F322: Chains, Energy and Resources
2.3.1 Enthalpy Changes

1. Some reactions of H_2O_2 are exothermic.

Use ideas about the enthalpy changes that take place during bond breaking and bond making to explain why some reactions are exothermic.

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[Total 2 marks]

2. Glucose, $C_6H_{12}O_6$, can be completely combusted to give carbon dioxide and water.

$$C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$$

In the body, the conversion of glucose into carbon dioxide and water takes place in a number of stages catalysed by enzymes.

What name is given to this oxidation process in the body?

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[Total 1 mark]

3. A student carries out an experiment to determine the enthalpy change of combustion of glucose.

In the experiment, 0.831 g of glucose is burned. The energy released is used to heat 100 cm^3 of water from 23.7 °C to 41.0 °C.

(i) Calculate the energy released, in kJ, during combustion of 0.831 g glucose.

The specific heat capacity of water = 4.18 J g^{-1} K^{-1}.
Density of water = 1.00 g cm^{-3}.

energy = ... kJ

[2]

(ii) Calculate the amount, in moles, of glucose that is burned.

amount = ... mol

[2]

(iii) Calculate the enthalpy change of combustion of glucose.
Give your answer to **three** significant figures.

ΔH_C = ... kJ mol^{-1}

[2]

[Total 6 marks]

4. The standard enthalpy change of combustion of glucose can also be determined indirectly.

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

substance	$H_f^{\ominus}$ **/ kJ** mol^{-1}
$C_6H_{12}O_6(s)$	–1250
$CO_2(g)$	–394
$H_2O(l)$	–286

$C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$

answer = ... kJ mol^{-1}

[Total 3 marks]

5. Suggest **two** reasons why standard enthalpy changes of combustion determined experimentally are less exothermic than the calculated theoretical values.

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[Total 2 marks]

6. Ethene and steam can be converted into ethanol.
The equilibrium is shown below.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \qquad \Delta H = -46 \text{ kJ mol}^{-1}$$

le Chatelier's principle can be used to predict the effect of changing conditions on the position of equilibrium.

(i) Name the catalyst used in this reaction.

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[1]

(ii) State le Chatelier's principle.

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[1]

(iii) Using le Chatelier's principle, predict and explain the conditions that would give the maximum equilibrium yield of ethanol from ethene and steam.

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[3]

(iv) The actual conditions used are 60 atmospheres pressure at 300 °C in the presence of a catalyst. Compare these conditions with your answer to (iii) and comment on why these conditions are used.

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[3]

[Total 8 marks]

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

Define the term *enthalpy change of combustion*.

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[Total 2 marks]

8. A student carried out an experiment to determine the enthalpy change of combustion of pentan-1-ol, $CH_3(CH_2)_4OH$.

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 J g^{-1} 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.

ΔH_c = ... kJ mol^{-1}

[3]

[Total 6 marks]

9. 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*?

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[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.

$$6C(\ldots\ldots) + 7H_2(\ldots\ldots) \rightarrow C_6H_{14}(\ldots\ldots)$$

[1]

(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	$\Delta H_c^{\ominus}$ / kJ mol^{-1}
C	–394
H_2	–286
C_6H_{14}	–4163

answer = ... kJ mol^{-1}

[3]

[Total 6 marks]

10. 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, $Cl^{\bullet}$, 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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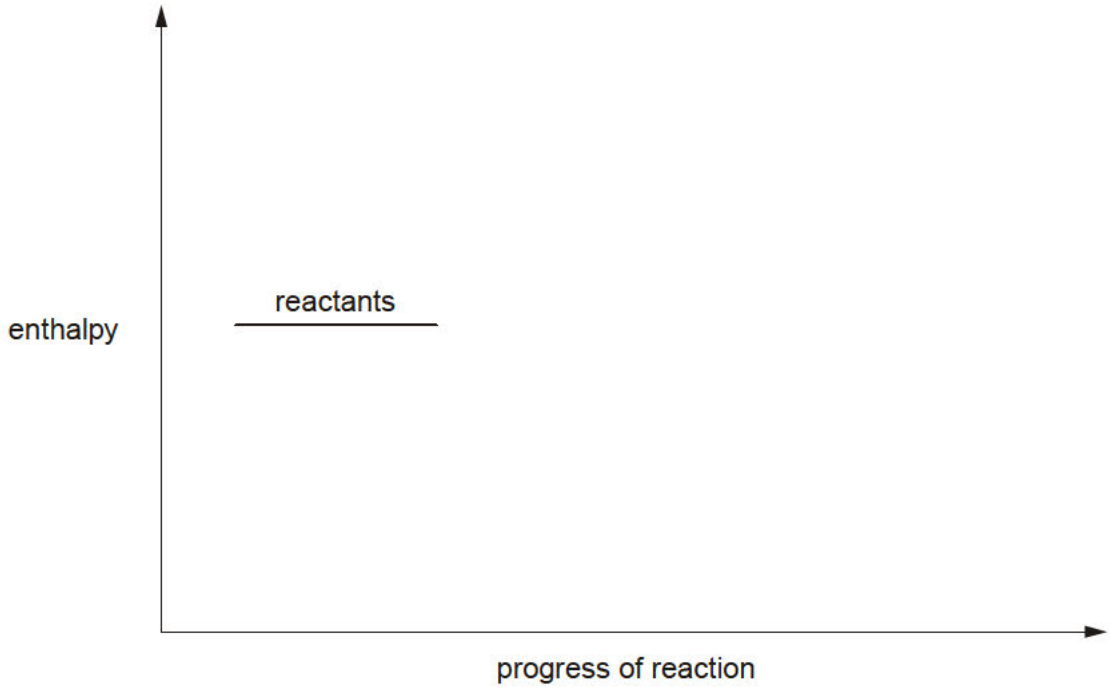
[3]

(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]

[Total 6 marks]

11. Enthalpy changes of reaction can be determined indirectly from average bond enthalpies and standard enthalpy changes.

The table below shows the values of some average bond enthalpies.

bond	average bond enthalpy /kJ mol^{-1}
C–H	+410
O–H	+465
O=O	+500
C=O	+805
C–O	+336

(i) Why do bond enthalpies have positive values?

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[1]

(ii) The equation below shows the combustion of methanol, CH_3OH, in the gaseous state.

$$CH_3OH(g) + 1½O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

Using the average bond enthalpies in the table above, calculate the enthalpy change of combustion, ΔH_c, of gaseous methanol.

ΔH_c = ... kJ mol^{-1}

[3]

[Total 4 marks]

12. (a) Methane reacts with steam to produce carbon monoxide and hydrogen. The equation for this process is given below.

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g)$$

The table below shows the standard enthalpy changes of formation for CH_4, H_2O and CO.

compound	**$\Delta H_f^{\ominus}$/kJ mol^{-1}**
CH_4	–75
H_2O	–242
CO	–110

(i) Define the term *enthalpy change of formation*.

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.....

.....

[2]

(ii) In $\Delta H_f^{\ominus}$, what are the conditions indicated by the symbol $^{\ominus}$?

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[1]

(iii) Write the equation, including state symbols, that represents the standard enthalpy change of formation for carbon monoxide, CO.

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[2]

(iv) Using the $\Delta H_f^{\ominus}$ values in the table above, calculate the enthalpy change for the reaction of methane with steam.

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g)$$

ΔH = ... kJ mol^{-1}

[3]

(b) State one important manufacturing process in which hydrogen is used.

.....

[1]

[Total 9 marks]

13. Propane, C_3H_8, is a gas at room temperature and pressure. It is used in blow torches to melt the bitumen needed to apply the felt to flat roofs.

Write the equation for the complete combustion of propane.

[Total 2 marks]

14. Define the term *standard enthalpy change of combustion.*

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[Total 3 marks]

15. Alkanes are important hydrocarbons since they are used as fuels in homes and in industry. It is important that the enthalpy changes involved in alkane reactions are known.

(i) Define the term *enthalpy change of formation of a compound*.

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[2]

(ii) Write the equation, including state symbols, that accompanies the enthalpy change of formation of hexane, $C_6H_{14}(l)$.

[2]

(iii) What conditions of temperature and pressure are used when measuring the **standard** enthalpy change of formation?

temperature .....

pressure .....

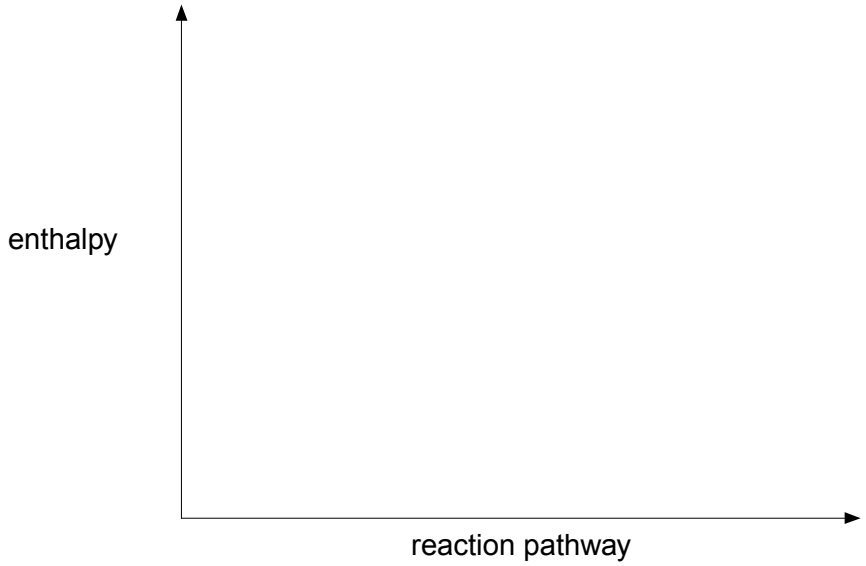
[1]

[Total 5 marks]

16. The standard enthalpy change of formation of hexane is –199 kJ mol^{-1}.

Using the axes below, show the enthalpy profile diagram for the formation of hexane.

On your diagram label the enthalpy change of reaction, ΔH, and the activation energy, E_a.



[Total 3 marks]

17. Enthalpy changes can be calculated using enthalpy changes of combustion. The table below shows some values for standard enthalpy changes of combustion.

substance	$\Delta H_c^{\ominus}$/ kJ mol^{-1}
C(s)	−394
$H_2(g)$	−286
$CH_4(g)$	−890

Use these values to calculate the standard enthalpy change of the reaction below.

$$C(s) + 2H_2(g) \rightarrow CH_4(g)$$

standard enthalpy change = ... kJ mol^{-1}

[Total 3 marks]

18. The equations for the combination of gaseous atoms of carbon and hydrogen to form methane, CH_4, and ethane, C_2H_6, are shown below.

$$C(g) + 4H(g) \rightarrow CH_4(g) \qquad \Delta H = -1652 \text{ kJ mol}^{-1}$$

$$2C(g) + 6H(g) \rightarrow C_2H_6(g) \qquad \Delta H = -2825 \text{ kJ mol}^{-1}$$

Use these data to calculate:

(i) the bond enthalpy of a C−H bond,

bond enthalpy = ... kJ mol^{-1}

[1]

(ii) the bond enthalpy of a C−C bond.

bond enthalpy = ... kJ mol^{-1}

[2]

[Total 3 marks]

19. Methane reacts with oxygen to produce carbon dioxide and water. The equation for this reaction is given below.

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

Gas cookers use methane as a fuel because this reaction is exothermic and takes place at a fairly fast rate.

Activation energy is important in considering the conditions needed to change the rate of a reaction.

(a) What is meant by the term *exothermic*?

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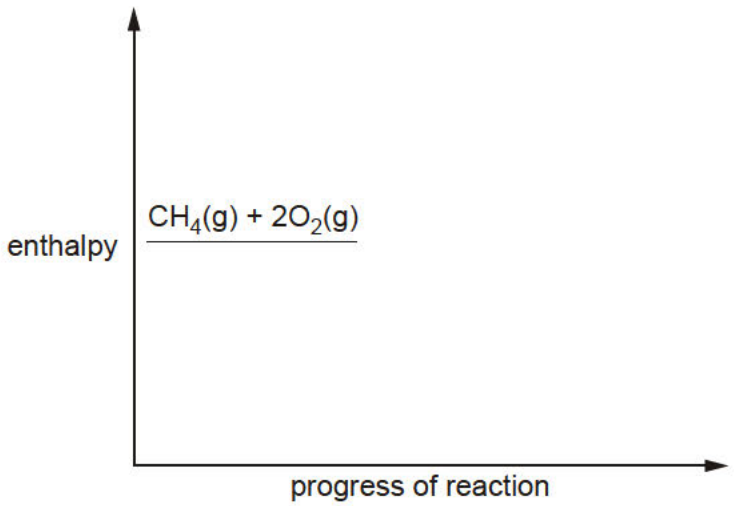
[1]

(b) The figure below is an incomplete enthalpy profile diagram for the reaction between methane and oxygen.



(i) Complete the figure to show the complete enthalpy profile for the reaction.

[2]

(ii) Label the activation energy, E_a, on the figure above.

[1]

[Total 4 marks]

20. Methane can be reacted with steam to produce carbon monoxide and hydrogen. The equation for this process is given below.

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g)$$

The table below shows the enthalpy changes of formation for methane, steam and carbon monoxide.

compound	ΔH_f / kJ mol^{-1}
CH_4	–75
H_2O	–242
CO	–110

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

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.....

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[2]

(b) Write the equation, including state symbols, representing the enthalpy change of formation for methane, CH_4.

.....

[2]

(c) Use the ΔH_f values in the table to calculate the enthalpy change for the reaction shown in the equation shown above.

..... kJ mol^{-1}

[3]

(d) State one important manufacturing process in which hydrogen is used.

.....

.....

[1]

[Total 8 marks]

21. Energy changes during reactions can be considered using several different enthalpy changes. These include average bond enthalpies and enthalpy changes of combustion.

Table below shows the values of some average bond enthalpies.

bond	average bond enthalpy / kJ mol^{-1}
C — H	+ 410
O — H	+ 465
O == O	+ 500
C == O	+ 805
C — O	+ 336

(i) Why do bond enthalpies have positive values?

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[1]

(ii) Define the term *bond enthalpy.*

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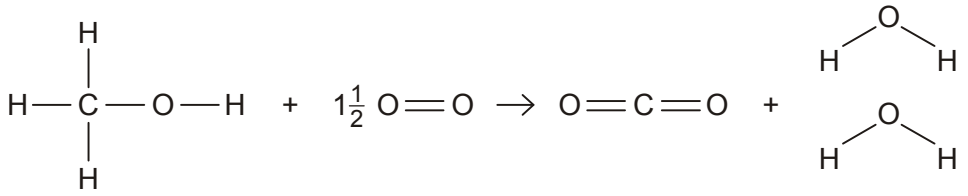
[2]

(iii) The equation below shows the combustion of methanol, CH_3OH, in the gaseous state.



Use the average bond enthalpies from the table above to calculate the enthalpy change of combustion of gaseous methanol, ΔH_c.

ΔH_c = ... kJ mol^{-1}

[3]

(iv) Suggest **two** reasons why the **standard** enthalpy change of combustion of methanol will be different from that calculated in part (iii).

reason 1 .....

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reason 2 .....

.....

[2]

[Total 8 marks]

22. The changes in energy during reactions are often considered using enthalpy changes of reaction. One such enthalpy change is the standard enthalpy change of formation.

(i) Define the term *standard enthalpy change of formation*.

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[3]

(ii) Write the equation for the reaction corresponding to the standard enthalpy change of formation of magnesium nitrate, $Mg(NO_3)_2$. Include state symbols.

[2]

(iii) When magnesium nitrate is heated, it decomposes to give magnesium oxide, nitrogen dioxide and oxygen.

Use the standard enthalpy changes of formation to find the enthalpy change of reaction for this decomposition.

substance	standard enthalpy change of formation / kJ mol^{-1}
$Mg(NO_3)_2$	–791
MgO	–602
NO_2	–33

The equation for this reaction is shown below.

$$Mg(NO_3)_2(s) \rightarrow MgO(s) + 2NO_2(g) + \frac{1}{2}O_2(g)$$

enthalpy change = ...kJ mol^{-1}

[3]

[Total 8 marks]

23. The combustion of butane is shown in the equation below.

$$C_4H_{10}(g) + 6\ \frac{1}{2}\ O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$$

(i) The standard enthalpy change of combustion of butane is –2877 kJ mol^{-1}. What does *standard* mean in this context?

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[1]

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

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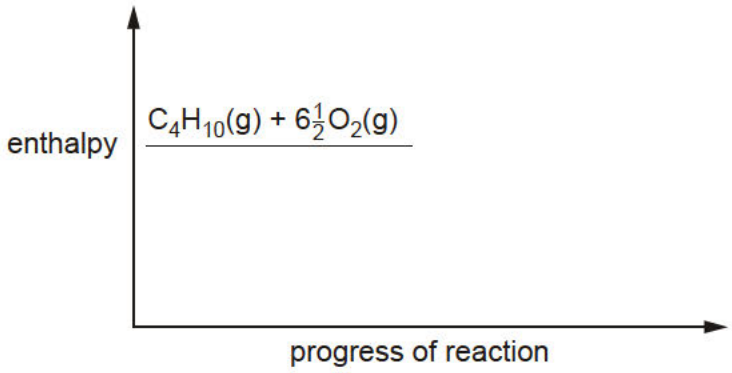
[2]

(iii) Complete the enthalpy profile diagram for the combustion of butane. Label the activation energy, E_a, and the enthalpy change, ΔH.



[3]

[Total 6 marks]

24. Enthalpy changes of combustion can be used to determine enthalpy changes of formation.

(i) Write the equation for the standard enthalpy change of formation of butane, C_4H_{10}. Include state symbols in your answer.

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[2]

(ii) Use the following data to calculate the standard enthalpy change of formation of butane.

	standard enthalpy change of combustion / kJ mol^{-1}
carbon	–394
hydrogen	–286
butane	–2877

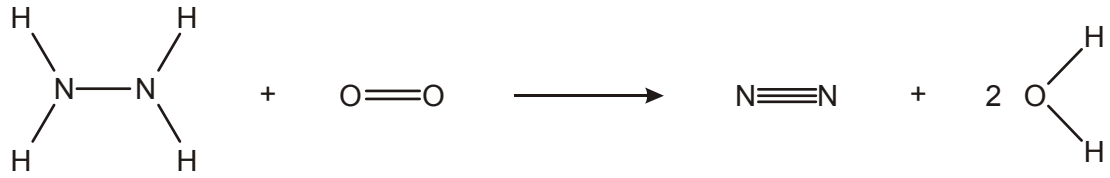
answer ..... kJ mol^{-1}

[3]

[Total 5 marks]

25. This question is about hydrazine, N_2H_4, and ammonia, NH_3. These are both compounds of nitrogen and hydrogen.

(a) Hydrazine can be oxidised and used as a rocket fuel. The equation for one possible reaction taking place is shown below.



Some average bond enthalpies are given below.

bond	bond enthalpy / kJ mol^{-1}
N–N	+163
N≡N	+945
N–H	+390
O=O	+497
O–H	+463

(i) Use these data to calculate the enthalpy change for the reaction of hydrazine with oxygen, as shown.

answer ..... kJ mol^{-1}

[4]

(ii) Calculate the enthalpy change for one gram of hydrazine in this reaction.

answer ..... kJ

[1]

(b) Ammonia reacts with oxygen in a very similar way to that shown for hydrazine. The enthalpy change for one gram of ammonia is approximately the same as that for one gram of hydrazine.

Using the table above, suggest a reason why hydrazine is used as a rocket fuel and ammonia is not.

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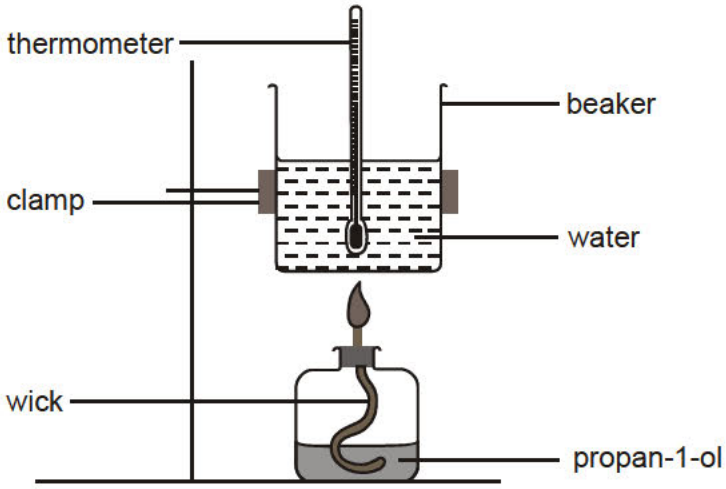
[1]

[Total 6 marks]

26. In an experiment to determine the standard enthalpy change of combustion of propan-1-ol, C_3H_7OH, a student used the apparatus shown below.



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

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[2]

(b) Write the equation for the standard enthalpy change of combustion of propan-1-ol, C_3H_7OH.

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[2]

(c) The student measured 50.0 cm^3 of water into the beaker and lit the burner. When the temperature of the water had gone up by 12.8 °C, he found that 0.100 g of propan-1-ol had been burnt.

(i) Calculate the energy, in kJ, produced by burning 0.100 g of propan-1-ol. The specific heat capacity of water is 4.18 J g^{-1} K^{-1}.

energy = ... kJ

[2]

(ii) Calculate the number of moles of propan-1-ol in 0.100 g.

number of moles = ...

[2]

(iii) Calculate the enthalpy change of combustion, in kJ mol^{-1}, of propan-1-ol.

enthalpy change ..... kJ mol^{-1}

[1]

(d) The student looked in a text book and found that the actual value for the standard enthalpy change of combustion of propan-1-ol was more exothermic than the experimental value.

Suggest **two** reasons for the difference between this value and the one he obtained experimentally.

1 .....

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2 .....

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[2]

[Total 11 marks]

27. There are several oxides of lead. This question is about the enthalpy changes that occur during the reactions of some of these oxides.

(i) Define the term *enthalpy change of formation*.

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.....

[2]

(ii) What are the standard conditions of temperature and pressure used in enthalpy calculations?

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[1]

[Total 3 marks]

28. Write an equation, including state symbols, representing the standard enthalpy change of formation of PbO.

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[Total 2 marks]

29. Metal priming paints often contain 'red lead', Pb_3O_4. Red lead can be made by heating PbO in the presence of air.

$$3PbO(s) + \frac{1}{2} O_2(g) \rightarrow Pb_3O_4(s)$$

(i) Use the ΔH_f^θ values in Table below to calculate the standard enthalpy change for the above reaction.

compound	ΔH_f^θ /kJ mol^{-1}
PbO(s)	–217
Pb_3O_4(s)	–718

ΔH^θ = ... kJ mol^{-1}

[3]

(ii) Red lead can also be obtained by reacting PbO_2 with PbO.

$$PbO_2(s) + 2PbO(s) \rightarrow Pb_3O_4(s) \quad \Delta H^{\theta} = -10 \text{ kJ mol}^{-1}$$

Use the value of ΔH^{θ} for this reaction, together with the values of ΔH_f^{θ} in the table above, to calculate a value for the enthalpy change of formation of $PbO_2(s)$.

ΔH_f^{θ} = ... kJ mol^{-1}

[3]

[Total 6 marks]

30. In the vapour state, hydrogen and iodine undergo the following reaction.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \quad \text{reaction 2.1}$$

Write an equation, including state symbols, for the bond enthalpy of I – I.

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[Total 2 marks]

31. This question is about the relationship between bond enthalpies and enthalpy changes of combustion.

Define the term *bond enthalpy*.

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[Total 2 marks]

32. Methane burns in air according to the following equation.

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

(i) Use the average bond enthalpies given in the table below to calculate a value for the enthalpy change of combustion of methane, ΔH_C.

bond	average bond enthalpy / kJ mol^{-1}
C–H	+410
O–H	+465
O=O	+500
C=O	+805

ΔH_C = ... kJ mol^{-1}

[3]

(ii) The standard enthalpy change of combustion of methane is −890 kJ mol^{-1}

Suggest why your calculated value differs from this value.

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[1]

[Total 4 marks]

33. The Table below gives values for the standard enthalpy changes of combustion for the first three alkanes.

alkane	formula	ΔH_c^{θ}/kJ mol^{-1}
methane	CH_4	**–**890
ethane	C_2H_6	**–**1560
propane	C_3H_8	**–**2220

(i) Write a balanced equation, including state symbols, illustrating the standard enthalpy change of combustion of propane gas.

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[2]

(ii) As the chain length in the alkanes increases, the value of ΔH_c^{θ} becomes more negative. Use your understanding of bond breaking and bond making to explain this trend.

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[2]

(iii) Propane can be cracked to form ethene and methane.

$$C_3H_8(g) \rightarrow C_2H_4(g) + CH_4(g)$$

The standard enthalpy change of combustion of ethene, ΔH_c^{θ} = –1410 kJ mol^{-1}.

Use this value together with relevant values in Table above to calculate the enthalpy change of this reaction.

ΔH_c^{θ} = ... kJmol^{-1}

[3]

[Total 7 marks]