Enthalpy 2

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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(3)

(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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(1)

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

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(1)

(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. A 50.0 cm^3 sample of a 0.200 mol dm^{-3} solution of silver nitrate was placed in a polystyrene beaker. An excess of powdered zinc was added to this solution and the mixture stirred. Zinc nitrate, $Zn(NO_3)_2$, and silver were formed and a rise in temperature of 3.20 °C was recorded.

(a) Write an equation for the reaction between silver nitrate and zinc.

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(1)

(b) Calculate the number of moles of silver nitrate used in the experiment.

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(2)

(c) Calculate the heat energy evolved by the reaction in this experiment assuming that all the energy evolved is used to heat only the 50.0 g of water in the mixture.
(Specific heat capacity of water is 4.18 J g^{-1} K^{-1})

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(d) Calculate the heat energy change for the reaction per mole of zinc reacted.

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(2)

(e) Explain why the experimental value for the heat energy evolved in this experiment is less than the correct value.

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(1)

(Total 8 marks)

3. 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) 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)

(b) 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 5 marks)

4. (a) State what is meant by the term *mean bond enthalpy*.

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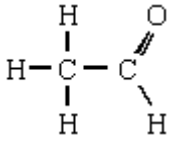
(b) Ethanal has the structure 

Gaseous ethanal burns as shown by the equation

$$CH_3CHO(g) + 2\frac{1}{2}O_2(g) \rightarrow 2H_2O(g) + 2CO_2(g)$$

Use the mean bond enthalpy data given below to answer the following questions.

Bond	Mean bond enthalpy/kJ mol^{-1}
C—H	+413
C—C	+347
C==O	+736
O==O	+498
O—H	+464

(i) Calculate the enthalpy change which occurs when all the bonds in the reactants shown in the above equation are broken.

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(ii) Calculate the enthalpy change which occurs when all the bonds in the products shown in the above equation are formed.

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(iii) Hence, calculate the enthalpy change for the complete combustion of ethanal as shown in the equation above.

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(5)
(Total 7 marks)

5. (a) Define the term *standard molar enthalpy of formation*, $\Delta H_f^{\ominus}$.

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(3)

(b) State Hess's law.

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(c) Propanone, CH_3COCH_3, burns in oxygen as shown by the equation

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

Use the data given below to calculate the standard enthalpy of combustion of propanone.

	$CO_2(g)$	$H_2O(l)$	$CH_3COCH_3(l)$
$\Delta H_f^{\ominus}$/kJ mol^{-1}	–394	–286	–248

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(3)
(Total 7 marks)

6. (a) What is the meaning of the term *enthalpy change*?

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(2)

(b) Write an equation, including state symbols, for the formation from its elements of solid sodium sulphate, Na_2SO_4.

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(2)

(c) Some standard enthalpy changes are difficult to measure directly but can be determined from standard enthalpies of combustion.
Maleic acid, $C_4H_4O_4$, reacts with oxygen to form carbon dioxide and water as shown by the following equation.

$$C_4H_4O_4(s) + 3O_2(g) \rightarrow 4CO_2(g) + 2H_2O(l)$$

Use the standard enthalpy of combustion data given below to calculate a value for the standard enthalpy change for the following reaction.

$$4C(s) + 2H_2(g) + 2O_2(g) \rightarrow C_4H_4O_4(s)$$

	$C_4H_4O_4(s)$	$C(s)$	$H_2(g)$
ΔH_c^θ / kJ mol^{-1}	–1356	–393.5	–285.8

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(3)
(Total 7 marks)

7. Ethanol is an important fuel.

(a) A student carried out a laboratory experiment to determine the enthalpy change when a sample of ethanol was burned. The heat produced was used to warm some water in a copper calorimeter. The student found that the temperature of 75.0 g of water increased by 5.50 °C when 2.40×10^{-3} mol of pure ethanol 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 ethanol is burned.
(The specific heat capacity of water is 4.18 J K^{-1} g^{-1})

Deduce **two** reasons why the student's value for the standard enthalpy of combustion of ethanol is different from a Data Book value of –1279 kJ mol^{-1}.

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(5)

(b) Mean bond enthalpies can be used to calculate enthalpies of reaction.

(ii) Consider the mean bond enthalpy data in the following table.

	C—H	**C—C**	**C—O**	**O=O**	**C=O**	**O—H**
Mean bond enthalpy / kJ mol^{-1}	412	348	360	to be calculated	805	463

Use the data in the table above and the equation shown to calculate a value for the bond enthalpy for the O=O double bond in an oxygen molecule.

$CH_3CH_2OH(g) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(g)$ $\Delta H = -1279$ kJ mol^{-1}

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(3)
(Total 8 marks)

8. (a) Anhydrous calcium chloride is not used as a commercial de-icer because it reacts with water. The reaction with water is exothermic and causes handling problems.

A student weighed out 1.00 g of anhydrous calcium chloride. Using a pipette, 25.0 cm^3 of water were measured out and transferred to a plastic cup. The cup was placed in a beaker to provide insulation. A thermometer was mounted in the cup using a clamp and stand. The bulb of the thermometer was fully immersed in the water.

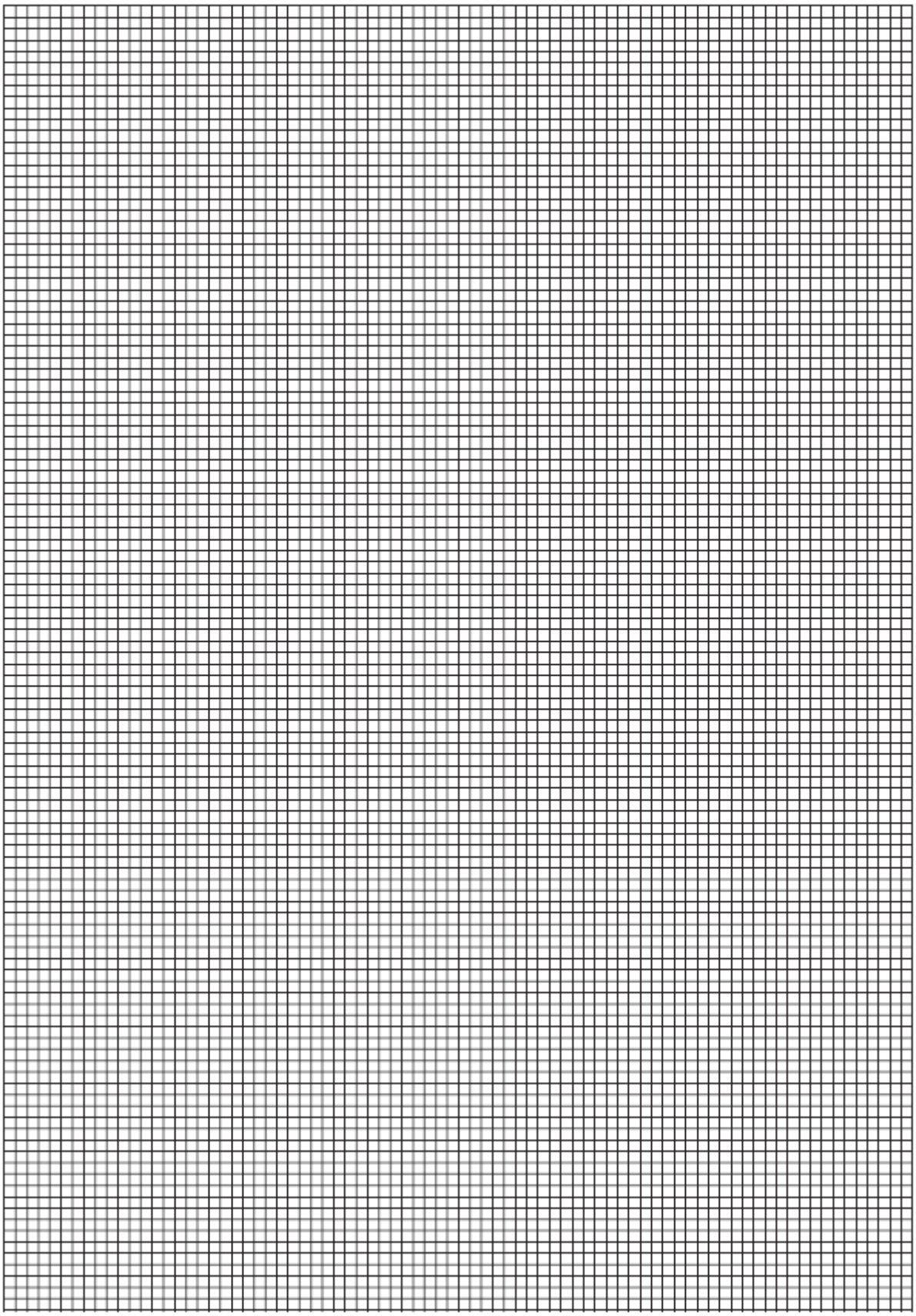
The student recorded the temperature of the water in the cup every minute, stirring the water before reading the temperature. At the fourth minute the anhydrous calcium chloride was added, but the temperature was not recorded. The mixture was stirred, then the temperature was recorded at the fifth minute. The student continued stirring and recording the temperature at minute intervals for seven more minutes.

The student's results are shown in the table below.

Time / minutes	0	1	2	3	4
Temperature / °C	19.6	19.5	19.5	19.5	

Time / minutes	4	5	6	7	8	9	10	11	12
Temperature / °C		24.6	25.0	25.2	24.7	24.6	23.9	23.4	23.0

Plot a graph of temperature (y-axis) against time on the grid below.
Draw a line of best fit for the points before the fourth minute.
Draw a second line of best fit for the appropriate points after the fourth minute.
Extrapolate both lines to the fourth minute.



(5)

(b) Use your graph to determine an accurate value for the temperature of the water at the fourth minute (**before** mixing).

Temperature before mixing .....

(1)

(c) Use your graph to determine an accurate value for the temperature of the reaction mixture at the fourth minute (**after** mixing).

Temperature after mixing .....

(1)

(d) Use your answers from parts (b) and (c) to determine an accurate value for the temperature rise at the fourth minute.
Give your answer to the appropriate precision.

Temperature rise .....

(1)

(e) Use your answer from part (d) to calculate the heat given out during this experiment. Assume that the water has a density of 1.00 g cm^{-3} and a specific heat capacity of 4.18 JK^{-1} g^{-1}. Assume that all of the heat given out is used to heat the water.
Show your working.

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(2)

(f) Calculate the amount, in moles, of $CaCl_2$ in 1.00 g of anhydrous calcium chloride (M_r = 111.0).

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(1)

(g) Use your answers from parts (e) and (f) to calculate a value for the enthalpy change, in kJ mol^{-1}, for the reaction that occurs when anhydrous calcium chloride dissolves in water.

$$CaCl_2(s) + aq \longrightarrow CaCl_2(aq)$$

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(h) Explain why it is important that the reaction mixture is stirred before recording each temperature.

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(1)

(i) Anhydrous calcium chloride can be prepared by passing chlorine over heated calcium. To prevent unreacted chlorine escaping into the atmosphere, a student suggested the diagram of the apparatus for this experiment shown below.

(i) Suggest **one** reason why the student wished to prevent unreacted chlorine escaping into the atmosphere.

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(1)

(ii) Suggest **one** hazard of using the apparatus as suggested by the student for this experiment.

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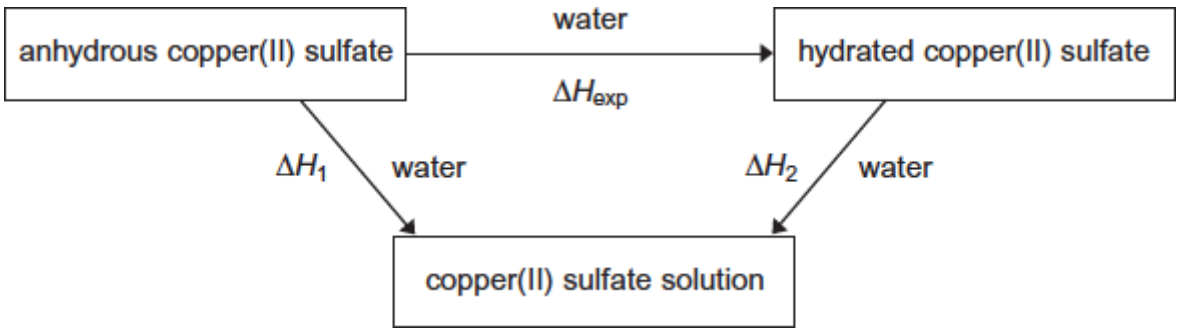
(Total 16 marks)

9. 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) 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)

(b) 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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(1)

(c) 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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(3)

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

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(1)
(Total 7 marks)

10. Using the data below, which is the correct value for the standard enthalpy of formation for $TiCl_4(l)$?

$C(s) + TiO_2(s) + 2Cl_2(g) \rightarrow TiCl_4(l) + CO_2(g)$ $\quad \Delta H^{\ominus} = -232$ kJ mol^{-1}

$Ti(s) + O_2(g) \rightarrow TiO_2(s)$ $\quad \Delta H_f^{\ominus} = -912$ kJ mol^{-1}

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\quad \Delta H_f^{\ominus} = -394$ kJ mol^{-1}

A −1538 kJ mol^{-1}

B −1094 kJ mol^{-1}

C −750 kJ mol^{-1}

D +286 kJ mol^{-1}

(Total 1 mark)

11. Use the information below to answer this question.

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\quad \Delta H^{\ominus} = -394$ kJ mol^{-1}

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ $\quad \Delta H^{\ominus} = -286$ kJ mol^{-1}

$4C(s) + 5H_2(g) \rightarrow C_4H_{10}(g)$ $\quad \Delta H^{\ominus} = -126$ kJ mol^{-1}

The standard enthalpy of combustion of butane, in kJ mol^{-1}, is

A −2880

B −2590

C −806

D −554

(Total 1 mark)

12. When 0.10 g of propane was burned the quantity of heat evolved was 5.0 kJ. The enthalpy of combustion of propane in kJ mol^{-1} is

A −800

B −1500

C −2200

D −2900

(Total 1 mark)

13. In which one of the following reactions is the standard enthalpy change equal to the standard enthalpy of formation of lithium fluoride?

A $Li(g) + F(g) \rightarrow LiF(s)$

B $Li^+(g) + F^-(g) \rightarrow LiF(s)$

C $Li^+(aq) + F^-(g) \rightarrow LiF(s)$

D $Li(s) + \frac{1}{2}F_2(g) \rightarrow LiF(s)$

(Total 1 mark)