1. A vessel and its contents of total heat capacity 120 J K^{-1} were heated using a methane burner. Calculate the maximum theoretical temperature rise when 0.10 g of methane was completely burned. The standard enthalpy of combustion of methane is –890 kJ mol^{-1}.

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(4)

(Total 4 marks)

2. When cyclohexanol, $C_6H_{11}OH$, is completely burned in oxygen, the products are carbon dioxide and water.

Write an equation to represent the reaction that occurs during the measurement of the enthalpy change of combustion of cyclohexanol.

(Total 1 mark)

3. The table below includes some values of standard enthalpies of formation ($\Delta H_f^{\ominus}$).

Substance	$H_2O(l)$	LiOH(s)	Li(s)
$\Delta H_f^{\ominus}$ /kJ mol^{-1}	–286	–487	0

The standard enthalpy of solution of lithium hydroxide is given below.

$LiOH(s) \rightarrow Li^+(aq) + OH^-(aq)$ $\quad \Delta H^{\ominus} = 21$ kJ mol^{-1}

(a) State why the standard enthalpy of formation of lithium is quoted as zero.

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(1)

(b) Write an equation for the chemical reaction which represents the formation of lithium hydroxide from its elements, in which the enthalpy change is equal to its standard enthalpy of formation.

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(2)

(c) Write an equation, including state symbols, for the reaction of lithium with water in which lithium ions are formed.

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(2)

(d) Use the data given above to calculate a value for the enthalpy change for the reaction of lithium with water.

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(3)

(Total 8 marks)

4. (a) Explain the meaning of the terms *mean bond enthalpy* and *standard enthalpy of formation*.

Mean bond enthalpy .....

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Standard enthalpy of formation .....

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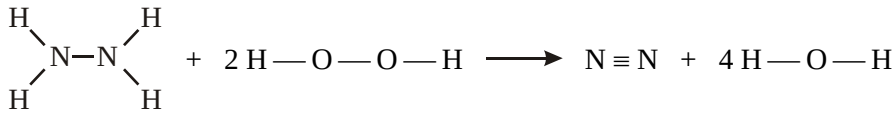
(5)

(b) Some mean bond enthalpies are given below.

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

Use these data to calculate the enthalpy change for the following gas-phase reaction between hydrazine, N_2H_4, and hydrogen peroxide, H_2O_2



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(3)

(c) Some standard enthalpies of formation are given below.

	$N_2H_4(g)$	$H_2O_2(g)$	$H_2O(g)$
$\Delta H_f^{\ominus}$ /kJ mol^{-1}	+75	–133	–242

These data can be used to calculate the enthalpy change for the reaction in part (b).

$$N_2H_4(g) + 2H_2O_2(g) \rightarrow N_2(g) + 4H_2O(g)$$

(i) State the value of $\Delta H_f^{\ominus}$ for $N_2(g)$.

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(ii) Use the $\Delta H_f^{\ominus}$ values from the table to calculate the enthalpy change for this reaction.

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(4)

(d) Explain why the value obtained in part (b) is different from that obtained in part (c)(ii).

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(1)

(Total 13 marks)

5. Methanol, CH_3OH, is a convenient liquid fuel.

(a) An experiment was conducted to determine the enthalpy of combustion of liquid methanol. The energy obtained from burning 2.12 g of methanol was used to heat 150 g of water. The temperature of the water rose from 298 K to 362 K. (The specific heat capacity of water is 4.18 J K^{-1} g^{-1})

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

(ii) Use the data above to calculate a value for the enthalpy of combustion of one mole of liquid methanol.

(7)

(b) Methanol can be synthesised from methane and steam by a process that occurs in two stages.

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

Stage 2 $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H^{\ominus} = -91 \text{ kJ mol}^{-1}$

The standard enthalpies of combustion of carbon monoxide and of hydrogen are -283 kJ mol^{-1} and -286 kJ mol^{-1}, respectively. Use these data and the enthalpy change for *Stage 2* to calculate a value for the standard enthalpy of combustion of gaseous methanol.

(3)

(Total 10 marks)

6. (a) Define the term *standard enthalpy of formation*.

(3)

(b) State Hess's Law and use it, together with the data given in the table below, to calculate the standard enthalpy change for the following reaction.

$$MgO(s) + 2HCl(g) \rightarrow MgCl_2(s) + H_2O(l)$$

	MgO	HCl(g)	$MgCl_2$	H_2O
$\Delta H_f^{\ominus}$/kJ mol^{-1}	–602	–92	–642	–286

(4)

(c) In an experiment, an excess of solid magnesium oxide was added to 50 cm^3 of 3.0 mol dm^{-3} hydrochloric acid. The initial temperature of the solution was 21 °C. After reaction, the temperature had risen to 53 °C. (The specific heat capacity of water is 4.2 J K^{-1} g^{-1})

Use this information to calculate the enthalpy change for the reaction of one mole of magnesium oxide with hydrochloric acid. For your calculation you should assume that all the heat from the reaction is used to raise the temperature of 50 g of water.

(8)

(Total 15 marks)

7. The table below contains some mean bond enthalpy data.

Bond	H—H	C—C	C=C	N≡N	N—H
Mean bond enthalpy / kJ mol^{-1}	436	348	612	944	388

(a) Explain the term *mean bond enthalpy*.

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(2)

(b) (i) Write an equation for the formation of one mole of ammonia, NH_3, from its elements.

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(ii) Use data from the table above to calculate a value for the enthalpy of formation of ammonia.

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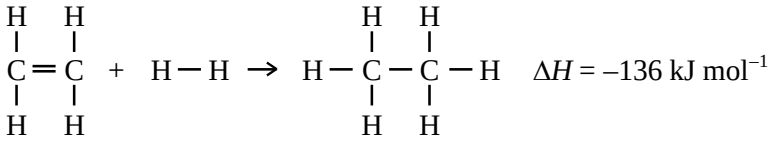
(4)

(c) Use the following equation and data from the table above to calculate a value for the C–H bond enthalpy in ethane.



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(3)

(Total 9 marks)

8. (a) Write an equation for the complete combustion of propanone, C_3H_6O, to form carbon dioxide and water.

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(1)

(b) In a laboratory experiment, 1.45 g of propanone were burned completely in oxygen. The heat from this combustion was used to raise the temperature of 100 g of water from 293.1 K to 351.2 K.

(i) Calculate the number of moles of propanone in the 1.45 g.

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(ii) Calculate the heat energy required to raise the temperature of 100 g of water from 293.1 K to 351.2 K.
(The specific heat capacity of water is 4.18 J K^{-1} g^{-1})

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(iii) Hence, calculate a value, in kJ mol^{-1}, for the enthalpy of combustion of propanone.

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(5)

(c) In a similar experiment, the enthalpy of combustion of butanone, C_4H_8O, was found to be –1290 kJ mol^{-1}. A data book value for the same reaction is $\Delta H_c^{\ominus}$ = –2430 kJ mol^{-1}.

(i) Suggest one reason why the experimental value is very different from the data book value.

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(ii) This data book value of $\Delta H_c^{\ominus}$ for butanone (–2430 kJ mol^{-1}) refers to the formation of carbon dioxide gas and water in the gaseous state. How would this value differ if it referred to the formation of water in the liquid state? Explain your answer.

Difference .....

Explanation .....

.....

(3)

(d) Calculate a value for the standard enthalpy of formation for liquid ethanethiol, C_2H_5SH. Use the equation given below and enthalpy of combustion data from the following table.

Substance	$C_2H_5SH(l)$	C(s)	$H_2(g)$	S(s)
$\Delta H_c^{\ominus}$ / kJ mol^{-1}	–1170	–394	–286	–297

$$2C(s) + 3H_2(g) + S(s) \rightarrow C_2H_5SH(l)$$

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(3)

(Total 12 marks)

9. (a) Define the term *standard enthalpy of formation.*

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(3)

(b) Write an equation, including state symbols, for a reaction for which the enthalpy change is the standard enthalpy of formation of liquid CH_3NO_2

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(2)

(c) Give the name of the principle or law which enables enthalpies of formation to be calculated from enthalpies of combustion.

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(1)

(d) In the presence of a catalyst, gaseous hydrogen cyanide, HCN, burns in an excess of oxygen as shown by the equation below.

$$HCN(g) + 2\tfrac{1}{4}\,O_2(g) \rightarrow \tfrac{1}{2}\,H_2O(g) + CO_2(g) + NO_2(g)$$

Some standard enthalpies of combustion, $\Delta H_c^{\ominus}$ are given in the table below.

Substance	HCN(g)	$H_2(g)$	C(s)	$N_2(g)$
$\Delta H_c^{\ominus}$/kJ mol^{-1}	–611	–242	–394	+68

Use these data to calculate a value for the standard enthalpy of formation for gaseous hydrogen cyanide.

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(4)

(Total 10 marks)

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

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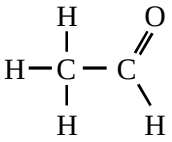
(2)

(b) Ethanal has the structure 

Gaseous ethanal burns as shown by the equation

$$CH_3CHO(g) + 2½O_2(g) \rightarrow 2H_2O(g) + 2CO_2(g)$$

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)

11. (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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(1)

(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)

12. Nitrogen, hydrogen and oxygen undergo the reactions shown below.

Reaction 1 $\frac{1}{2}N_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons NO(g)$ $\Delta H_f^{\ominus} = +91$ kJ mol^{-1}

Reaction 2 $\frac{1}{2}N_2(g) + 1\frac{1}{2}H_2(g) \rightleftharpoons NH_3(g)$ $\Delta H_f^{\ominus} = -46$ kJ mol^{-1}

Reaction 3 $H_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons H_2O(g)$ $\Delta H_f^{\ominus} = -242$ kj mol^{-1}

Use this information in answering the questions that follow.

(a) What name is given to the symbol $\Delta H_f^{\ominus}$? Explain fully what it means.

Name. .....

Explanation. .....

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(4)

(b) (i) Write an equation for the reaction of nitrogen monoxide, NO, with hydrogen to form ammonia and steam.

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(ii) Calculate the value of $\Delta H^{\ominus}$ for this reaction, using the data given at the beginning of Question 3.

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(4)
(Total 8 marks)

13. A student added 50.0 cm^3 of hydrochloric acid to 50.0 cm^3 of sodium hydroxide solution in a polystyrene cup. The temperature rose by 6.5 °C. The initial concentration of each solution was 1.00 mol dm^{-3}.

(a) Write an ionic equation for the reaction occurring.

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(1)

(b) Calculate the number of moles of acid used in the reaction.

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(1)

(c) Calculate the heat energy evolved in the reaction. (Assume that the final solution has a specific heat capacity of 4.18 J g^{-1} K^{-1} and a density of 1.00 g cm^3.)

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(2)

(d) Calculate the molar enthalpy change for the reaction.

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(2)

(Total 6 marks)

14. (a) Define the term *standard enthalpy of combustion*.

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(3)

(b) Using the data given below, calculate the standard enthalpy change for the following reaction.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

$\Delta H_f^{\ominus}$ $CO_2(g)$ = –394 kJ mol^{-1}

$\Delta H_f^{\ominus}$ $H_2O(l)$ = –286 kJ mol^{-1}

$\Delta H_f^{\ominus}$ $CH_4(g)$ = –75 kJ mol^{-1}

(3)

(c) (i) State what is meant by the term *mean bond enthalpy*.

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(ii) Using the standard enthalpy of formation of methane given in part (b) and the data given below, calculate the mean bond enthalpy of the **C-H** bond in methane.

$C(s) \rightarrow C(g)$ $\quad \Delta H^{\ominus} = +715 \text{ kJ mol}^{-1}$

$H_2(g) \rightarrow 2H(g)$ $\quad \Delta H^{\ominus} = +436 \text{ kJ mol}^{-1}$

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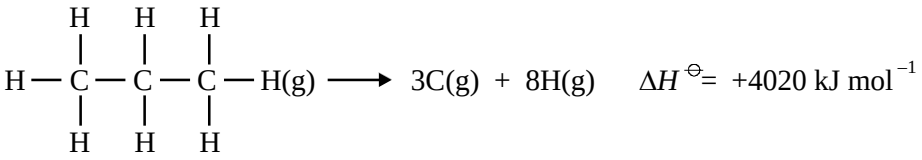
(iii) Using the C–H bond enthalpy calculated in part (c)(ii) and the standard enthalpy change for the reaction given below, calculate the mean bond enthalpy of the C–C bond in propane.

N.B. If you failed to complete part (c)(ii), you may assume that the mean bond enthalpy of the C–H bond is +390 kJ mol^{-1}. (This is not the correct value.)



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(7)

(Total 13 marks)

15. (a) Define the term *standard enthalpy of combustion*, $\Delta H_c^{\ominus}$.

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(3)

(b) Methanethiol, CH_3SH, is added to natural gas in order to give it a smell. When methanethiol burns in air it forms carbon dioxide, water and sulphur dioxide. Write a balanced equation for this combustion reaction.

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(1)

(c) A value for the enthalpy of formation of methanethiol can be determined using Hess's Law and enthalpies of combustion. In this calculation, which three enthalpy values would be needed in addition to the enthalpy of combustion of methanethiol?

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(2)

(d) Carbon disulphide, CS_2, burns in air as follows:

$$CS_2(l) + 3O_2(g) \rightarrow CO_2(g) + 2SO_2(g)$$

Some standard enthalpies of formation, $\Delta H_f^{\ominus}$ are given in the table below.

Substance	$CS_2(l)$	$CO_2(g)$	$SO_2(g)$
$\Delta H_f^{\ominus}$ /kJ mol^{-1}	+88	–394	–297

Use these data to calculate a value for the enthalpy of combustion of liquid carbon disulphide.

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(3)

(Total 9 marks)

16. The tables below contain values of standard enthalpy of combustion, $\Delta H_c^{\ominus}$ and standard enthalpy of formation, $\Delta H_f^{\ominus}$.

	C(graphite)	S(s)
ΔH_c^t /kJ mol^{-1}	–394	–297

	CS_2(l)	NO(g)	CO(g)	SO_2(g)
ΔH_f^t /kJ mol^{-1}	88	90	–111	–297

(a) State Hess's Law.

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(2)

(b) Explain the meaning of the term *standard enthalpy of combustion* of a compound.

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(3)

(c) (i) Write equations, with state symbols, for the formation of liquid carbon disulphide (CS_2) from its elements and for the combustion of carbon disulphide to form carbon dioxide and sulphur dioxide.

Equation for formation of CS_2

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Equation for combustion of CS_2

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(ii) Calculate the enthalpy of combustion of carbon disulphide, using its enthalpy of formation and the enthalpies of combustion from the tables on above.

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(5)

(d) Carbon disulphide reacts explosively with nitrogen monoxide (NO) according to the following equation.

$$CS_2(l) + 5NO(g) \rightarrow CO(g) + 2SO_2(g) + \tfrac{5}{2} N_2(g)$$

Use the enthalpies of formation given in the table to calculate the enthalpy change in this reaction.

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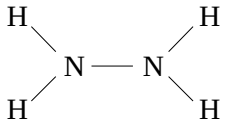
(3)

(Total 13 marks)

17. The structure of hydrazine can be represented as shown below.



(a) (i) Write an equation for the formation of hydrazine from its elements.

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(ii) Steam and nitrogen gas are the combustion products of gaseous hydrazine. Write an equation for this reaction.

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(iii) Use the data given below to calculate the standard enthalpy of formation of gaseous hydrazine.

$\Delta H_c^{\ominus}$ $N_2H_4(g)$ = –568 kJ mol^{-1}

$\Delta H_f^{\ominus}$ $H_2O(g)$ = –242 kJ mol^{-1}

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(4)

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

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(2)

(c) Use the enthalpy of formation of hydrazine calculated in part (a) and the mean bond enthalpies given below to calculate the enthalpy of the bond between the two nitrogen atoms in hydrazine.

NB If you failed to complete part (a) you may assume that $\Delta H_f^{\ominus}$ $N_2H_4(g)$ = +50 kJ mol^{-1} (not the correct value).

Bond	N–H	N≡N	H–H
Mean bond enthalpy/kJ mol^{-1}	389	945	436

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(3)

(d) The measured N-N bond enthalpy in hydrazine is 158 kJ mol^{-1}. Explain why the bond enthalpy when calculated correctly in part (c) does not agree with the measured value.

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(1)
(Total 10 marks)

18. The table below gives some *standard enthalpies of formation*, $\Delta H_f^{\ominus}$.

Substance	$C_2H_6(g)$	$F_2(g)$	$CF_4(g)$	HF(g)
$\Delta H_f^{\ominus}$ /kJ mol^{-1}	–85	0	–680	–269

(a) Define the term *standard enthalpy of formation*.

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(3)

(b) Why is the value for the standard enthalpy of formation for fluorine equal to zero?

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(1)

(c) Calculate the standard enthalpy change for the following reaction.

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

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(3)

(d) The table below shows some bond enthalpies.

Bond	C–C	C–H	F–F
Bond enthalpy /kJ mol–1	348	412	158

(i) Why are the values for C–C and C—H described as **mean** bond enthalpies?

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(ii) Suggest the most likely first step in the reaction shown in part (c) and give a reason for your answer.

First step in the reaction .....

Reason .....

(4)

(Total 11 marks)

19. (a) Define the terms *standard enthalpy of formation* and *standard enthalpy of combustion*.

Standard enthalpy of formation.....

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Standard enthalpy of combustion.....

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(6)

(b) Use the standard enthalpies of formation, $\Delta H_f^{\ominus}$, given below

Compound	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$CO_2(g)$	–394
$C_3H_7OH(l)$	–304
$H_2O(l)$	–286

to calculate the standard enthalpy of combustion of an alcohol C_3H_7OH, as shown by the equation:

$$C_3H_7OH(l) + 4½O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$$

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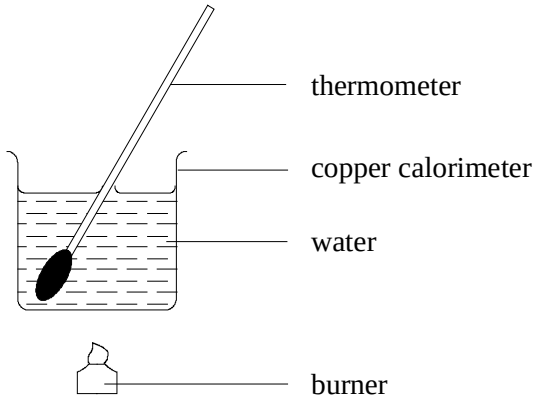
(3)

(c) A value for the enthalpy of combustion of the alcohol C_3H_7OH was determined in the laboratory using the apparatus shown below. The following results were obtained.



Mass of water in the calorimeter	= 200 g
Initial temperature of water	= 15 ºC
Final temperature	= 30 ºC
Mass of alcohol burned	= 0.90 g

(i) Calculate the heat energy required to raise the temperature of the water from 15 °C to 30 °C. The specific heat capacity of water is 4.2 J g^{-1} K^{-1}.

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(ii) Calculate the number of moles of the alcohol, C_3H_7OH, burned.

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(iii) Hence, calculate a value for the enthalpy of combustion of 1.0 mol of the alcohol.

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(iv) Give **two** reasons why you would expect your answer to part (c)(iii) to differ from that in part (b).

Reason 1 .....

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Reason 2 .....

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(8)

(Total 17 marks)

20. An equation for the combustion of cyclopropane, C_3H_6, is shown below.

$$C_3H_6(g) + 4\tfrac{1}{2}\,O_2(g) \rightarrow 3CO_2(g) + 3H_2O(g)$$

The standard enthalpy of combustion of cyclopropane can be calculated either from standard enthalpies of formation or by using mean bond enthalpies.

(a) Use the standard enthalpies of formation given below to calculate the standard enthalpy of combustion of cyclopropane.

$\Delta H_f^{\ominus}$ $C_3H_6(g)$ = +53 kJ mol^{-1}

$\Delta H_f^{\ominus}$ $CO_2(g)$ = –393 kJ mol^{-1}

$\Delta H_f^{\ominus}$ $H_2O(g)$ = –242 kJ mol^{-1}

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(3)

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

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(2)

(c) The following mean bond enthalpies have been obtained from a data book. Use these values to calculate the standard enthalpy of combustion of cyclopropane.

C–C	347 kJ mol^{-1}
C–H	413 kJ mol^{-1}
C=O	805 kJ mol^{-1}
O=O	498 kJ mol^{-1}
O–H	464 kJ mol^{-1}

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(3)

(d) Explain, by reference to the structure of cyclopropane, why the enthalpy of combustion calculated in part (a) is more exothermic than that calculated in part (c).

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(2)

(Total 10 marks)