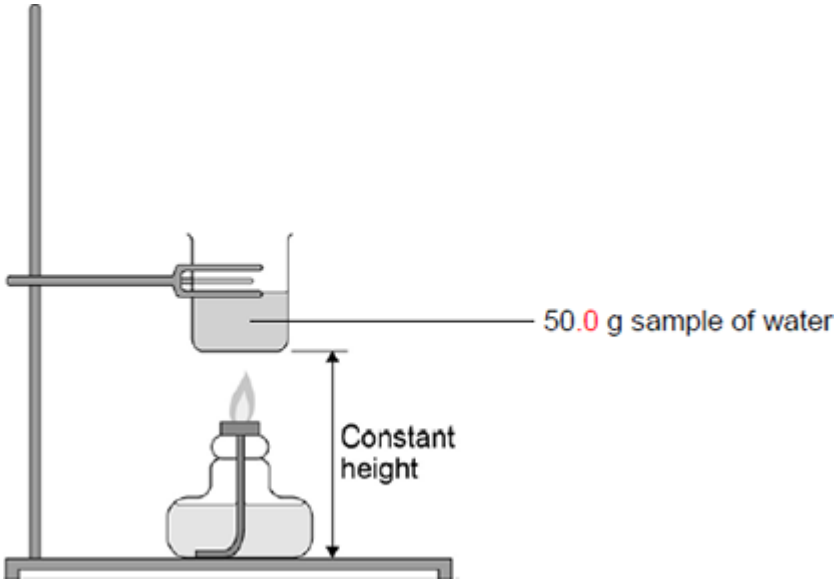
(4)
(Total 10 marks)

5 The figure below shows apparatus used in an experiment to determine the enthalpy of combustion of leaf alcohol.



The alcohol is placed in a spirit burner and weighed. The burner is lit and the alcohol allowed to burn for a few minutes. The flame is extinguished and the burner is re-weighed. The temperature of the water is recorded before and after heating.

The following table shows the results obtained.

Initial mass of spirit burner and alcohol / g	56.38
Final mass of spirit burner and alcohol / g	55.84
Initial temperature of water / °C	20.7
Final temperature of water / °C	40.8

(a) Write an equation for the complete combustion of leaf alcohol ($CH_3CH_2CH=CHCH_2CH_2OH$).

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(1)

(b) Use the results from the table above to calculate a value for the enthalpy of combustion of leaf alcohol. Give units in your answer.
(The specific heat capacity of water is 4.18 J K^{-1} g^{-1})

Enthalpy of combustion = ... Units = ...

(4)

(c) State how your answer to part (b) is likely to differ from the value quoted in reference sources.
Give **one** reason for your answer.

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(2)

(d) A 50.0 g sample of water was used in this experiment.

Explain how you could measure out this mass of water without using a balance.

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(2)

(Total 9 marks)

6 Many chemical processes release waste products into the atmosphere. Scientists are developing new solid catalysts to convert more efficiently these emissions into useful products, such as fuels. One example is a catalyst to convert these emissions into methanol. The catalyst is thought to work by breaking a H–H bond.

An equation for this formation of methanol is given below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \quad \Delta H = -49 \text{ kJ mol}^{-1}$$

Some mean bond enthalpies are shown in the following table.

Bond	C=O	C–H	C–O	O–H
Mean bond enthalpy / kJ mol^{-1}	743	412	360	463

(a) Use the enthalpy change for the reaction and data from the table to calculate a value for the H–H bond enthalpy.

H–H bond enthalpy = ... kJ mol^{-1}

(3)

(b) A data book value for the H–H bond enthalpy is 436 kJ mol^{-1}.

Suggest **one** reason why this value is different from your answer to part (a).

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(1)

(c) Suggest **one** environmental advantage of manufacturing methanol fuel by this reaction.

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(1)

(d) Use Le Chatelier's principle to justify why the reaction is carried out at a high pressure rather than at atmospheric pressure.

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(3)

(e) Suggest why the catalyst used in this process may become less efficient if the carbon dioxide and hydrogen contain impurities.

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(1)

(f) In a laboratory experiment to investigate the reaction shown in the equation below, 1.0 mol of carbon dioxide and 3.0 mol of hydrogen were sealed into a container. After the mixture had reached equilibrium, at a pressure of 500 kPa, the yield of methanol was 0.86 mol.

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

Calculate a value for K_p
Give your answer to the appropriate number of significant figures.
Give units with your answer.

K_p = ... Units = ...

(7)

(Total 16 marks)

7 A 5.00 g sample of potassium chloride was added to 50.0 g of water initially at 20.0 °C. The mixture was stirred and as the potassium chloride dissolved, the temperature of the solution decreased.

(a) Describe the steps you would take to determine an accurate minimum temperature that is **not** influenced by heat from the surroundings.

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(4)

(b) The temperature of the water decreased to 14.6 °C.

Calculate a value, in kJ mol^{-1}, for the enthalpy of solution of potassium chloride.

You should assume that only the 50.0 g of water changes in temperature and that the specific heat capacity of water is 4.18 J K^{-1} g^{-1}.
Give your answer to the appropriate number of significant figures.

Enthalpy of solution = ... kJ mol^{-1}

(4)

(c) The enthalpy of solution of calcium chloride is −82.9 kJ mol^{-1}.
The enthalpies of hydration for calcium ions and chloride ions are −1650 and −364 kJ mol^{-1}, respectively.

Use these values to calculate a value for the lattice enthalpy of dissociation of calcium chloride.

Lattice enthalpy of dissociation = ... kJ mol^{-1}

(2)

(d) Explain why your answer to part **(c)** is different from the lattice enthalpy of dissociation for magnesium chloride.

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(2)
(Total 12 marks)

8 (a) Propanone can be formed when glucose comes into contact with bacteria in the absence of air.

(i) Balance the following equation for this reaction of glucose to form propanone, carbon dioxide and water.

.....$C_6H_{12}O_6$ ⟶ .....CH_3COCH_3 + ...CO_2 + ...H_2O

(1)

(ii) Deduce the role of the bacteria in this reaction.

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(1)

(b) Propanone is also formed by the oxidation of propan−2−ol.

(i) Write an equation for this reaction using [O] to represent the oxidising agent.

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(1)

(ii) State the class of alcohols to which propan−2−ol belongs.

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(1)

(c) A student determined a value for the enthalpy change when a sample of propanone was burned. The heat produced was used to warm some water in a copper calorimeter. The student found that the temperature of 150 g of water increased by 8.0 °C when 4.50×10^{-3} mol of pure propanone was burned in air.

Use the student's results to calculate a value, in kJ mol^{-1}, for the enthalpy change when one mole of propanone is burned.
(The specific heat capacity of water is 4.18 J K^{-1} g^{-1})

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(3)

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

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(3)

(e) Use the mean bond enthalpy data in the table and the equation given below the table to calculate a value for the standard enthalpy change when gaseous propanone is burned.

	C−H	**C−C**	**C−O**	**O−H**	**C=O**	**O=O**
Mean bond enthalpy / kJ mol^{-1}	412	348	360	463	805	496

$$CH_3COCH_3(g) + 4O_2(g) \longrightarrow 3CO_2(g) + 3H_2O(g)$$

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(3)

(f) Suggest **two** reasons why the value obtained by the student in part (c) is different from the value calculated in part (e).

Reason 1 .....

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Reason 2 .....

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(2)

(Total 15 marks)

9 Vanadium is an important metal. Ferrovanadium, an alloy of iron and vanadium, is used to make a strong type of vanadium-steel. Pure vanadium is used in nuclear reactors.

(a) The table shows some standard enthalpy of formation data.

	V_2O_5(s)	**CaO(s)**
ΔH_f^θ / kJ mol^{-1}	−1560	−635

In the oldest method of extraction of vanadium, V_2O_5 is reacted with calcium at a high temperature.

$$5Ca(s) + V_2O_5(s) \longrightarrow 2V(s) + 5CaO(s)$$

Use data from the table and the equation to calculate the standard enthalpy change for this reaction.

State the type of reaction that V_2O_5 has undergone.

Suggest **one** major reason why this method of extracting vanadium is expensive, other than the cost of heating the reaction mixture.

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(5)

(b) Ferrovanadium is produced by the reaction of aluminium with a mixture of V_2O_5 and iron(III) oxide.

Write an equation for the reaction of aluminium with iron(III) oxide.

State the change in oxidation state of aluminium in this reaction.

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(2)

(c) Pure vanadium, for nuclear reactors, is formed by the reaction of hydrogen with purified VCl_2

Write an equation for this reaction in which the only other product is HCl gas.

Identify **two** hazards in this process, other than the fact that it operates at a high temperature.

Deduce why this process produces **pure** vanadium, other than the fact that purified VCl_2 is used.

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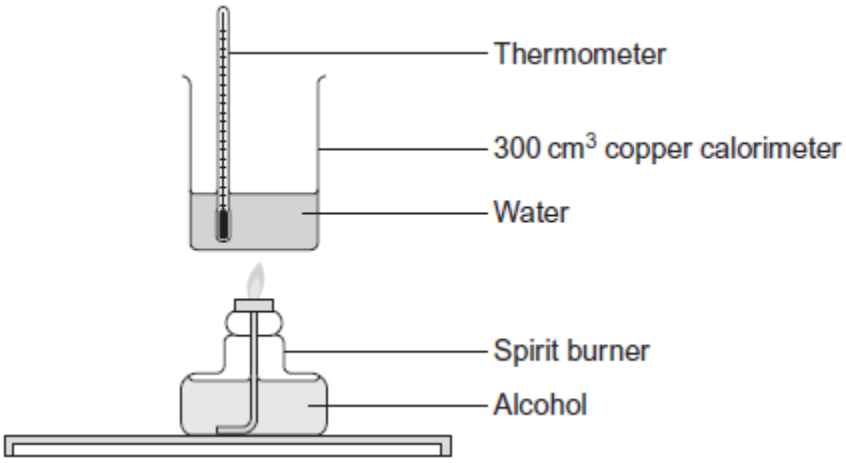
(4)
(Total 11 marks)

10 A value for the enthalpy of combustion of an alcohol can be determined using the apparatus shown in the diagram. The calorimeter is held in position by a clamp.



This experiment can be repeated by using a different volume of water that would result in a more accurate value for the enthalpy of combustion because there would be a reduction in the heat lost.

State a change in the volume of water that would cause a reduction in heat loss and explain your answer.

Change in volume: .....

Explanation: .....

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(Total 2 marks)

11 The table contains some bond enthalpy data.

Bond	H−H	O=O	H−O
Bond enthalpy / kJ mol^{-1}	436	496	464

(a) The value for the H−O bond enthalpy in the table is a mean bond enthalpy.

State the meaning of the term **mean bond enthalpy** for the H−O bond.

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(2)

(b) Use the bond enthalpies in the table to calculate a value for the enthalpy of formation of water in the gas phase.

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(3)

(c) The standard enthalpy of combustion of hydrogen, forming water in the gas phase, is almost the same as the correct answer to part (b).

(i) Suggest **one** reason why you would expect the standard enthalpy of combustion of hydrogen to be the same as the answer to part (b).

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(1)

(ii) Suggest **one** reason why you would expect the standard enthalpy of combustion of hydrogen to differ slightly from the answer to part (b).

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(1)
(Total 7 marks)

12 Antimony is a solid element that is used in industry. The method used for the extraction of antimony depends on the grade of the ore.

(a) Antimony can be extracted by reacting scrap iron with low-grade ores that contain antimony sulfide (Sb_2S_3).

(i) Write an equation for the reaction of iron with antimony sulfide to form antimony and iron(II) sulfide.

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(1)

(ii) Write a half-equation to show what happens to the iron atoms in this reaction.

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(1)

(b) In the first stage of the extraction of antimony from a high-grade ore, antimony sulfide is roasted in air to convert it into antimony(III) oxide (Sb_2O_3) and sulfur dioxide.

(i) Write an equation for this reaction.

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(1)

(ii) Identify **one** substance that is manufactured directly from the sulfur dioxide formed in this reaction.

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(1)

(c) In the second stage of the extraction of antimony from a high-grade ore, antimony(III) oxide is reacted with carbon monoxide at high temperature.

(i) Use the standard enthalpies of formation in the table and the equation given below the table to calculate a value for the standard enthalpy change for this reaction.

	Sb_2O_3(s)	**CO(g)**	**Sb(l)**	**CO_2(g)**
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	-705	-111	+20	-394

$$Sb_2O_3(s) + 3CO(g) \longrightarrow 2Sb(l) + 3CO_2(g)$$

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(3)

(ii) Suggest why the value for the standard enthalpy of formation of liquid antimony, given in the table above, is **not** zero.

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(1)

(iii) State the type of reaction that antimony(III) oxide has undergone in this reaction.

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(1)

(d) Deduce **one** reason why the method of extraction of antimony from a low-grade ore, described in part (a), is a low-cost process. Do **not** include the cost of the ore.

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(1)

(Total 10 marks)