AQA A-LEVEL CHEMISTRY · 7405

CHEMISTRY



EXAM QUESTION PACK

3.1.4 ENERGETICS

SCORE	PERCENTAGE
/1178	%

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Q1.

This question is about energetics.

(a) Write an equation, including state symbols, for the reaction with an enthalpy change equal to the enthalpy of formation for iron(III) oxide.

_____

(1)

(b) **Table 1** contains some standard enthalpy of formation data.

Table 1

	$CO(g)$	$Fe_2O_3(s)$
$\Delta_f H^\ominus$ / kJ mol^{-1}	−111	−822

$Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(s) + 3CO_2(g)$ $\Delta H = -19$ kJ mol^{-1}

Use these data and the equation for the reaction of iron(III) oxide with carbon monoxide to calculate a value for the standard enthalpy of formation for carbon dioxide.

Show your working.

$\Delta_f H^\ominus$ _____ kJ mol^{-1}

(3)

(c) Some enthalpy data are given in **Table 2**.

Table 2

Process	**ΔH / kJ mol^{-1}**
$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$	−92
$N_2(g) \longrightarrow 2N(g)$	+944
$H_2(g) \longrightarrow 2H(g)$	+436

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Use the data from **Table 2** to calculate the bond enthalpy for N−H in ammonia.

N−H bond enthalpy _____ kJ mol^{-1}

(3)

(d) Give one reason why the bond enthalpy that you calculated in part (c) is different from the mean bond enthalpy quoted in a data book (388 kJ mol^{-1}).

_____

_____

_____

(1)

(Total 8 marks)

Q2.

This question is about enthalpy changes.

(a) Write an equation, including state symbols, to show the reaction taking place when the standard enthalpy of combustion for ethanol is measured.

_____

(2)

(b) State the name given to the enthalpy change represented by the following chemical equation.

Explain why this enthalpy change would be difficult to determine directly.

$$C(s) + \frac{1}{2}O_2(g) \rightarrow CO(g)$$

Enthalpy change _____

Explanation _____

_____

_____

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(2)

(c) Standard enthalpies of combustion for carbon and carbon monoxide are −393 kJ mol^{-1} and −283 kJ mol^{-1}, respectively.

Use these data to calculate the enthalpy change for the reaction in part **(b)**.

Enthalpy change = _____ kJ mol^{-1}

(2)

(d) Use the following data to calculate a value for the Xe–F bond enthalpy in XeF_4

$$Xe(g) + 2F_2(g) \rightarrow XeF_4(g) \quad \Delta H = -252 \text{ kJ mol}^{-1}$$
$$F_2(g) \rightarrow 2F(g) \quad \Delta H = +158 \text{ kJ mol}^{-1}$$

Xe–F bond enthalpy = _____ kJ mol^{-1}

(3)

(e) Suggest a reason why the value calculated in part **(d)** differs from the mean Xe–F bond enthalpy quoted in a data source.

_____

_____

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_____

(1)

(Total 10 marks)

Q3.

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

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

_____

_____

_____

_____

(3)

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

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

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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_____

_____

_____

_____

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_____

_____

(3)

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

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

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.

_____

_____

_____

_____

_____

_____

_____

_____

(3)

(Total 9 marks)

Q4.

(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.

.....$C_6H_{12}O_6$ $\longrightarrow$ .....CH_3COCH_3 + ...CO_2 + ...H_2O

(1)

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

_____

(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.

_____

(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})

(3)

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

(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

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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 _____

_____

_____

Reason 2 _____

_____

_____

(2)

(Total 15 marks)

Q5.

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

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

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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_____

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_____

(2)

(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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(3)

(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.

_____

_____

_____

(2)

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

_____

(2)

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

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

_____

_____

_____

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_____

_____

_____

_____

(3)

(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.

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

_____

_____

_____

_____

_____

_____

_____

(3)

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

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

_____

(1)

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

(1)

(Total 17 marks)

Q6.

A student calculated that a value for the enthalpy change of neutralisation is –51.2 kJ mol^{-1}.

The design of a possible hand-warmer using hydrochloric acid and sodium hydroxide was discussed. It was proposed that 500 cm^3 of hydrochloric acid should be used in a flexible, sealed plastic container with a breakable tube of solid sodium hydroxide also in the container. On breaking the tube, the sodium hydroxide would be released, react with the

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acid and produce heat.
A 40 °C temperature rise was thought to be suitable.

(a) Calculate the heat energy, in J, required to raise the temperature of the reaction mixture by 40 °C. Assume that the reaction mixture has a density of 1.00 g cm^{-3} and a specific heat capacity of 4.18 J K^{-1} g^{-1}.
Assume that all of the heat energy given out is used to heat the reaction mixture.

_____

_____

_____

_____

(2)

(b) Use your answer from part (a) and the value for the enthalpy change of neutralisation of –51.2 kJ mol^{-1} to calculate the minimum amount, in moles, and hence the minimum mass of sodium hydroxide required in the breakable tube.
(If you could not complete the calculation in part (a) assume that the heat energy required was 77 400 J. This is **not** the correct answer).

Show your working.

Moles of NaOH _____

_____

Mass of NaOH _____

_____

(3)

(c) Use the amount, in moles, of sodium hydroxide from part (b) to calculate the minimum concentration, in mol dm^{-3}, of hydrochloric acid required in the 500 cm^3 of solution used in the sealed container.

_____

_____

_____

(1)

(d) Suggest **one** possible risk to a person who uses a hand-warmer containing sodium hydroxide and hydrochloric acid.

_____

_____

(1)

(e) A commercial hand-warmer uses powdered iron sealed in a plastic container.
A valve allows air to enter the container, and oxygen in the air reacts slowly with the iron to form solid iron(III) oxide. The heat released warms the container.

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(i) Write an equation for this reaction between iron and oxygen to form iron(lll) oxide.

_____

(1)

(ii) One version of an iron-oxygen hand-warmer advertises that it is designed to stay warm for up to four hours.
Other than by increasing the amount of iron in the container, state **one** change to the iron in the hand-warmer that would increase this time.
Explain why this change to the iron might **not** be an advantage.

Change to the iron _____

_____

Explanation _____

_____

_____

(3)

(f) Another type of hand-warmer uses sodium thiosulfate. Sodium thiosulfate is very soluble in water at 80 °C but is much less soluble at room temperature.
When a hot, concentrated solution of sodium thiosulfate is cooled it does not immediately crystallise. The sodium thiosulfate stays dissolved as a stable 'super-saturated' solution until crystallisation is triggered.
Heat energy is then released when the sodium thiosulfate crystallises.

(i) This type of hand-warmer is re-usable.
Suggest **one** environmental advantage that a sodium thiosulfate hand-warmer has over the other two types.

_____

(1)

(ii) Describe the **two** steps that you would take to make the sodium thiosulfate hand-warmer ready for re-use.

Step 1 _____

_____

Step 2 _____

_____

(2)

(Total 14 marks)

Q7.

(a) Iron is extracted from iron(III) oxide using carbon at a high temperature.

(i) State the type of reaction that iron(III) oxide undergoes in this extraction.

_____

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(1)

(ii) Write a half-equation for the reaction of the iron(III) ions in this extraction.

_____

(1)

(b) At a high temperature, carbon undergoes combustion when it reacts with oxygen.

(i) Suggest why it is **not** possible to measure the enthalpy change directly for the following combustion reaction.

$$C(s,graphite) + \frac{1}{2}O_2(g) \longrightarrow CO(g)$$

_____

_____

(1)

(ii) State Hess's Law.

_____

_____

_____

(1)

(iii) State the meaning of the term *standard enthalpy of combustion.*

_____

_____

_____

_____

_____

(3)

(c) Use the standard enthalpies of formation in the table below and the equation to calculate a value for the standard enthalpy change for the extraction of iron using carbon monoxide.

	$Fe_2O_3(s)$	$CO(g)$	$Fe(l)$	$CO_2(g)$
ΔH_f/ kJ mol^{-1}	- 822	- 111	+14	- 394

$$Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(l) + 3CO_2(g)$$

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_____

_____

_____

_____

_____

_____

(3)

(d) (i) Write an equation for the reaction that represents the standard enthalpy of formation of carbon dioxide.

_____

(1)

(ii) State why the value quoted in part (c) for the standard enthalpy of formation of $CO_2(g)$ is the same as the value for the standard enthalpy of combustion of carbon.

_____

_____

(1)

(Total 12 marks)

Q8.

This question is about the extraction of titanium from titanium(IV) oxide by a two-stage process.
The first stage in the process produces titanium(IV) chloride. In the second stage, titanium(IV) chloride is converted into titanium.
The enthalpy change for the second stage can be determined using Hess's Law.

(a) Give **one** reason why titanium is **not** extracted directly from titanium(IV) oxide using carbon.

_____

_____

(1)

(b) Give the meaning of the term *enthalpy change*.

_____

_____

_____

(1)

(c) State Hess's Law.

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(1)

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

(3)

(e) The following standard enthalpy of formation data refer to the second stage in the extraction of titanium.

	$TiCl_4(g)$	Na(l)	NaCl(s)	Ti(s)
$\Delta H_f^{\ominus}$/ kJ mol^{-1}	–720	+3	–411	0

(i) State why the value for the standard enthalpy of formation of Na(l) is **not** zero.

(1)

(ii) Use data from the table to calculate a value for the standard enthalpy change of the following reaction.

$$TiCl_4(g) + 4Na(l) \longrightarrow 4NaCl(s) + Ti(s)$$

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_____

(3)

(iii) State the role of sodium in this reaction.

_____

(1)

(Total 11 marks)

Q9.

Comparison of lattice enthalpies from Born-Haber cycles with lattice enthalpies from calculations based on a perfect ionic model are used to provide information about bonding in crystals.

(a) Define the terms *enthalpy of atomisation* and *lattice dissociation enthalpy*.

Enthalpy of atomisation _____

_____

_____

Lattice dissociation enthalpy _____

_____

_____

(4)

(b) Use the following data to calculate a value for the lattice dissociation enthalpy of sodium chloride.

	$\Delta H^{\ominus}$/kJ mol^{-1}
$Na(s) \longrightarrow Na(g)$	+109
$Na(g) \longrightarrow Na^+(g) + e^-$	+494
$Cl_2(g) \longrightarrow 2Cl(g)$	+242
$Cl(g) + e^- \longrightarrow Cl^-(g)$	−364
$Na(s) + \frac{1}{2}Cl_2(g) \longrightarrow NaCl(s)$	−411

_____

_____

_____

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_____

(3)

(c) Consider the following lattice dissociation enthalpy (ΔH_L°) data.

	NaBr	AgBr
ΔH_L°(experimental)/kJ mol^{-1}	+733	+890
ΔH_L°(theoretical)/kJ mol^{-1}	+732	+758

The values of ΔH_L° (experimental) have been determined from Born–Haber cycles.

The values of ΔH_L° (theoretical) have been determined by calculation using a perfect ionic model.

(i) Explain the meaning of the term *perfect ionic model*.

_____

_____

_____

_____

(2)

(ii) State what you can deduce about the bonding in NaBr from the data in the table.

_____

_____

(1)

(iii) State what you can deduce about the bonding in AgBr from the data in the table.

_____

_____

(1)

(Total 11 marks)

Q10.

A scientist used mass spectrometry to analyse a sample of the air near a fertiliser factory. The sample of air included traces of a gas which was shown by its molecular ion to have a precise M_r = 44.00105

(a) State the meaning of the term *molecular ion*.

_____

_____

(1)

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(b) (i) Use the following data to show that the trace gas was dinitrogen oxide (N_2O).

Show your working.

Atom	Precise relative atomic mass
^{12}C	12.00000
^{14}N	14.00307
^{16}O	15.99491

_____

_____

(1)

(ii) Propane is used as a fuel in the fertiliser factory. State why both propane and its combustion product, carbon dioxide, might have been identified as the trace gas if the scientist had used relative molecular masses calculated to one decimal place.

_____

_____

(1)

(iii) State why the precise relative atomic mass for the ^{12}C isotope is exactly 12.00000

_____

(1)

(c) Dinitrogen oxide is formed when ammonia is oxidised according to the following equation.

$$2NH_3(g) + 2O_2(g) \rightarrow N_2O(g) + 3H_2O(l)$$

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

	$NH_3(g)$	$O_2(g)$	$N_2O(g)$	$H_2O(l)$
ΔH_f^o/ kJ mol^{-1}	–46	0	+82	–286

_____

_____

_____

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_____

(3)

(ii) State **one** condition necessary for enthalpies of formation to be quoted as standard values at a specified temperature of 298 K.

_____

(1)

(Total 8 marks)

Q11.

Hess's Law is used to calculate the enthalpy change in reactions for which it is difficult to determine a value experimentally.

(a) State the meaning of the term *enthalpy change*.

_____

(1)

(b) State Hess's Law.

_____

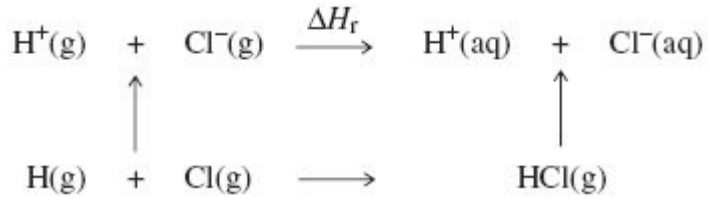
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(1)

(c) Consider the following table of data and the scheme of reactions.

Reaction	Enthalpy change / kJ mol^{-1}
$HCl(g) \rightarrow H^+(aq) + Cl^-(aq)$	–75
$H(g) + Cl(g) \rightarrow HCl(g)$	–432
$H(g) + Cl(g) \rightarrow H^+(g) + Cl^-(g)$	+963



Use the data in the table, the scheme of reactions and Hess's Law to calculate a value for ΔH_r

_____

_____

_____

_____

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_____

(3)

(Total 5 marks)

Q12.

Barium can be extracted from barium oxide (BaO) in a process using aluminium.
A mixture of powdered barium oxide and powdered aluminium is heated strongly.
The equation for this extraction process is shown below.

$$3BaO(s) + 2Al(s) \rightarrow 3Ba(s) + Al_2O_3(s)$$

Some standard enthalpies of formation are given in the table below.

Substance	BaO(s)	$Al_2O_3(s)$
$\Delta H_f^{\⦵}$/kJ mol^{-1}	–558	–1669

(a) (i) State what is meant by the term *standard enthalpy of formation*.

_____

_____

_____

_____

_____

(3)

(ii) State why the standard enthalpy of formation of barium and that of aluminium are both zero.

_____

(1)

(iii) Use the data to calculate the standard enthalpy change for the reaction shown by the equation above.

_____

_____

_____

_____

_____

(3)

(b) (i) Suggest the major reason why this method of extracting barium is expensive.

_____

(1)

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(ii) Using barium oxide and aluminium powders increases the surface area of the reactants. Suggest **one** reason why this increases the rate of reaction.

_____

(1)

(c) (i) Write an equation for the reaction of barium with water.

_____

(1)

(ii) A solution containing barium ions can be used to test for the presence of sulfate ions in an aqueous solution of sodium sulfate.

Write the **simplest ionic** equation for the reaction which occurs and state what is observed.

Simplest ionic equation

_____

Observation _____

(2)

(iii) State how barium sulfate can be used in medicine. Explain why this use is possible, given that solutions containing barium ions are poisonous.

Use _____

Explanation _____

_____

(2)

(Total 14 marks)

Q13.

The combustion of hydrocarbons is an important source of energy.

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

_____

_____

_____

(3)

(b) (i) Write an equation for the complete combustion of ethane, C_2H_6.

_____

(ii) Use the standard enthalpies of formation given below to calculate the standard enthalpy of combustion of ethane.

Formula and state of compound	$C_2H_6(g)$	$CO_2(g)$	$H_2O(l)$

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Standard enthalpy of formation (at 298 K)/kJ mol^{-1}	–85	–394	–286

(4)

(c) A container 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}.

(4)

(Total 11 marks)

Q14.

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

(3)

(b) Use the data in the table to calculate the standard enthalpy of formation of liquid methylbenzene, C_7H_8

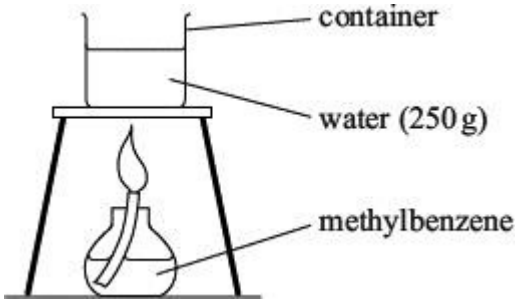
Substance	C(s)	$H_2(g)$	$C_7H_8(l)$
Standard enthalpy of combustion, $\Delta H_c^{\ominus}$ /kJ mol^{-1}	–394	–286	–3909

$7C(s) + 4H_2(g) \rightarrow C_7H_8(l)$

(3)

(c) An experiment was carried out to determine a value for the enthalpy of combustion of liquid methylbenzene using the apparatus shown in the diagram.

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Burning 2.5 g of methylbenzene caused the temperature of 250 g of water to rise by 60°C. Use this information to calculate a value for the enthalpy of combustion of methylbenzene, C_7H_8

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

(4)

(d) A 25.0 cm^3 sample of 2.00 mol dm^{-3} hydrochloric acid was mixed with 50.0 cm^3 of a 1.00 mol dm^{-3} solution of sodium hydroxide. Both solutions were initially at 18.0 °C.

After mixing, the temperature of the final solution was 26.5°C.

Use this information to calculate a value for the standard enthalpy change for the following reaction.

$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

In your calculation, assume that the density of the final solution is 1.00 g cm^{-3} and that its specific heat capacity is the same as that of water. (Ignore the heat capacity of the container.)

(4)

(e) Give **one** reason why your answer to part (d) has a much smaller experimental error than your answer to part (c).

(1)

(Total 15 marks)

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Q15.

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

Mean bond enthalpy _____

_____

_____

Standard enthalpy of formation _____

_____

_____

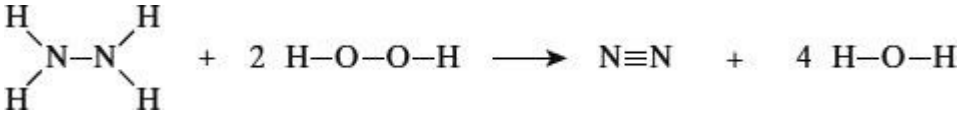
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(5)

(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



_____

_____

_____

_____

_____

(3)

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

	$N_2H_4(g)$	$H_2O_2(g)$	$H_2O(g)$
ΔH_f° /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.

(4)

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

(1)

(Total 13 marks)

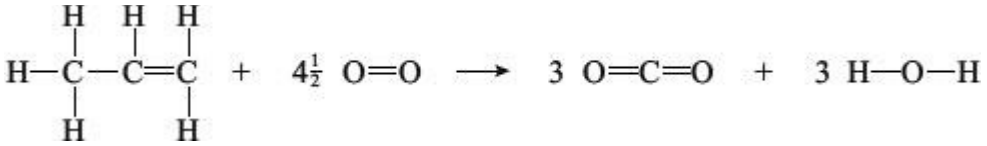
Q16.

(a) Define the term *standard enthalpy of combustion*, ΔH_c⦵

(3)

(b) Use the mean bond enthalpy data from the table and the equation given below to calculate a value for the standard enthalpy of combustion of propene. All substances are in the gaseous state.

Bond	C == C	C—C	C—H	O == O	O == C	O—H
Mean bond enthalpy/ kJ mol^{-1}	612	348	412	496	743	463



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(3)

(c) State why the standard enthalpy of formation, ΔH_f°, of oxygen is zero.

_____

(1)

(d) Use the data from the table below to calculate a more accurate value for the standard enthalpy of combustion of propene.

Compound	$C_3H_6(g)$	$CO_2(g)$	$H_2O(g)$
Standard enthalpy of formation, ΔH_f°/ kJ mol^{-1}	+20	–394	–242

_____

_____

_____

_____

_____

(3)

(e) Explain why your answer to part (b) is a less accurate value than your answer to part (d).

_____

_____

(2)

(Total 12 marks)

Q17.

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)

Q18.

(a) The table below contains some mean bond enthalpy data.

Bond	H–O	O–O	O=O

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Mean bond enthalpy/kJ mol^{-1}	463	146	496

The bonding in hydrogen peroxide, H_2O_2, can be represented by H–O–O–H. Use these data to calculate the enthalpy change for the following reaction.

$$H_2O_2(g) \rightarrow H_2O_2(g) + \tfrac{1}{2} O_2(g)$$

(3)

(b) The standard enthalpy of formation, $\Delta H_f^{\ominus}$ for methane, is –74.9 kJ mol^{-1}. Write an equation, including state symbols, for the reaction to which this enthalpy change applies.

(2)

(c) The enthalpy changes for the formation of atomic hydrogen and atomic carbon from their respective elements in their standard states are as follows.

$$\tfrac{1}{2} H_2(g) \rightarrow H(g) \qquad \Delta H^{\ominus} = +218 \text{ kJ mol}^{-1}$$

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

(i) By reference to its structure, suggest why a large amount of heat energy is required to produce free carbon atoms from solid carbon.

(ii) Parts (b) and (c) give enthalpy data for the formation of $CH_4(g)$, H(g) and C(g). Use these data and Hess's Law to calculate the value of the enthalpy change for the following reaction.

$$CH_4(g) \rightarrow C(g) + 4H(g)$$

(iii) Use your answer from part (c)(ii) to calculate a value for the mean bond

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enthalpy of a C–H bond in methane.

_____

(5)

(Total 10 marks)

Q19.

(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})

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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)

Q20.

The table below contains some standard enthalpy of formation data.

Substance	C(s)	$N_2(g)$	$H_2O(g)$	$CO_2(g)$	$NH_4NO_3(s)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	0	0	–242	–394	–365

(a) Why are the values of the standard enthalpy of formation for carbon and nitrogen zero?

(1)

(b) State Hess's Law.

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_____

_____

(2)

(c) Use $\Delta H_f^{\ominus}$ data from the table to calculate a value for the enthalpy change for the following reaction.

$$NH_4NO_3(s) + \frac{1}{2}C(s) \rightarrow N_2(g) + 2H_2O(g) + \frac{1}{2}CO_2(g)$$

_____

_____

_____

_____

(3)

(Total 6 marks)

Q21.

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

_____

_____

_____

(2)

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

_____

_____

_____

_____

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

_____

(5)

(c) State Hess's Law.

_____

_____

(1)

(d) Some standard enthalpy changes are difficult to measure directly but can be

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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)	$H_2(g)$
$\Delta H_c^{\ominus}$ / kJ mol^{-1}	–1356	–393.5	–285.8

(3)
(Total 11 marks)

Q22.

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

(3)

(b) State Hess's law.

(1)

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

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

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

_____

_____

_____

_____

(3)

(Total 7 marks)

Q23.

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)

Q24.

When ethanamide (CH_3CONH_2) burns in oxygen the carbon is converted into carbon dioxide, the hydrogen is converted into water and the nitrogen forms nitrogen gas.

Substance	ethanamide	carbon dioxide	water
Enthalpy of formation ($\Delta H_f^{\ominus}$) / kJ mol^{-1}	−320	−394	−286

Using the data above, which one of the following is a correct value for the enthalpy of combustion of ethanamide?

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A $-1823\ kJ\ mol^{-1}$

B $-1183\ kJ\ mol^{-1}$

C $-1000\ kJ\ mol^{-1}$

D $-360\ kJ\ mo1^{-1}$

(Total 1 mark)

Q25.

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)

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Q1.

(a) $2Fe(s) + \frac{3}{2}O_2(g) \rightarrow Fe_2O_3(s)$ ONLY

Don't allow multiples. States must be shown

1

(b) M1 Correct cycle or equation

If M1 and M2 not awarded then M3 can be awarded for their M2 divided by 3

1

M2 $(3 \times \Delta_f HCO_2) = -19 + (-822) + 3(-111) - 0$

$(3 \times \Delta_f HCO_2) = -1174$

1

M3 $\Delta_f HCO_2 = -391$ kJ mol^{-1}

−317 for 1 mark

+391 for 1 mark

1

Allow 2 sig fig or more

(c) M1 Correct Hess's law cycle or equation

If M1 and M2 not awarded then M3 can be awarded for their M2 divided by 6

1

M2 $(6(N-H)) = 944 + 3(+436) + 92$

$(6(N-H)) = 2344$

−391 for 1 mark

1

M3 N−H = (+)391 kJ mol^{-1}

1

Allow 2 sig fig or more

(d) Data book value derived from (a number of) different compounds (not just different NH_3 molecules)

1

[8]

Q2.

(a) $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

1 mark for correct formulae and balancing

1

1 mark for all correct state symbols

1

(b) (Standard) enthalpy of formation

1

Difficult to prevent C reacting with O_2 to form some CO_2

1

(c) $\Delta H = \Sigma\Delta H_c$ reactants − $\Sigma\Delta H_c$ products or a correct cycle

1

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OR ΔH = −393−(−283)

ΔH = −110 (kJ mol^{-1})

1

(d) Correctly drawn Hess's law cycle

1

4 (Xe–F) = 252 + (2 × 158) = 568

Xe–F = 568 / 4

1

Xe–F = 142 (kJ mol^{-1})

1

(e) Mean bond enthalpy found by taking an average for Xe–F in a range of compounds

1

[10]

Q3.

(a) The <u>enthalpy / heat energy change</u> when <u>1 mol</u> (of a substance)

If enthalpy of formation definition given CE=O

***NOT** just 'energy'*

***ALLOW** alternatives for substance e.g. molecule/compound/element*

1

Is <u>burned/reacts completely in oxygen</u>

***ALLOW** reacts in excess oxygen*

1

With all reactants and products in their <u>standard states</u>
OR
With all reactants and products in their normal states at 298K/given temp & 100kPa

***ALLOW** 'everything' for 'reactants and products'*

Penalise incorrect conditions if given

***ALLOW** 'normal states under standard conditions'*

1

(b) $\Delta H = \Sigma\Delta H_c$(reactants) - $\Sigma\Delta H_c$ (products)
OR
Correctly and fully balanced cycle

Correct answer scores 3

1

ΔH = [3(-394) + 4(-286)] – (-2010)
OR
ΔH = -2326 + 2010

M2 also scores M1

1

ΔH = -316 (kJ mol^{-1})
+316 scores 1 mark only

***IGNORE** units*

Check for AE in working – can award M3 as ecf (error carried

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forward) from M2 if M2 not given due to AE

1

(c) ΔH/-1893 = ΣB(reactants) - ΣB(products)
OR
ΔH/-1893 = ΣBonds broken - ΣBonds formed
OR
ΔH/-1893 = 2B(C-C) + 7B(C-H) + B(C-O) + B(O-H) + 4½ B(O=O) – 6B(C=O) – 8B(O-H)

Correct answer scores 3

1

-1893= 2B(C-C) + 7(412) + 360 + 463 + 4½(496) – 6(805) – 8(463)
OR
-1893= 2B(C-C) +5939 – 8534
OR
-1893= 2B(C-C) -2595
OR
2B(C-C) = 702

M2 also scores M1

May see no 463 in bonds broken and 7x463 in made (gives 5476 – 8071)

1

B(C-C) = (+)351(kJ mol^{-1})

*If **NOT** 351 check for AE. This would lose M2, but could gain M1 and M3*

(+)234 scores 1 (due to 3(C-C))

***NOT** M3 from incorrect M2 unless incorrect M2 is due to AE*

***IGNORE** units*

If no other mark awarded then

***ALLOW** 1 if 5939 or 5476 or 8534 or 8071 seen*

1

[9]

Q4.

(a) (i) $\mathbf{2}C_6H_{12}O_6 \longrightarrow \mathbf{3}CH_3COCH_3 + \mathbf{3}CO_2 + \mathbf{3}H_2O$

Or multiples

1

(ii) to speed up the reaction
OR
(provide a) catalyst or catalyses the reaction or biological catalyst
OR
release / contain / provides an enzyme

Ignore "fermentation"

Ignore "to break down the glucose"

Not simply "enzyme" on its own

1

(b) (i) $CH_3CH(OH)CH_3 + [O] \longrightarrow CH_3COCH_3 + H_2O$

Any correct representation for the two organic structures. Brackets not essential.

Not "sticks" for the structures in this case

1

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(ii) Secondary (alcohol) OR 2° (alcohol)

1

(c) **M1** $q = m\ c\ \Delta T$

OR $q = 150 \times 4.18 \times 8.0$

Award full marks for correct answer

*In **M1**, do not penalise incorrect cases in the formula*

M2 = (±) 5016 (J) ***OR*** 5.016 (kJ) ***OR*** 5.02 (kJ)
(also scores M1)

M3 This mark is for dividing correctly the number of kJ by the number of moles and arriving at a final answer in the range shown.
Using 0.00450 mol

therefore ΔH = **− 1115** (kJ mol^{-1})

OR **− 1114.6 to − 1120** (kJ mol^{-1})

Range (+)1114.6 to (+)1120 gains 2 marks

BUT − 1110 gains 3 marks and +1110 gains 2 marks

AND − 1100 gains 3 marks and +1100 gains 2 marks

Award full marks for correct answer

*In **M1**, do not penalise incorrect cases in the formula*

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect; **(+)1114.6 to (+)1120 gains 2 marks***

*Penalise **M2** for arithmetic error and mark on*

If $\Delta T = 281$; score $q = m\ c\ \Delta T$ only

*If c = 4.81 (leads to 5772) penalise **M2** ONLY and mark on for **M3** = − 1283*

*Ignore incorrect units in **M2***

*If units are given in **M3** they must be either kJ or kJ mol^{-1} in this case*

3

(d) **M1** The enthalpy change / heat change at constant pressure when 1 mol of a compound / substance / element

M2 is burned / combusts / reacts completely in oxygen
OR
burned / combusted / reacted in excess oxygen

M3 with (all) reactants and products / (all) substances in standard / specified states

OR
(all) reactants and products / (all) *substances in normal states under standard conditions* / 100 kPa / 1 bar and specified T / 298 K

*For **M3***

Ignore reference to 1 atmosphere

3

(e) **M1**

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$\underline{\Sigma \text{ B } \textbf{(reactants)} - \Sigma \text{ B } \textbf{(products)} = \Delta H}$

OR

$\underline{\text{Sum of bonds broken} - \text{Sum of bonds formed} = \Delta H}$

OR

2B(C−C) + B(C=O) + 6B(C−H) + 4B(O=O) (LHS)

− 6B(C=O) − 6B(O−H) (RHS) = $\underline{\Delta H}$

M2 (also scores **M1**)

2(348)+805+6(412)+4(496) [LHS = **5957**]

(696) (2472) (1984)

− 6(805) − 6(463) [RHS = (−) **7608**] = Δ*H*

(4830) (2778)

OR using only bonds broken and formed (**5152 − 6803**)

M3

Δ*H*= $\underline{\textbf{− 1651}}$ (kJ mol^{-1})

Candidates may use a cycle and gain full marks.

Correct answer gains full marks

Credit 1 mark for (+) 1651 (kJ mol^{-1})

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication / addition error; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with $4O_2$, $3CO_2$ and $3H_2O$ OR a clear statement of **M1** which could be in words and scores **only M1***

Allow a maximum of one mark if the only scoring point is LHS = 5957 (or 5152) OR RHS = 7608 (or 6803)

Award 1 mark for + 1651

3

(f) **For the two marks M1 and M2, any two from**

- heat loss or not all heat transferred to the apparatus or heat absorbed by the apparatus or (specific) heat capacity of the apparatus not considered
- incomplete combustion / not completely burned / reaction is not complete
- The idea that the water may end up in the gaseous state (rather than liquid)
- reactants and / or products may not be in standard states.
- MBE data refers to gaseous species but the enthalpy of combustion refers to liquids in their standard states / liquid propanone and liquid water in standard states
- MBE do not refer to specific compounds OR MBE values vary with different compounds / molecules OR are average / mean values taken from a range of compounds / molecules

Apply the list principle but ignore incomplete reasons that contain correct chemistry

Ignore "evaporation"

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Ignore "faulty equipment"

Ignore "human error"

Not enough simply to state that "MBE are mean / average values"

2

[15]

Q5.

(a) (i) M1 <u>c(oncentrated) phosphoric acid / c(onc.) H_3PO_4</u>
OR <u>c(oncentrated) sulfuric acid / c(onc.) H_2SO_4</u>

*In **M1**, the acid must be concentrated.*
Ignore an incorrect attempt at the correct formula that is written in addition to the correct name.

M2 Re-circulate / re-cycle the (unreacted) ethene (and steam) / the reactants
OR pass the gases over the catalyst several / many times

*In **M2**, ignore "remove the ethanol".*
Credit "re-use".

2

(ii) M1
(By Le Chatelier's principle) the equilibrium is <u>driven / shifts / moves to the right / L to R / forwards / in the forward direction</u>

M2 depends on a correct statement of M1
The <u>equilibrium moves / shifts to</u>

- <u>oppose the addition of / increased concentration of / increased moles / increased amount of water / steam</u>
- to <u>decrease the amount of steam / water</u>

Mark M3 independently
M3 Yield of product / conversion increase ***OR*** ethanol increases / goes up / gets more

3

(iii) M1 Poly(ethene) / polyethene / polythene / HDPE / LDPE

M2 At higher pressures
More / higher <u>cost</u> of electrical <u>energy to pump</u> / <u>pumping cost</u>
OR
<u>Cost</u> of higher pressure <u>equipment / valves / gaskets / piping etc</u>.
OR <u>expensive equipment</u>

*Credit all converse arguments for **M2***

2

(b) M1 for balanced equation

M2 for state symbols in a <u>correctly balanced equation</u>

$2C(s / graphite) + 3H_2(g) + ½O_2(g) \longrightarrow CH_3CH_2OH(l)$ (C_2H_5OH)

Not multiples but credit correct state symbols in a correctly balanced equation.

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Penalise C_2H_6O but credit correct state symbols in a correctly balanced equation.

2

(c) (i) M1 The <u>enthalpy change</u> / <u>heat change at constant pressure</u> when <u>1 mol</u> of a compound / substance / element

*If standard enthalpy of formation **CE=0***

M2 is <u>burned / combusts / reacts completely</u> in <u>oxygen</u>
OR <u>burned / combusted / reacted in excess oxygen</u>

M3 with (all) <u>reactants and products /</u> (all) <u>substances in standard / specified states</u>
OR (all) <u>reactants and products /</u> (all) <u>substances in normal states under standard conditions</u> / 100 kPa / 1 bar <u>and</u> specified T / 298 K

*For **M3***
Ignore reference to 1 atmosphere

3

(ii) M1

Correct answer gains full marks

<u>ΣB(**reactants**) − ΣB(**products**) = *ΔH*</u>

Credit 1 mark for (+) 1279 (kJ mol^{-1})

OR
<u>Sum of bonds broken − Sum of bonds formed = ΔH</u>
OR
B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O) (LHS)
− 4B(C=O) − 6B(O−H) (RHS) = <u>*ΔH*</u>

M2 (also scores **M1**)
348+360+463+5(412)+3(496) [LHS = **4719**]
(2060) (1488)
− 4(805) − 6(463) [RHS = − **5998**] = *ΔH*
(3220) (2778)
OR using only bonds broken and formed (**4256 − 5535**)

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with 2C and 6H and 7O OR a clear statement of **M1** which could be in words and scores **<u>only M1</u>***

M3
ΔH= **<u>− 1279</u>** (kJ mol^{-1})

*Allow a maximum of one mark if the only scoring point is LHS = 4719 **OR** RHS = 5998*

Award 1 mark for +1279

Candidates may use a cycle and gain full marks

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3

(d) (i) Reducing agent ***OR*** reductant ***OR*** electron donor ***OR*** to reduce the copper oxide

Not "reduction".

Not "oxidation".

Not "electron pair donor".

1

(ii) CH_3COOH

1

[17]

Q6.

(a) q = 500 × 4.18 × 40

Do not penalise precision.

1

= 83600 J

Accept this answer only.

Ignore conversion to 83.6 kJ if 83600 J shown.

Unit not required but penalise if wrong unit given.

Ignore the sign of the heat change.

An answer of 83.6 with no working scores one mark only.

An answer of 83600 with no working scores both marks.

1

(b) Moles (= 83.6 / 51.2) = 1.63

Using 77400 alternative gives 1.51 mol

Allow (a) in kJ / 51.2

Do not penalise precision.

1

Mass = 1.63 × 40(.0) = 65.2 (g)

Allow 65.3 (g)

Using 77400 alternative gives 60.4 to 60.5

Allow consequential answer on M1.

1 mark for M_r (shown, not implied) and 1 for calculation.

Do not penalise precision.

2

(c) Molarity = 1.63 / 0.500 = 3.26 mol dm–3

Allow (b) M1 × 2

Using 1.51 gives 3.02

1

(d) Container splitting and releasing irritant / corrosive chemicals

*Must have reference to both aspects; splitting or leaking (can be implied such as contact with body / hands) **and** hazardous chemicals.*

Allow 'burns skin / hands' as covering both points

Ignore any reference to 'harmful'.

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Do not allow 'toxic'.

1

(e) (i) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$

Allow fractions / multiples in equation.

Ignore state symbols.

1

(ii) Iron powder particle size could be increased / surface area lessened

Decrease in particle size, chemical error = 0 / 3

Change in oxygen, chemical error = 0 / 3

1

Not all the iron reacts / less reaction / not all energy released / slower release of energy / lower rate of reaction

Mark points M2 and M3 independently.

1

Correct consequence of M2

An appropriate consequence, for example

- *too slow to warm the pouch effectively*
- *lower temperature reached*
- *waste of materials*

1

(f) (i) Conserves resources / fewer disposal problems / less use of landfill / fewer waste products

Must give a specific point.

Do not allow 'does not need to be thrown away' without qualification.

Do not accept 'no waste'.

1

(ii) Heat to / or above 80 °C (to allow thiosulfate to redissolve)

Accept 'heat in boiling water'.

If steps are transposed, max 1 mark.

1

Allow to cool before using again

Reference to crystallisation here loses this mark.

1

[14]

Q7.

(a) (i) reduction **OR** reduced **OR** redox ***OR*** reduction–oxidation

Not "oxidation" alone

1

(ii) $Fe^{3+} + \mathbf{3}e^- \longrightarrow Fe$

Ignore state symbols

Do not penalise absence of charge on electron

Credit $Fe^{3+} \longrightarrow Fe - \mathbf{3}e^-$

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Credit multiples

1

(b) (i) **Because (one of the following)**

CO is not the only product ***OR***

Reference to "incomplete combustion to form CO" does not answer the question

(Some) complete combustion (also)occurs ***OR***

CO_2 is (also) formed

Further oxidation occurs

1

(ii) The <u>enthalpy change</u> / <u>heat (energy) change at constant pressure</u> in a reaction is <u>independent of the route / path taken</u> (and depends only on the initial and final states)

1

(iii) **M1** The <u>enthalpy change</u> / <u>heat change at constant pressure</u> when <u>1 mol</u> of a compound / substance / element

For M1, credit correct reference to molecule/s or atom/s

M2 is <u>burned completely</u> / <u>undergoes complete combustion</u> in (excess) <u>oxygen</u>

M3 with <u>all reactants and products / all substances in standard states</u>

For M3

Ignore reference to 1 atmosphere

OR <u>all reactants and products / all substances in normal / specified states under standard conditions</u> / 100 kPa / 1 bar <u>and</u> specified T / 298 K

3

(c) **M1 (could be scored by a correct mathematical expression which <u>must</u> have <u>all</u> <u>ΔH</u> symbols and the ∑)**

Correct answer gains full marks

Credit 1 mark ONLY for –1 (kJ mol^{-1})

M1 $\Delta H_r = \sum \Delta H_f$ (**products**) – $\sum \Delta H_f$ (**reactants**)

Credit 1 mark ONLY for – 27 (kJ mol^{-1}) i.e. assuming value for Fe(l) = 0

OR <u>correct cycle of balanced equations with 2Fe, 3C and $3O_2$</u>

M2 ΔH_r = 2(+14) + 3(– 394) – (– 822) – 3(–111)

= 28 –1182 + 822 + 333

(This also scores M1)

M3 = **(+) 1** (kJ mol^{-1})

(Award 1 mark ONLY for – 1)

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(Award 1 mark ONLY for – 27)

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (M1 and M2)*
- *If no AE, check for a correct method; this requires either a correct cycle with 2Fe, 3C and $3O_2$ OR a clear statement of M1 which could be in words and scores <u>only M1</u>*

3

(d) (i) $C(s) + O_2(g) \quad CO_2(g)$

State symbols essential

Possible to include C(s, graphite)

1

(ii) These two enthalpy changes are for <u>the same reaction / same equation / same reactants and products</u>

Penalise reference to CO_2 being produced by a different route

OR

They <u>both make one mole of carbon dioxide only from carbon and oxygen</u> (or this idea clearly implied)

"both form CO_2" is not sufficient (since other products might occur e.g.CO)

OR

The <u>same number and same type of bonds are broken and formed</u>

1

[12]

Q8.

(a) One from

- Ti is not produced
- TiC / <u>carbide</u> is produced OR titanium reacts with carbon
- Product is brittle
- Product is a poor engineering material

Penalise ''titanium carbonate''

Ignore ''impure titanium''

Credit ''titanium is brittle''

1

(b) <u>Heat</u> (energy) <u>change at constant pressure</u>

QoL

1

(c) The <u>enthalpy change</u> in a reaction is independent of

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the route taken (and depends only on the initial and final states)

Credit ''heat change at constant pressure" as an alternative to ''enthalpy change''

1

(d) **M1** The enthalpy change / heat change at constant pressure when 1 mol of a compound / substance / product

For M1, credit correct reference to molecule/s or atom/s

M2 is formed from its (constituent) elements

M3 with all reactants and products / all substances in standard states

OR all reactants and products / all substances in normal states under standard conditions / 100 kPa / 1 bar and any specified T (usually 298 K)

Ignore reference to 1 atmosphere

3

(e) (i) Na / it is not in its standard state / normal state under standard conditions

OR

Standard state / normal state under standard conditions for Na is solid / (s)

QoL

Ignore ''sodium is a liquid or sodium is not a solid''

1

(ii) **M1** $\Delta H_r = \sum \Delta H_f$ **(products)** $- \sum \Delta H_f$ **(reactants)**

M2 $\Delta H_r = 4(-411) - (-720) - 4(+3)$
$= -1644 + 720 - 12$
(This also scores M1)

M3 = **−936** (kJ mol^{-1})

Correct answer gains full marks

Credit 1 mark for + 936 *(kJ mol^{-1})*

Credit 1 mark for – 924 *(kJ mol^{-1})*
i.e. assuming value for Na(l) = 0

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (M1 and M2)*
- *If no AE, check for a correct method; this requires* ***either*** *a correct cycle with $2Cl_2$ and 4Na OR a* ***clear complete statement*** *of M1 which could be in words and scores only M1*

3

(iii) Reducing agent

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Ignore "reduces titanium"

OR reductant OR reduces $TiCl_4$

OR electron donor

1

[7]

Q9.

(a) Enthalpy change for the formation of 1 mol of gaseous atoms

allow heat energy change for enthalpy change

1

From the element (in its standard state)

ignore reference to conditions

1

Enthalpy change to separate 1 mol of an ionic lattice/solid/compound

enthalpy change not required but penalise energy

1

Into (its component) gaseous ions

mark all points independently

1

(b) $\Delta H_L = {}^{-}\Delta H_f + \Delta H_a$ + I.E. + 1/2E(Cl-Cl) + EA

Or correct Born-Haber cycle drawn out

1

= +411 + 109 + 494 + 121 – 364

1

= +771 (kJ mol^{-1})

–771 scores 2/3
+892 scores 1/3
–51 scores 1/3
–892 scores zero
+51 scores zero *ignore units*

1

(c) (i) Ions are perfect spheres (or point charges)

1

Only electrostatic attraction/no covalent interaction

mention of molecules/intermolecular forces/covalent bonds CE = 0
allow ionic bonding only
If mention of atoms CE = 0 for M2

1

(ii) Ionic

Allow no covalent character/bonding

1

(iii) Ionic with additional covalent bonding

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Or has covalent character/partially covalent

Allow mention of polarisation of ions or description of polarisation

1

[11]

Q10.

(a) The molecular ion is

- The molecule with one/an electron knocked off/lost

  Ignore the highest or biggest m/z peak

OR

- The molecule with a (single) positive charge

OR

- the ion with/it has the largest/highest/biggest m/z (value/ratio)

  Ignore "the peak to the right"

OR

- the ion with/it has an m/z equal to the M_r

  Ignore "compound"

1

(b) (i) 2(14.00307) + 15.99491 = 44.00105

A sum is needed to show this

1

(ii) Propane/C_3H_8 and carbon dioxide/CO_2 (and N_2O) or they or both the gases/molecules or all three gases/molecules have an (imprecise) M_r of 44.0 (OR 44)

OR

they have the same $\boldsymbol{M_r}$ or molecular mass (to one d.p)

This could be shown in a calculation of relative masses for propane and carbon dioxide

1

(iii) By definition

OR

The standard/reference (value/isotope)

Ignore "element"

Ignore "atom"

1

(c) (i) **M1 (could be scored by a correct mathematical expression)**

$\Delta H = \Sigma\Delta H_{products} - \Sigma\Delta H_{reactants}$

OR a correct cycle of balanced equations

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M1 and M2 can be scored with correct moles as follows
$\Delta H + 2(-46) = +82 + 3(-286)$

$\Delta H - 92 = -776$

$\Delta H = 92 - 776$ OR $92 + 82 - 858$

M3
$\Delta H =$ <u>– 684</u> (kJ mol^{-1}) (This is worth 3 marks)

Award 1 mark ONLY for + 684

Full marks for correct answer.

Ignore units.

Deduct one mark for an arithmetic error.

3

(ii) The value is quoted at a pressure of <u>100 kPa</u> OR <u>1 bar</u> or <u>10^5 Pa</u>

OR

<u>All reactants and products</u> are in their <u>standard states/their normal states at 100 kPa or 1 bar</u>

Ignore 1 atmosphere/101 kPa

Ignore "constant pressure"

1

[8]

Q11.

(a) <u>Heat (energy) change at constant pressure</u>

Ignore references to standard conditions, but credit specified pressure.

1

(b) The <u>enthalpy change</u>/<u>heat (energy) change</u> (at constant pressure) in a reaction is independent of the route/path taken (and depends only on the initial and final states)

1

(c) $\Delta H + 963 = -75 - 432$ OR $\Delta H + 963 = -507$ (**M1**)

$\Delta H = -75 - 432 - 963$ (**M1** and **M2**)

$\Delta H =$ **<u>–1470</u>** (kJ mol^{-1})

Award 1 mark for + 1470

<u>Award full marks for correct answer</u>

Ignore units.

Ignore numbers on the cycle

***M1** and **M2** can score for an arithmetic error*

3

[5]

Q12.

(a) (i) **M1** The enthalpy change / heat change at constant pressure

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when 1 mol of a compound / substance / product

1

M2 Is formed from its (constituent) elements

1

M3 With all reactants and products / all substances in standard states
OR
All reactants and products / all substances in normal states under standard conditions / 100 kPa / 1 bar and specified T / 298 K
Ignore reference to 1 atmosphere

1

(ii) By definition
OR
Because they are elements

1

(iii) **M1** $\Delta H_f = \Sigma\Delta H_f$ **(products)** – $\Sigma\Delta H_f$**(reactants)**

1

M2 = –1669 – 3(–558)
(This also scores M1)

1

M3 = **(+) 5** (kJ mol^{-1})
Correct answer gains full marks.
Assume the value is positive unless specifically stated as negative.
Credit 1 mark if – 5 (kJ mol^{-1}).
For other incorrect or incomplete answers, proceed as follows:
- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (M1 and M2)*
- *If no AE, check for a correct method; this requires either a correct cycle with 3BaO OR a clear statement of M1 which could be in words and scores only M1*

1

(b) (i) *One from*

- Aluminium is expensive (to extract *OR* due to electrolysis)
- High energy cost
- The cost of heating strongly
  This requires a clear statement about cost

1

(ii) *One from*

- increase collision frequency
- OR more collisions

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- OR <u>more chance of colliding</u>

  The answer MUST refer to <u>more collisions</u>.

  Ignore "more available to collide"

1

(c) (i) $Ba + \mathbf{2}H_2O \rightarrow Ba(OH)_2 + H_2$

Ignore state symbols
Allow multiples and correct ionic equations

1

(ii) **M1** $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$
(or the ions together)

Allow crossed out Na^+ ions, but penalise if not crossed out

1

M2 <u>White precipitate</u> / <u>white solid</u>

Ignore state symbols
Ignore "milky"

1

(iii) **M1** Barium meal or (internal) X-ray or to block X-rays

1

M2 <u>$BaSO_4$ / barium sulfate is insoluble</u> (and therefore not toxic)

Accept a correct reference to M1 written in the explanation in M2, unless contradictory.

For M2 NOT barium ions
NOT barium
NOT barium meal and NOT "It".

Ignore radio-tracing.

1

[14]

Q13.

(a) The enthalpy change when 1 mol of a compound

1

is completely burnt in oxygen

1

under standard conditions, or 298K and 100kPA

1

(b) (i) $C_2H_6 + 3½O_2 \rightarrow 2CO_2 + 3H_2O$

1

(ii) $\Delta H = 2 \times \Delta H_f^{\ominus} (CO_2) + 3 \times \Delta H_f^{\ominus} (H_2O) - \Delta H_f^{\ominus} (C_2H_6)$

1

$= -788 - 858 - (-85)$

1

$= -1561 \text{ kJ mol}^{-1}$

1

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(c) moles methane = $\frac{0.10}{16}$ = 6.25×10^{-3}

1

kJ evolved = $6.25 \times 10^{-3} \times 890 = 5.56$

1

5.56×10^3 joules = (mc)ΔT

1

$\Delta T = \frac{5.56 \times 10^3}{120}$ = 46.4 K

1

[11]

Q14.

(a) Enthalpy change when 1 mol of compound (1)

Is formed from it's elements (1)

All substances in their standard state (1)

3

(b) $\Delta H = \Sigma \Delta H^{\ominus}c$ (reactants) – $\Sigma \Delta H^{\ominus}c$ (products) (1)

= (7*x* – 394) + (4 *x* – 286) – (– 3909) (1)

= + 7 $kJmol^{-1}$ (1)

3

(c) Heat change = m c Δ*T* (1)

= 250 × 4.18 × 60 = 62700J = 62.7kJ (1)

Moles C_7H_8 = 2.5 /92 = 0.0272 (1)

ΔH = 62.7 / 0.0272 = – 2307 kJ mol^{-1} (1)
(allow –2300 to –2323)

4

(d) Mass of water heated = 25 + 50 = 75g
Temp rise = 26.5 – 18 = 8.5 °C
*both for **(1)** mark*

Heat change = 75 × 4.18 × 8.5 = 2665 J = 2.665 kJ (1)

Moles HCl = <u>0.05</u> (1)

Δ*H* = – 2.665 / 0.05 = –53.3 $kJmol^{-1}$ (1)
(allow –53 to –54)

4

(e) Less heat loss (1)

1

[15]

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Q15.

(a) enthalpy (or energy) to break (or dissociate) a bond;

1

averaged over different molecules (environments);

1

enthalpy (or heat energy) change when one mole of a compound;

1

is formed from its elements;

1

in their standard states;

1

(b) enthalpy change = Σ(bonds broken) – Σ(bonds formed) or cycle;

1

= 4 × 388 +163 + 2 × 146 + 4 × 463 – (944 + 8 × 463);
(or similar)

1

= –789;
(+ 789 scores 1 only)

1

(c) (i) zero;

1

(ii) *AH* = Σ (enthalpies of formation of products)
–Σ (enthalpies of formation of reactants)

1

= 4 × –242-(75 + 2 × –133);

1

= –777;
(+ 777 scores one only)

1

(d) mean bond enthalpies are not exact
(or indication that actual values are different from real values)

1

[13]

Q16.

(a) enthalpy change/ heat energy change when 1 mol of a substance

1

is completely burned in oxygen

1

at 298K and 100 kPa or standard conditions

1

(not 1atm)

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(b) $\Delta H = \sum$ bonds broken – $\sum$ bonds formed

1

= (6 × 412) + 612 +348 + (4.5 × 496) – ((6 × 743) + (6 × 463))

1

= – 1572 kJ mol^{-1}

1

(c) by definition ΔH_f is formation from an element

1

(d) $\Delta H_c = \sum \Delta H_f$ products -$\sum \Delta H_f$ reactants or cycle

1

= (3 × – 394) + (3 × –242) – (+20)

1

= − 1928 kJ mol^{-1}

1

(e) bond enthalpies are mean/average values

1

from a range of compounds

1

[12]

Q17.

C

[1]

Q18.

(a) $\Delta H = \Sigma$(bonds broken) – Σ(bonds formed) (or cycle)

1

= +146 – 496/2 (or 2 × 463 + 146 –(2 × 463 + 496/2)

1

= – 102 (kJ mol^{-1}) **(1)**

*(accept no units, wrong units loses a mark; +102 scores **(1)** only)*

1

(b) $C(s) + 2H_2(g) \rightarrow CH_4(g)$ equation **(1)** Correct state symbols **(1)**

2

(c) (i) Macromolecular

(accept giant molecule or carbon has many (4) bonds)

1

(ii) $\Delta H = \Sigma \Delta H_f$(products) – $\Sigma \Delta H_f$(reactants) (or cycle)

1

= 715 + 4 × 218 – (–74.9)

1

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= 1662 (kJ mol^{-1})

(accept no units, wrong units loses one mark, allow 1660 to 1663, –1662 scores one mark only)

1

(iii) 1662/4 = 415.5

(mark is for divide by four, allow if answer to (c)(ii) is wrong)

1

[10]

Q19.

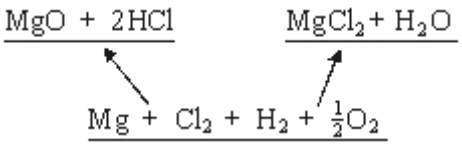
(a) (i) enthalpy (or heat or heat energy) change when 1 mol of a substance **(1)** (QL mark) is formed from its elements **(1)** all substances in their standard states **(1)** (or normal states at 298K, 100 kPa or std condits)

***not** STP, NTP*

3

(b) enthalpy change (or enthalpy of reaction) is independent of route **(1)**

$\Delta H = \Sigma\Delta H_f^{\ominus}$ prods - $\Sigma\Delta H_f^{\ominus}$ reactants (or cycle) **(1)**
minimum correct cycle is:



ΔH = -642 – 286 – (–602 + 2 × –92) **(1)**
= –142 (kJ mol^{-1}) **(1)**

penalise this mark for wrong units

+142 scores 1 mark out of the last three

4

(c) $\Delta H = mcT$ **(1)** (or $mc\Delta T$)
= 50 × 4.2 × 32 = 6720 J = 6.72J **(1)**

mark is for 6720 J or 6.72 kJ

moles HCl = $\frac{\text{vol}}{1000}$ × conc = $\frac{50}{1000}$ × 3 **(1)**

= 0.15 **(1)**

if error here mark on conseq.

Therefore moles of MgO reacted = moles HCl/2 **(1)**
(mark is for/2, CE if not/2)
= 0.15/2 = 0.075

Therefore ΔH = 6.72/0.075 **(1)**
= –90 kJ (mol^{-1})

kJ must be given, allow 89 to 91

*value **(1)***

*sign **(1)**; this mark can be given despite CE for /2*

8

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Note various combinations of answers to part (c) score as follows:

–89 to –91 kJ **(8)** (or –89000 to 91000J)
*no units **(7)***

+89 to +91 kJ **(7)** (or + 89000 to +91000J)
*no units **(6)***

–44 to –46 kJ **(5)** (or -44000 to -46000J)
*no units **(4)** if units after 6.72 or 6720 (5)*

+44 to +46 kJ **(4)** (or +44000 to + 46000)
if no units and
*if no units after 6.72 or 6720 **(3)***
*otherwise check, could be **(4)***

[15]

Q20.

(a) They are elements **(1)**
Ignore irrelevant comments

1

(b) Enthalpy <u>change</u> **(1)**
or heat energy change or heat change or ΔH or any named enthalpy change C.E. if change not mentioned

Independent of route **(1)**
OR depends on initial and final <u>states</u>
Only give second mark if first mark awarded except allow if energy used instead of enthalpy

2

(c) $\Delta H = \Sigma \Delta H_f^{\ominus}$(products) - $\Sigma \Delta H_f^{\ominus}$(reactants) **(1) (Or a cycle)**
$= 2 \times -242 + ½ \times -394 - (-365)$ **(1) (also implies first mark)**
$= -316$ kJ mol^{-1} **(1)**

3

Ignore no units penalise wrong units
+316 scores 1/3

[6]

Q21.

(a) Heat energy change **(1)**
Not energy on its own

measured at constant pressure **(1)**
Mark separately, ignore constant temperature statements

2

(b) (i) Enthalpy change when 1 mol of a substance (or compound / product) **(1)** is formed from its constituent elements **(1)** in their standard states **(1)** under standard conditions **(1)**
Mark separately

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(ii) $2Na(s) + S(s) + 2O_2(g) \rightarrow Na_2SO_4(s)$

Balanced (1) State symbols (1), but only if all species are correct

Allow $\frac{1}{8} S_8(s)$

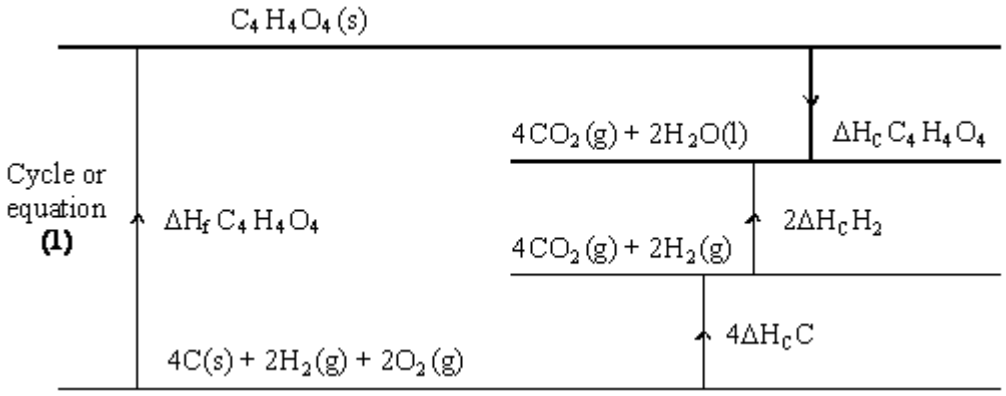
5

(c) Enthalpy change is independent of reaction route **(1)**

Penalise incorrect additional statements

1

(d)



$-1356 + (2 \times 285.8) + (4 \times 393.5) + \Delta H_f C_4H_4O_4 = 0$

$\Delta H_f = -789.6$ kJ mol^{-1}

If answer is incorrect:

Score +789.6 two marks

Score (× 1); (× 2) and (× 4) for species - one mark

If an incorrect negative answer given check for AE for loss of one mark

3

[11]

Q22.

(a) (Enthalpy change) when 1 mol **(1)** of a compound is formed from its constituent elements **(1)** in their standard states **(1)**

3

Allow energy or heat, Ignore evolved or absorbed
Mark each point independently

(b) (The enthalpy change for a reaction is) independent of the route **(1)**

1

(c) $\Delta H_R = \Sigma\Delta H_f$ products - $\Sigma\Delta H_f$ reactants **(1)**
= [(3 × -286) + (3 × -394)] - (-248) **(1)**
= -1792 **(1)** (kJ mol^{-1})

Deduct one mark for each error to zero

3

[7]

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Q23.

C

[1]

Q24.

B

[1]

Q25.

D

[1]

Q1.

(a) This was poorly answered, with many students missing state symbols and balancing the equation incorrectly. Only the best students (24.6%) gained the mark here.

(b) This proved challenging compared to questions set in the previous specification from this topic area. 34.3% of students failed to pick up even one mark.

(c) Again challenging for all but the best students, only 26.3% scored more than one mark.

(d) This was not as well answered as might have been expected. The fact that mean bond enthalpies are calculated using a range of compounds was not well understood.

Q3.

Two-thirds of the marks in this enthalpy-based question involved students being able to carry out calculations based on Hess' Law and, as always, there was a divide between those who could cope with such questions and those who couldn't.

In part (a) the importance of learning definitions was illustrated. Many students failed to make clear that all reactants and products need to be in their standard states.

In questions such as part (b) students are strongly advised to start with a clear and complete indication of the expression relating the enthalpy change of the reaction to the data given or to draw out a clearly labelled cycle. Students who relied on the use of a learned expression often got this wrong way round, possibly due to confusion with the use of enthalpies of formation whereas, in this case, the data provided were enthalpies of combustion.

In a question like part (c) students are strongly advised to sketch out the displayed formulae of all reactants and products when working with bond energies. Failing to do so in many cases meant that bonds were omitted or miscounted (3 × C-C in propan-1-ol was often seen) by students.

Q4.

This question was answered well. Balancing the equation in part (a)i looks straightforward when you know the answer, but it is quite demanding if you have to work it out, and impressively half the students gave the correct answer. In part (b)i, it was necessary to draw unambiguous structures both for propan-2-ol (not given in the question) and propanone (given in part (a)i). The calculation in part (c) was well answered with the focus on correct chemistry rather than on the number of significant figures and the mathematics of rounding the final answer. The definition in part (d) was expected to be straightforward and yet still resulted in only 40% gaining all three marks. As many as 45% gained all three marks and 80% gained at least one mark from the very straightforward calculation in part (e), with errors occurring because some students did not know the bonding either in propanone or in carbon dioxide and used the unnecessary C−O that was given in the data set. It was decided that the very straightforward idea of "heat loss", in whatever context, was worth only one mark in part (f) and that students needed to come up with other reasons why the values in part (c) and part (e) differed; many were able to do so and this led to 54% scoring both marks.

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Q5.

In part (a)(i), some students missed either the fact that the catalyst has to be a concentrated strong acid or that the unreacted ethene is re-circulated to achieve an overall yield of 95% and this meant that only a small number of students scored both marks. Considerable latitude was allowed in the responses for part (a)(ii), since it was clear that many students did not really understand what was happening in this process and this approach to the marking enabled the majority of students to gain at least two marks out of three. In part (a)(iii), some students recognised the possibility of poly(ethene) being formed and approximately 17% of students gained both marks.

It has been a while since a question like part (b) has been asked and it was not well answered with few students gaining full marks and over half scoring zero. Balancing the correct equation and then including the correct state symbols were both needed for full marks. Parts (c) and (d) proved straightforward for many and full marks were seen from over a third of students in each of parts (c)(i) and (c)(ii), respectively.

Q6.

Section B proved more demanding. In part (a), the calculation had similar faults to Question 5 but some students failed to read that the answer was to be in Joules - an answer in kJ was penalized unless there was a clear correct answer in the working. Part (b) and part (c) were well done though the alternative answer to part (a) was frequently used in these. In part (d), only a few students failed to highlight the need for the bag to split or the chemicals to come into contact with skin / hands. Part (e)(i) indicated that a considerable number of students found difficulties with the equation; common errors were the wrong formula for iron (III) oxide, the inclusion of ions on the reagent side of the equation and using Fe2 for the metal. Part (e)(ii) contained many good partial answers but there was a significant failure to focus finally on why longer times might not be an advantage. In part (f)(i), the main errors were to re-state the question about being reusable or to indicate that there would be no waste following use of these handwarmers. There were some vague answers to part (f)(ii) which referred to 'heating' the bag or 'keeping it in a warm place' and, for some, the contents were removed before further treatment. Nevertheless, sensible answers were frequently seen.

Q7.

The thinking required in part (b)(i) proved too much for many and only a few were able to state that, in practice, CO is not the only product and that some complete combustion to form CO_2 would occur. The answer of +1 kJ mol^{-1} was seen frequently in part (c), but some were disconcerted by this value and sought to find an alternative. State symbols were often missed in part (d)(i) and a clear statement in part (d)(ii) that the same reaction occurs for the two specified standard enthalpies was not well understood.

Q8.

Overall, this was a relatively high-scoring question although only 26% of the candidates stated that enthalpy change is the heat change at constant pressure in part (b). Definitions continue to be learned poorly by a proportion of candidates and 15% of candidates failed to score any marks in part (d).

Q9.

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Answers to part (a) were disappointing. Very few candidates scored all four marks and the average score was less than half marks. Typical errors were a failure to mention the formation of one mole of atoms and also to omit to state that the atoms and ions formed should be gaseous. In part (b), only the best candidates gained full marks. Most candidates either failed to use the correct enthalpy change for the formation of one mole of chlorine atoms, using the bond enthalpy without halving it, or incorrectly doubled the electron affinity of chlorine. In part (c)(i), very few candidates were able to give a full explanation of the term perfect ionic model but answers to parts (c)(ii) and (c)(iii) were usually correct.

Q10.

In part (a), candidates rarely knew the meaning of the term molecular ion. In part (b), most could show why the answer for the precise M_r of N_2O was 44.00105, but the fact that both propane and carbon dioxide could be confused with N_2O using M_r values to one decimal place, was not always explained. In part (b)(iii), the idea that the precise M_r for the ^{12}C isotope is defined as exactly 12.00000 was poorly understood. The calculation proved straightforward for many candidates with 65% gaining full marks. The common mistake was an answer of +684 kJ mol^{-1}. Only half of the candidates knew about a standard pressure of 100 kPa in part (c)(ii).

Q11.

Only 20% of the candidates stated that enthalpy change is the heat change at constant pressure, even though this is stated clearly in the specification. It was pleasing to see that more than half the candidates could correctly apply Hess's Law to an unfamiliar cycle and arrive at the right answer for the specified enthalpy change.

Q12.

The range of answers given to the meaning of the term *standard enthalpy of formation* in part (a)(i) indicated the variation in the ability of the candidates to learn basic information. Application of that information in the remainder of part (a) was generally well done, although too many candidates had their data the wrong way around in part (a)(iii).

Part (b) was answered correctly by approximately half of the candidates and there were some good answers in each section of part (c). The ability to construct and balance equations, including the simplest ionic equation in part (c)(ii), was made impossible for those candidates who did not know that Ba^{2+} is the formula of the barium ion.

Q14.

Part (a) was generally well done by most candidates. The most common error was not referring to standard states. The calculation in part (b) proved more demanding for students than some previous enthalpy calculations with many candidates giving the incorrect answer of –7kJmor\ A large number of candidates did not give the correct mass or correct temperature rise in part (c) and therefore only scored the mark for the $Q = mc\Delta t$ equation. Many of the candidates who did calculate the heat evolved then failed to calculate molar quantities. The calculation in part (d) proved very difficult for candidates with very few scoring full marks. Common errors were incorrect mass, incorrect temperature rise and lack of conversion to molar quantities. Candidates should know that exothermic reactions are shown by a negative sign e.g. –53.3kJmol^{-1}. In part (e) many candidates failed to make the comparison regarding heat loss between the two experiments.

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Q15.

More able candidates were able to obtain high marks for this question but less able candidates found the calculations hard. In part (a) candidates lost a mark if they referred to bond-formation instead of bond-breaking. Less able candidates were unable to explain that mean bond enthalpy refers to an average of bonds where the environment is different, usually due to existence in different molecules. In part (b) many candidates provided incorrect answers because they did not work out the correct number of bonds being broken or formed. For example, only the best candidates recognised that two O—O bonds were broken. It was disappointing in part (c) (i) that many candidates did not understand the question. It was quite common to find candidates attempting a calculation using the equation, the enthalpy of formation values given in the table and an assumption that the enthalpy change for the equation was zero. Answers to part (c) (ii) were more usually correct though weaker candidates failed to take account of the two moles of hydrogen peroxide and the four moles of water. Answers to part (d) were usually incorrect. A common wrong answer was the statement 'Heat loss'.

Q16.

More able candidates were able to obtain high marks in this question but the weaker candidates found the calculations difficult. The definition in (a) was usually attempted well with the majority of candidates scoring 3 marks. Answers to (b) discriminated between candidates. There were several arithmetic errors in the calculation, and a few candidates who did not know to subtract the sum of the bonds made from the sum of the bonds broken leading to an incorrect sign in the final answer. Most candidates realised that oxygen was an element in (c). Again the calculation in (d) discriminated well. A common incorrect answer was 1888 $kJmol^{-1}$ which was usually due to doing the calculation the wrong way round. Weaker candidates also failed to take account of the 3 moles of water and carbon dioxide in their calculation. The explanation of why answers to (b) were less accurate than (a) was not done as well as expected with many candidates scoring one out of the 2 marks. Candidates should know that mean bond enthalpies are averaged over a range of compounds which contain the same bond, or from the same compound which contains several of the same type of bond. A common incorrect answer here was ‘heat loss’.

Q18.

Good candidates were able to obtain high marks for this question but weak candidates found it very difficult and marks of zero out of ten were not unusual. In part (a), a common mistake was to use the O—O single bond enthalpy rather than the correct value for the O=O double bond and also to use one mole of oxygen rather than half a mole. In part (b) the balanced equation was usually correct but the state symbol for carbon was frequently shown as gaseous rather than solid (or graphite). In Part (c) (i) only the best candidates appeared to notice the wording in the question which required a reference to the structure of solid carbon. Part (c) (ii) also proved to be a difficult question for weaker candidates who rarely multiplied the enthalpy of formation of hydrogen atoms by the factor four. Also, the enthalpy of formation of methane (–74.9 kJ mol^{-1}) was usually added rather than subtracted. Incorrect cycles and equations involving combustion of methane were also common errors. Part (c) (iii) was answered well; the mark was awarded for dividing the answer to part (c) (ii) by four.

Q19.

Most candidates answered this question well though it proved to be difficult to score maximum marks. The definition of standard enthalpy of formation in part (a) was usually correct though some candidates lost one mark because they did not make it clear that reactants and products should be in their standard states. In part (b) good candidates

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were able to score maximum marks but weaker candidates sometimes referred to energy rather than enthalpy when stating Hess's Law and such candidates often predicted an endothermic enthalpy change (+142 kJ mol^{-1}) rather than an exothermic one. Part (c) proved to be the most difficult part of this question. The major error was in the number of moles of magnesium oxide. Most candidates assumed that the number of moles of MgO would be the same as that of hydrochloric acid whereas it should have been half of that. This error led to a value for the enthalpy change that was too small by a factor of two. Such an answer resulted in the loss of three marks.

Q20.

This question was answered well by many candidates. Answers to part (a) were usually correct. Most candidates provided good answers to part (b) but some lost marks because they referred to energy or to enthalpy alone rather than to enthalpy change. In part (c) the most common error was to invert signs leading to an answer of 316 kJ mol-1 rather than to –316 kJ mol^{-1}.

Q21.

The meaning of the term enthalpy change, required in part (a), was not well stated and whilst many correctly referred to the heat energy change, most failed to state that this was measured at constant pressure. Part (b) was well answered with many correct definitions of the term standard enthalpy of formation of a compound though slightly fewer candidates gave a correct equation with state symbols in section (ii). Hess's Law was correctly stated by many candidates and it is particularly pleasing to report that the calculation required in part (d) was very well done.

Q22.

This question was very well answered and many candidates were able to score full marks. Happily, as candidates showed working in part (c), part marks could be awarded when incorrect answers were given.

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Q1.

This question is about enthalpy changes.

(a) When ethanoic acid reacts with sodium hydroxide, the enthalpy change, ΔH, is –56.1 kJ mol^{-1}

$$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$$

Calculate the temperature rise when 25 cm^3 of 2.0 mol dm^{-3} aqueous ethanoic acid react with 25 cm^3 of 2.0 mol dm^{-3} aqueous sodium hydroxide.

Assume that both solutions have the same initial temperature, have a density of 1.0 g cm^{-3} and a specific heat capacity of 4.18 J K^{-1} g^{-1}

Temperature rise _____ °C

(4)

(b) A student recorded the temperature of aqueous ethanoic acid in a polystyrene cup for three minutes.

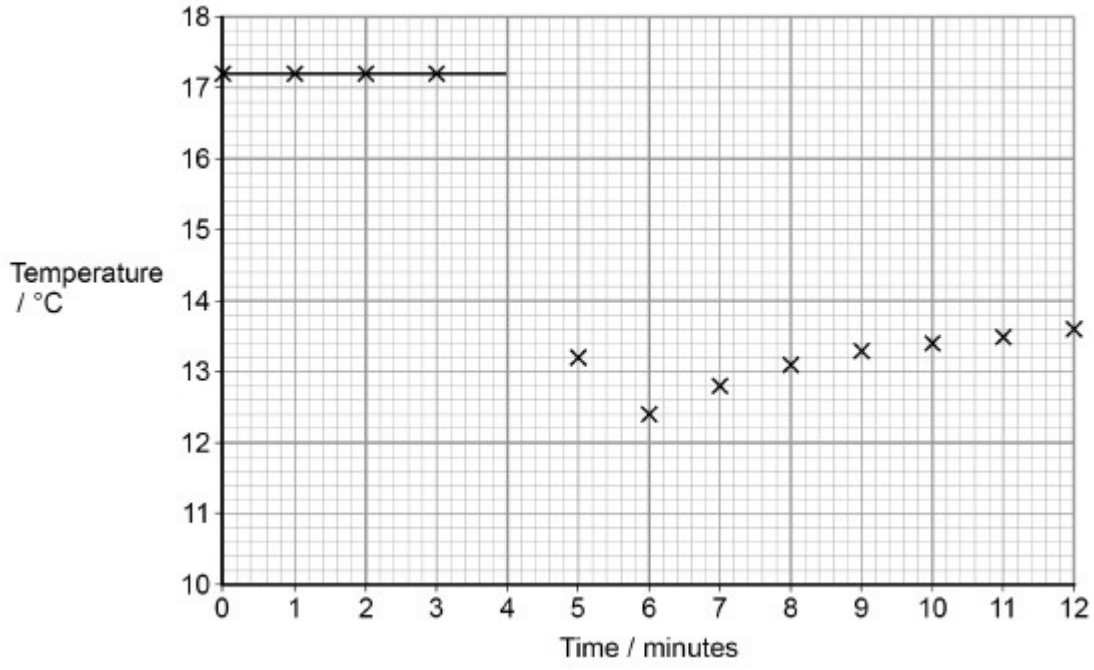
At the fourth minute, the student added sodium hydrogencarbonate.

The student stirred the mixture and carried on recording the temperature every minute for several minutes.

The student's measurements are shown in the graph.

A best-fit line showing the temperature before mixing has been drawn.

Draw an appropriate best-fit line on the graph and use it to find the temperature change at the time of mixing.



Temperature change at time of mixing _____ °C

(2)

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(Total 6 marks)

Q2.

The oxidation of propan-1-ol can form propanal and propanoic acid.
The boiling points of these compounds are shown in the table.

Compound	Boiling point / °C
propan-1-ol	97
propanal	49
propanoic acid	141

In a preparation of propanal, propan-1-ol is added dropwise to the oxidising agent and the aldehyde is separated from the reaction mixture by distillation.

(a) Explain, with reference to intermolecular forces, why distillation allows propanal to be separated from the other organic compounds in this reaction mixture.

(3)

(b) Give **two** ways of maximising the yield of propanal obtained by distillation of the reaction mixture.

1. _____

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_____

_____

_____

2. _____

_____

_____

_____

_____

_____

(2)

(c) Describe how you would carry out a simple test-tube reaction to confirm that the sample of propanal obtained by distillation does **not** contain any propanoic acid.

_____

_____

_____

_____

_____

_____

(2)

(d) A student carried out an experiment to determine the enthalpy of combustion of ethanol.
Combustion of 457 mg of ethanol increased the temperature of 150 g of water from 25.1 °C to 40.2 °C

Calculate a value, in kJ mol^{-1}, for the enthalpy of combustion of ethanol in this experiment.
Give your answer to the appropriate number of significant figures.

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

Enthalpy of combustion _____ kJ mol^{-1}

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(3)

(e) A mixture of isomeric alkenes is produced when pentan-2-ol is dehydrated in the presence of hot concentrated sulfuric acid. Pent-1-ene is one of the isomers produced.

Name and outline a mechanism for the reaction producing pent-1-ene.

Name of mechanism _____

Mechanism

(4)

(f) A pair of stereoisomers is also formed in the reaction in **part (e)**.

Name the less polar stereoisomer formed.
Explain how this type of stereoisomerism arises.

Name _____

Explanation _____

_____

_____

_____

(2)

(Total 16 marks)

Q3.

A student carried out an experiment to find the temperature rise for a reaction between hydrochloric acid and sodium hydroxide solution.

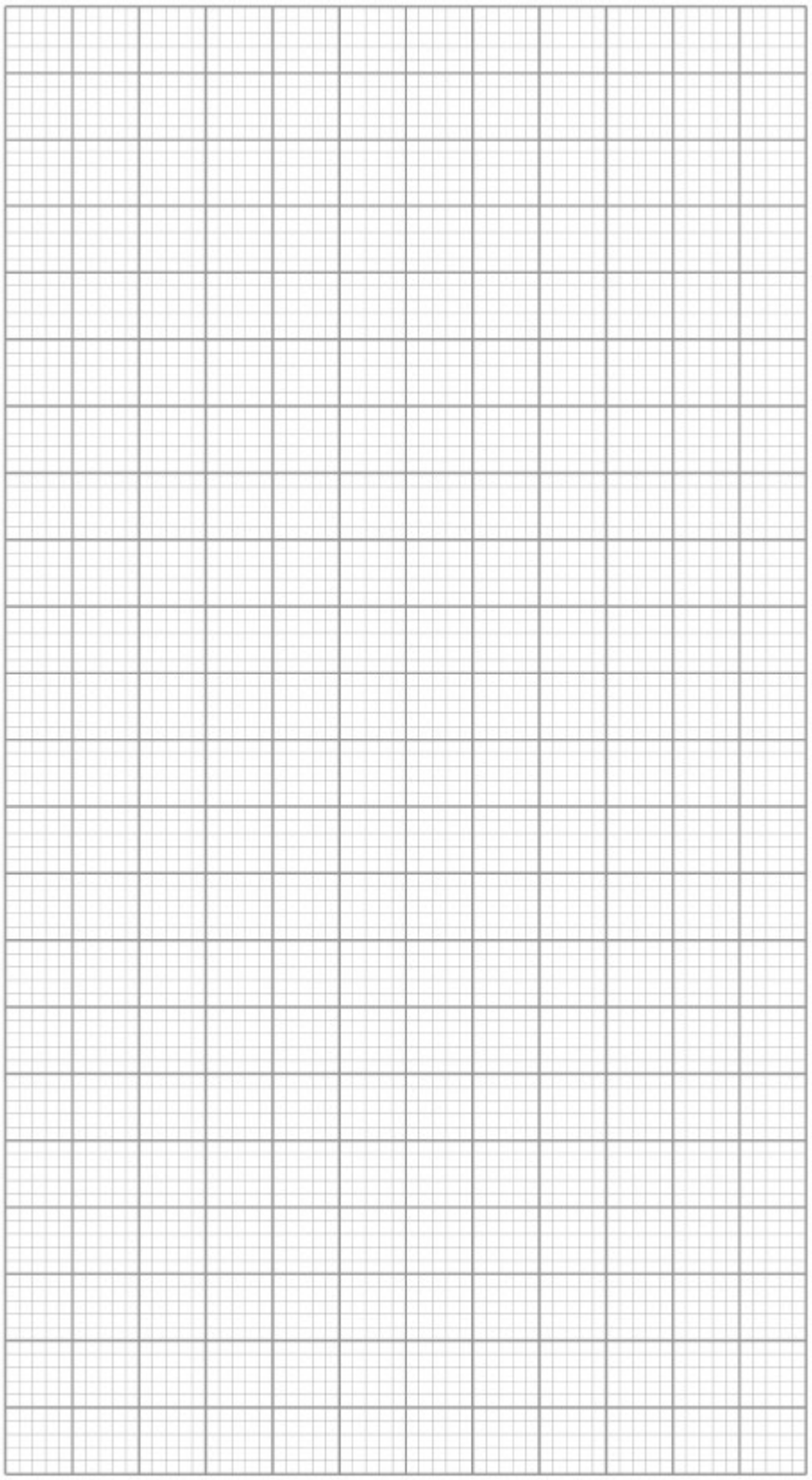
- The student used a measuring cylinder to place 50 cm^3 of 0.400 mol dm^{-3} hydrochloric acid into a glass beaker.
- The student recorded the temperature at one-minute intervals for three minutes.
- At the fourth minute the student added 50 cm^3 of 0.400 mol dm^{-3} sodium hydroxide solution and stirred to mix the solutions, but did not record the temperature.
- The student recorded the temperature at one-minute intervals for a further eight minutes.

The results are shown in the table.

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Time / min	0	1	2	3	4	5	6	7	8	9	10	11	12
Temperature / °C	19.8	19.8	19.8	19.8		21.4	21.7	21.6	21.5	21.4	21.3	21.2	21.1

(a) Plot a graph of temperature against time on the grid below.



Use your graph to find the temperature rise, ΔT, at the fourth minute.

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Show your working on the graph by drawing suitable lines of best fit.

ΔT _____ °C

(5)

(b) The uncertainty in each of the temperature readings from the thermometer used in this experiment was ±0.1° C

Calculate the percentage uncertainty in the value for the temperature rise.

Percentage uncertainty _____

(1)

(c) Suggest a change to the experiment that would minimise heat loss.

_____

_____

(1)

(d) Suggest and explain another change to the experiment that would decrease the percentage uncertainty in the use of the same thermometer.

_____

_____

_____

_____

(2)

(e) A second student completed an experiment to determine the enthalpy of neutralisation for the reaction between ethanedioic acid solution (HOOCCOOH) and potassium hydroxide solution.

The student added 25 cm^3 of 0.80 mol dm^{-3} ethanedioic acid solution to 75 cm^3 of 0.60 mol dm^{-3} potassium hydroxide solution.
The temperature increased by 3.2 °C

Give an equation for the reaction between ethanedioic acid solution and potassium hydroxide solution.

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Calculate the enthalpy change (ΔH) per mole of water formed in this reaction.
Assume that the specific heat capacity of the reaction mixture is 4.2 J K^{-1} g^{-1}
Assume that the density of the reaction mixture is 1.00 g cm^{-3}
Equation _____

ΔH _____ kJ mol^{-1}

(5)

(f) In a similar experiment to that in **part (e)**, the enthalpy of neutralisation for the reaction between sulfuric acid and potassium hydroxide solution was found to be –57.0 kJ mol^{-1} per mole of water formed.

Suggest an explanation for the difference between this value and your answer to **part (e)**.

(If you were unable to obtain an answer to **part (e)** you should assume a value of –28.5 kJ mol^{-1}. This is **not** the correct answer.)

_____

_____

_____

_____

_____

_____

(2)

(Total 16 marks)

Q4.

A student planned and carried out an experiment to determine the enthalpy of reaction when magnesium metal displaces zinc from aqueous zinc sulfate.

$$Mg(s) + Zn^{2+}(aq) \longrightarrow Mg^{2+}(aq) + Zn(s)$$

The student used this method:

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- A measuring cylinder was used to transfer 50 cm^3 of a 1.00 mol dm^{-3} aqueous solution of zinc sulfate into a glass beaker.
- A thermometer was placed in the beaker.
- 2.08 g of magnesium metal powder were added to the beaker.
- The mixture was stirred and the maximum temperature recorded.

The student recorded a starting temperature of 23.9 °C and a maximum temperature of 61.2 °C.

(a) Show by calculation which reactant was in excess.

Use the data to calculate the experimental value for enthalpy of reaction in kJ mol^{-1}(Assume that the specific heat capacity of the solution is 4.18 J $K^{-1}g^{-1}$and the density of the solution is 1.00 g cm^{-3}).

Reactant in excess _____

Enthalpy of reaction _____ kJ mol^{-1}

(6)

(b) Another student used the same method and obtained a value for the enthalpy of reaction of −142 kJ mol^{-1}

A data book value for the enthalpy of reaction is −310 kJ mol^{-1}

Suggest the most likely reason for the large difference between the student's experimental value and the data book value.

_____

_____

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_____

(1)

(c) Suggest how the students' method, and the analysis of the results, could be improved in order to determine a more accurate value for the enthalpy of reaction.

Justify your suggestions.

Do not refer to the precision of the measuring equipment. Do not change the amounts or the concentration of the chemicals.

_____

_____

_____

_____

_____

_____

_____

_____

(6)

(Total 13 marks)

Q5.

Anhydrous magnesium chloride, $MgCl_2$, can absorb water to form the hydrated salt $MgCl_2.4H_2O$

$$MgCl_2(s) + 4H_2O(l) \longrightarrow MgCl_2.4H_2O(s)$$

(a) Suggest **one** reason why the enthalpy change for this reaction cannot be determined directly by calorimetry.

_____

_____

(1)

(b) Some enthalpies of solution are shown in Table 1.

Table 1

Salt	Enthalpy of solution / kJ mol^{-1}
$MgCl_2(s)$	−155
$MgCl_2.4H_2O(s)$	−39

Calculate the enthalpy change for the absorption of water by $MgCl_2(s)$ to form $MgCl_2.4H_2O(s)$.

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Enthalpy change _____ kJ mol^{-1}

(2)

(c) Describe how you would carry out an experiment to determine the enthalpy of solution of anhydrous magnesium chloride.

You should use about 0.8 g of anhydrous magnesium chloride.

Explain how your results could be used to calculate the enthalpy of solution.

_____

_____

_____

_____

_____

_____

_____

_____

(6)

(d) Anhydrous magnesium chloride can be formed by direct reaction between its elements.

$$Mg(s) + Cl_2(g) \longrightarrow MgCl_2(s)$$

The free-energy change, ΔG, for this reaction varies with temperature as shown in **Table 2**.

Table 2

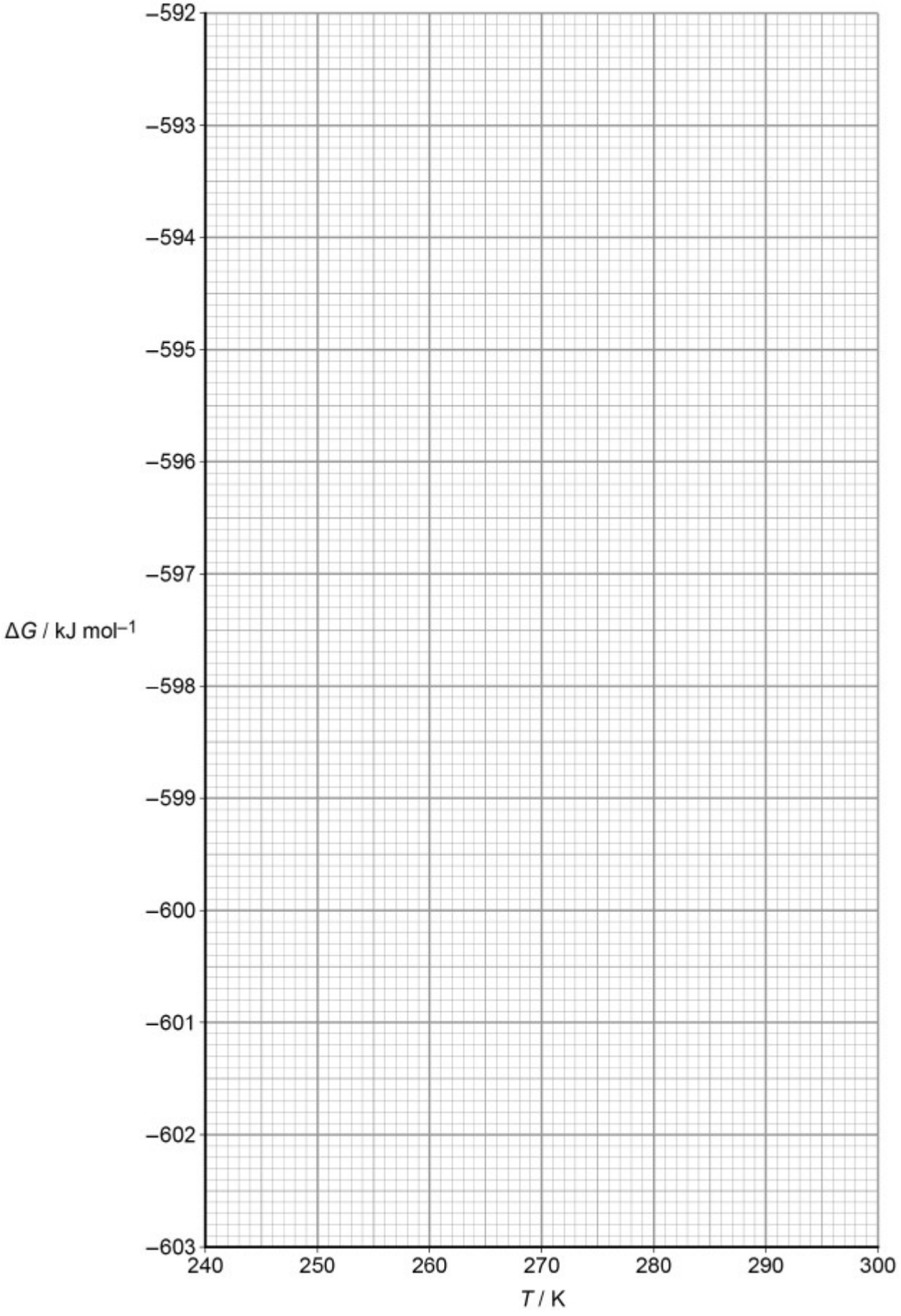
T / K	ΔG / kJ mol^{-1}
298	−592.5
288	−594.2
273	−596.7
260	−598.8
240	−602.2

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Use these data to plot a graph of free-energy change against temperature on the grid below.

Calculate the gradient of the line on your graph and hence calculate the entropy change, ΔS, in $J K^{-1} mol^{-1}$, for the formation of anhydrous magnesium chloride from its elements.

Show your working.



ΔS _____ $JK^{-1}mol^{-1}$

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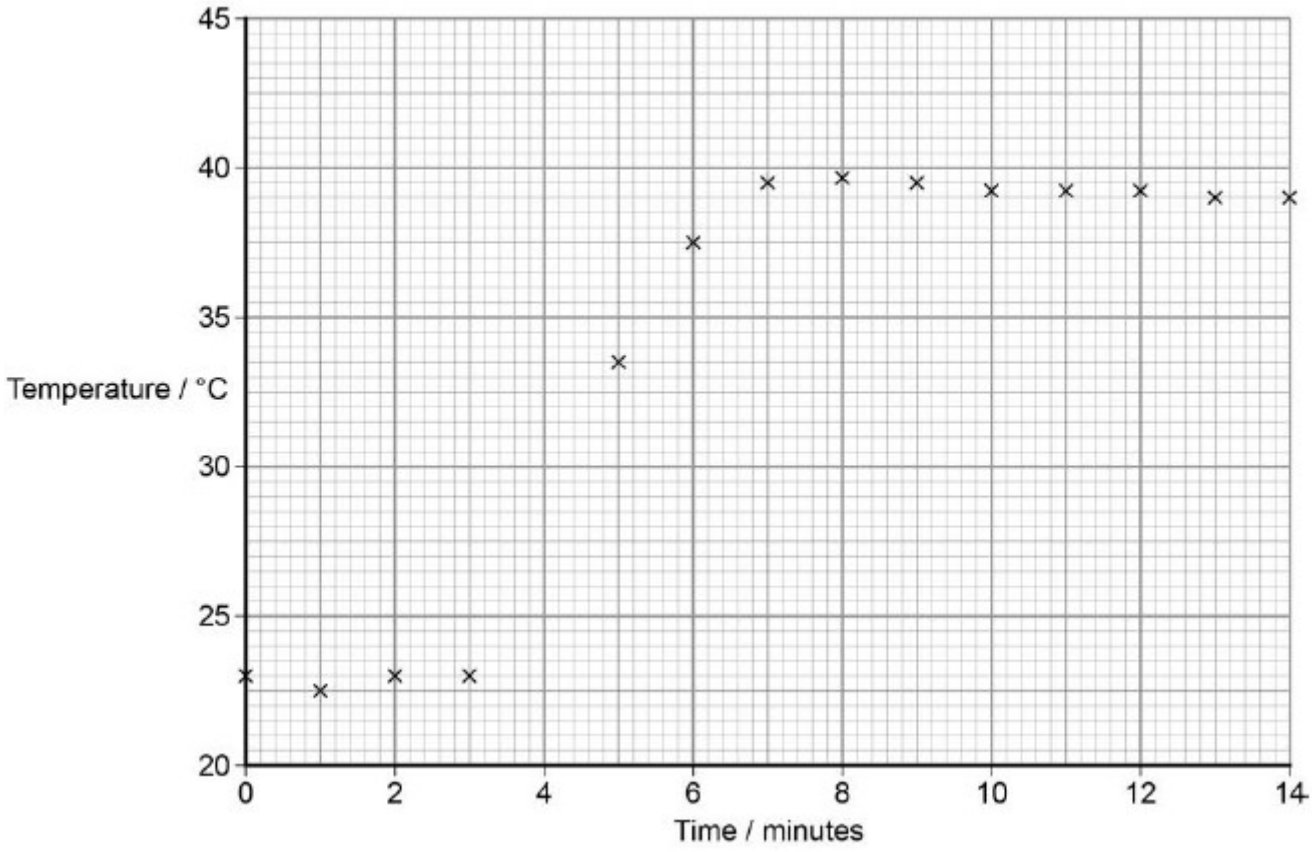
(5)
(Total 14 marks)

Q6.

A student carried out a reaction between magnesium ribbon and aqueous trichloroethanoic acid in order to determine the enthalpy change. The equation for the reaction is shown:

$$Mg(s) + 2H^+(aq) \longrightarrow Mg^{2+}(aq) + H_2(g)$$

The student measured the initial temperature of the trichloroethanoic acid and again every minute for 3 minutes before adding the magnesium ribbon at the fourth minute.
The student continued to measure the temperature every minute for a further 10 minutes.
The graph for these measurements is shown below.



The student used 240 mg of magnesium and 10.0 cm^3 of aqueous trichloroethanoic acid (an excess).

Use these data and information determined from the graph above to calculate the enthalpy change, in kJ mol^{-1}, for this reaction.
Show your working.
Give your answer to an appropriate precision.
(The specific heat capacity of water = 4.18 J K^{-1} g^{-1})

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Enthalpy change = _____ kJ mol^{-1}

(Total 7 marks)

Q7.

What is the temperature rise, in K, when 504 J of heat energy are absorbed by 0.110 kg of solid iron?
Specific heat capacity of iron = 0.448 J K^{-1} g^{-1}

A 9.78×10^{-2} ⬭

B 1.02×10^{1} ⬭

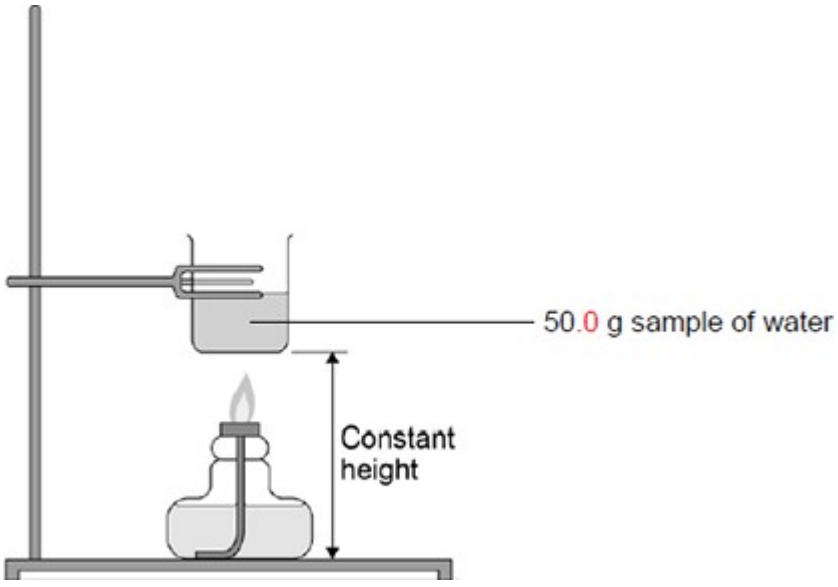
C 2.83×10^{2} ⬭

D 1.02×10^{4} ⬭

(Total 1 mark)

Q8.

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.

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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 ($CH_3CH_2CH=CHCH_2CH_2OH$).

_____

(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.

_____

_____

_____

_____

_____

(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)

Q9.

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.

_____

_____

_____

_____

_____

_____

_____

_____

(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}

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(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.

_____

_____

_____

_____

_____

(2)
(Total 12 marks)

Q10.

An engineer was trying to develop a new fuel for a motorboat by blending mixtures of different alcohols in order to find out which mixture released the most energy when used in the engine.

The engineer had a number of alcohols in unlabelled bottles. It was decided to identify the alcohols by determining their enthalpies of combustion and comparing these values with those from a data book.

(a) Outline a simple practical experiment that the engineer could use, including the measurements to be taken, in order to determine the enthalpy of combustion for one of the unknown alcohols. You do **not** need to include details of any calculations.

_____

_____

_____

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_____

_____

_____

_____

_____

(5)

(b) Other than heat loss to the surroundings, identify **two** major sources of error in the experiment. Do **not** refer to the precision of the equipment.

_____

_____

_____

_____

_____

(2)

(c) The engineer found that the experimental values for the enthalpies of combustion of butan-1-ol and methylpropan-2-ol were very similar and so these values could not be used to distinguish between the two alcohols.

Identify a reagent that the engineer could use to distinguish between these two alcohols.
Give the observation in each case.

Reagent _____

_____

Butan-1-ol _____

_____

Methylpropan-2-ol _____

_____

(3)

(d) The filter in the air intake for the engine in the motorboat may become partially blocked by dust and debris.

Explain with the aid of an equation why combustion of methylpropan-2-ol under these circumstances would be of economic and environmental concern to the engineer.

_____

_____

_____

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(3)
(Total 13 marks)

Q11.

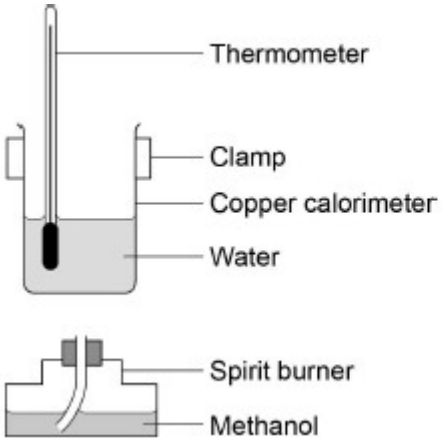
Alcohols such as methanol (CH_3OH), ethanol (CH_3CH_2OH) and propan-1-ol ($CH_3CH_2CH_2OH$) are good fuels.

(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.

_____

_____

(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.

_____

_____

(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.

_____

_____

_____

(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.

_____

_____

_____

_____

(3)

(Total 10 marks)

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Q12.

(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.

_____

(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.

_____

(1)

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

_____

(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)

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(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 _____

_____

_____

Reason 2 _____

_____

_____

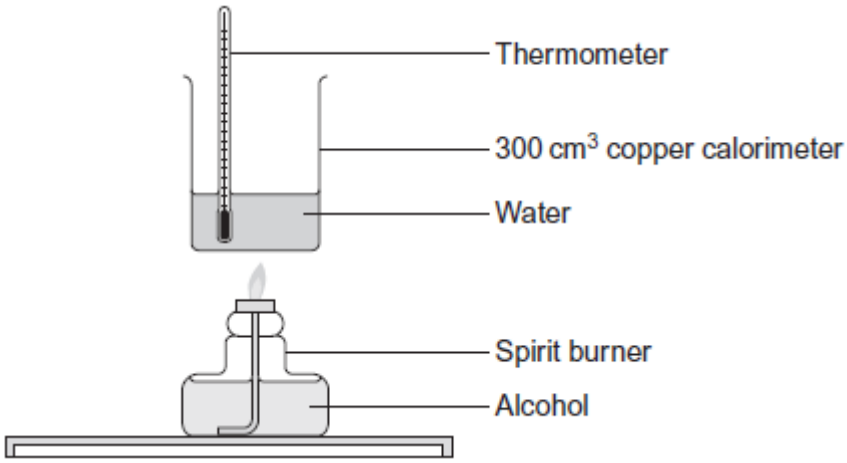
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(Total 15 marks)

Q13.

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: _____

_____

(Total 2 marks)

Q14.

Ethanol is an important fuel.

(a) A dilute aqueous solution of ethanol can be produced by the fermentation of an aqueous solution of glucose.
It is claimed that the ethanol obtained from this solution is a carbon-neutral biofuel.

Write an equation for this fermentation reaction.

Give **two** other essential conditions for this reaction to produce a good yield of ethanol.

Name a process used to produce a much more concentrated solution of ethanol from a dilute aqueous solution.

State the meaning of the term **carbon-neutral** in the context of this biofuel.

_____

_____

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(5)

(b) 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}.

(5)

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

(i) Give the meaning of the term **mean bond enthalpy**.

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_____

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(2)

(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 15 marks)

Q15.

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

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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.

(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.)

(3)

(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)

Q16.

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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(3)

(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.

(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.

(3)

(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.

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Calculate the final temperature of the solution.

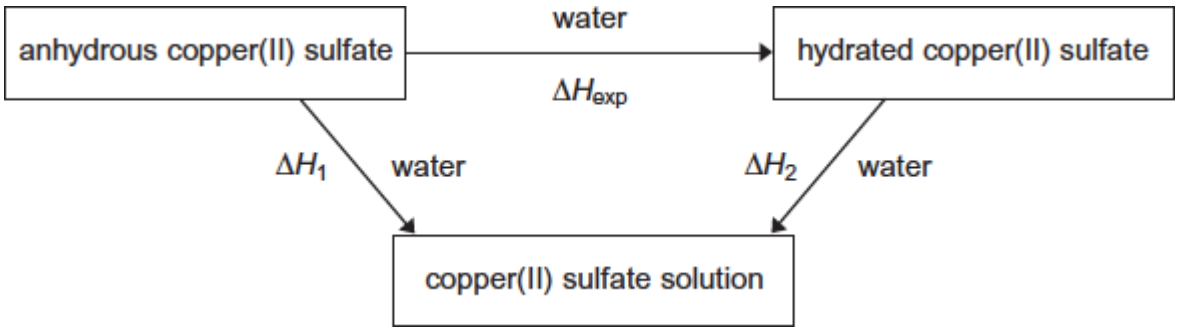
In your calculation, assume that only the 20.0 g of water changes in temperature and that the specific heat capacity of water is 4.18 J K^{-1} g^{-1}.

(5)

(Total 13 marks)

Q17.

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.

(1)

(b) Write a mathematical expression to show how ΔH_{exp}, ΔH_1 and ΔH_2 are related to

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each other by Hess's Law.

_____

(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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(1)

(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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(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).

_____

_____

(1)

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

_____

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_____

(1)

(Total 8 marks)

Q18.

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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_____

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_____

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_____

(3)

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

_____

_____

(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 _____

_____

_____

_____

_____

_____

(3)

(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.

_____

(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

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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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(3)

(Total 16 marks)

Q19.

(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

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minutes.

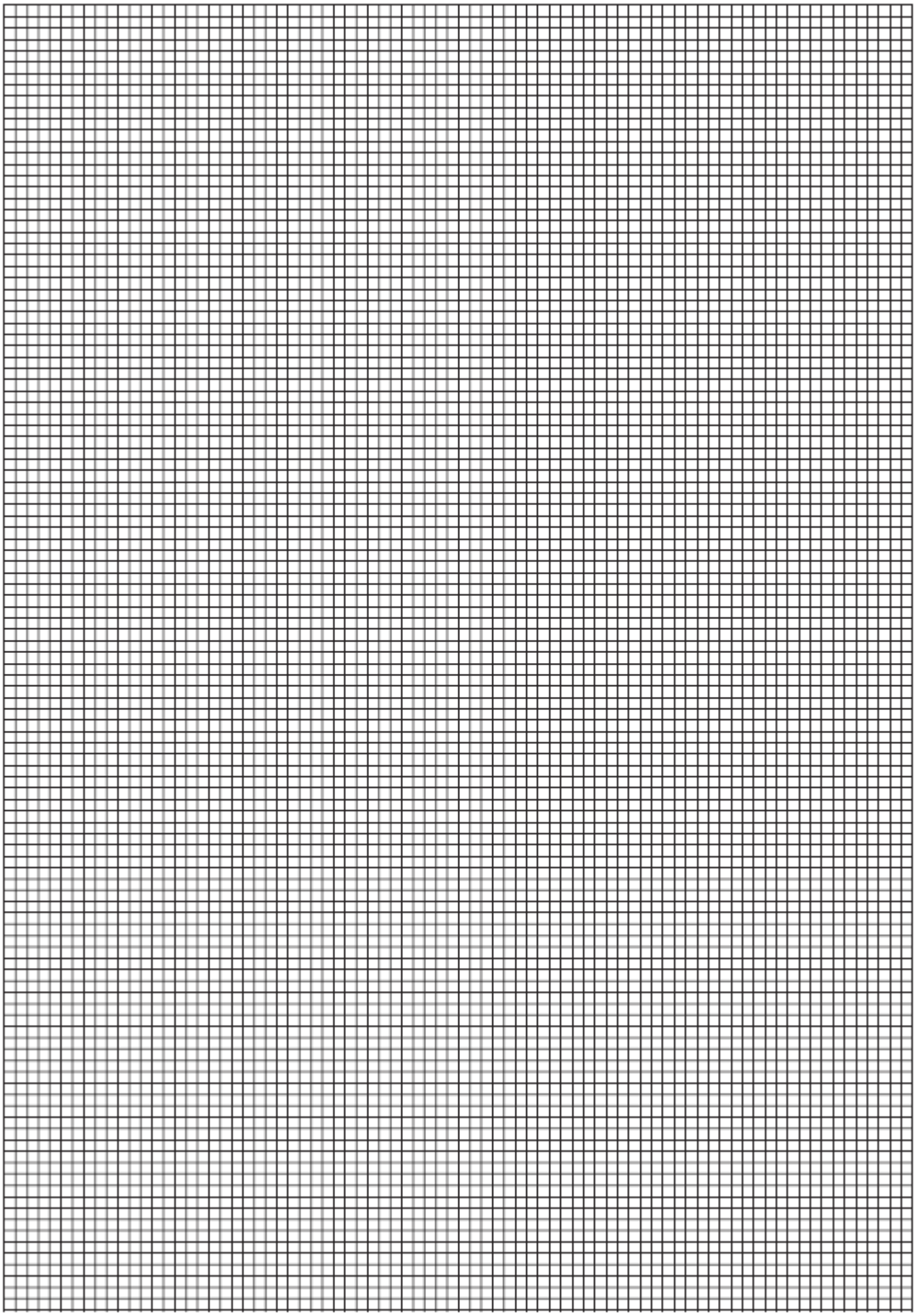
The student's results are shown in the table below.

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.

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(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 _____

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(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).

_____

(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.

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

_____

_____

_____

_____

(2)

(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.

_____

_____

(1)

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

_____

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(1)

(Total 16 marks)

Q20.

A student calculated that a value for the enthalpy change of neutralisation is –51.2 kJ mol^{-1}.

The design of a possible hand-warmer using hydrochloric acid and sodium hydroxide was discussed. It was proposed that 500 cm^3 of hydrochloric acid should be used in a flexible, sealed plastic container with a breakable tube of solid sodium hydroxide also in the container. On breaking the tube, the sodium hydroxide would be released, react with the acid and produce heat.
A 40 °C temperature rise was thought to be suitable.

(a) Calculate the heat energy, in J, required to raise the temperature of the reaction mixture by 40 °C. Assume that the reaction mixture has a density of 1.00 g cm^{-3} and a specific heat capacity of 4.18 J K^{-1} g^{-1}.
Assume that all of the heat energy given out is used to heat the reaction mixture.

_____

_____

_____

_____

(2)

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(b) Use your answer from part (a) and the value for the enthalpy change of neutralisation of –51.2 kJ mol^{-1} to calculate the minimum amount, in moles, and hence the minimum mass of sodium hydroxide required in the breakable tube.
(If you could not complete the calculation in part (a) assume that the heat energy required was 77 400 J. This is **not** the correct answer).

Show your working.

Moles of NaOH _____

_____

Mass of NaOH _____

_____

(3)

(c) Use the amount, in moles, of sodium hydroxide from part (b) to calculate the minimum concentration, in mol dm^{-3}, of hydrochloric acid required in the 500 cm^3 of solution used in the sealed container.

_____

_____

_____

(1)

(d) Suggest **one** possible risk to a person who uses a hand-warmer containing sodium hydroxide and hydrochloric acid.

_____

_____

(1)

(e) A commercial hand-warmer uses powdered iron sealed in a plastic container.
A valve allows air to enter the container, and oxygen in the air reacts slowly with the iron to form solid iron(III) oxide. The heat released warms the container.

(i) Write an equation for this reaction between iron and oxygen to form iron(III) oxide.

_____

(1)

(ii) One version of an iron-oxygen hand-warmer advertises that it is designed to stay warm for up to four hours.
Other than by increasing the amount of iron in the container, state **one** change to the iron in the hand-warmer that would increase this time.
Explain why this change to the iron might **not** be an advantage.

Change to the iron _____

_____

Explanation _____

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_____

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(3)

(f) Another type of hand-warmer uses sodium thiosulfate. Sodium thiosulfate is very soluble in water at 80 °C but is much less soluble at room temperature.
When a hot, concentrated solution of sodium thiosulfate is cooled it does not immediately crystallise. The sodium thiosulfate stays dissolved as a stable 'super-saturated' solution until crystallisation is triggered.
Heat energy is then released when the sodium thiosulfate crystallises.

(i) This type of hand-warmer is re-usable.
Suggest **one** environmental advantage that a sodium thiosulfate hand-warmer has over the other two types.

_____

(1)

(ii) Describe the **two** steps that you would take to make the sodium thiosulfate hand-warmer ready for re-use.

Step 1 _____

_____

Step 2 _____

_____

(2)

(Total 14 marks)

Q21.

Glucose, produced during photosynthesis in green plants, is a renewable source from which ethanol can be made. Ethanol is a liquid fuel used as a substitute for petrol.
The processes involved can be summarised as follows.

Process **1**	Photosynthesis in green plants $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
Process **2**	Fermentation of glucose to form ethanol
Process **3**	Complete combustion of ethanol $CH_3CH_2OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

(a) State **three** essential conditions for the fermentation of aqueous glucose in Process **2**.

Write an equation for the reaction that takes place during this fermentation.

_____

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(4)

(b) It has been claimed that there is no net carbon (greenhouse gas) emission to the atmosphere when ethanol made by Process **2** is used as a fuel.

State the term that is used to describe fuels of this type.

Use the equations for Processes **1, 2** and **3** to show why it can be claimed that there is no net emission of carbon-containing greenhouse gases.

(3)

(c) Use the information from the equation for Process **3** above and the mean bond enthalpies from the table below to calculate a value for the enthalpy change for this process.

	C–H	C–C	C–O	O–H	C=O	O=O
Mean bond enthalpy / kJ mol^{-1}	+412	+348	+360	+463	+743	+496

Give **one** reason why the value calculated from mean bond enthalpies is different from the value given in a data book.

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_____

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(4)

(d) A student carried out a simple laboratory experiment to measure the enthalpy change for Process **3**. The student showed that the temperature of 200 g of water increased by 8.0 °C when 0.46 g of pure ethanol was burned in air and the heat produced was used to warm the water.

Use these results to calculate the value, in kJ mol^{-1}, obtained by the student for this enthalpy change. (The specific heat capacity of water is 4.18 J K^{-1} g^{-1})

Give **one** reason, other than heat loss, why the value obtained from the student's results is less exothermic than a data book value.

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(4)

(Total 15 marks)

Q22.

A group of students devised an experiment which they believed would enable them to investigate the strength of the intermolecular forces between ethyl ethanoate molecules ($CH_3COOCH_2CH_3$) and trichloromethane molecules ($CHCl_3$).

They mixed exactly 0.10 mol of each of the two liquids in a copper calorimeter and recorded the following results. The starting temperature of both liquids was the same.

Mass of 0.10 mol of ethyl ethanoate / g	8.80
Mass of 0.10 mol of trichloromethane / g	11.95
Increase in temperature (ΔT) on mixing / K	9.5

(a) (i) Write an expression for the heat change (q) which relates mass (m), specific heat capacity (c) and change in temperature (ΔT).

_____

(1)

(ii) Calculate the amount of heat required to increase the temperature of 8.80 g of

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ethyl ethanoate by 9.5 K during the mixing process. (You should assume that *c* for ethyl ethanoate = 1.92 J g^{-1} K^{-1})

_____

(1)

(iii) Calculate the amount of heat required to increase the temperature of 11.95 g of trichloromethane by 9.5 K during the mixing process. (You should assume that *c* for trichloromethane = 0.96 J g^{-1} K^{-1})

_____

(1)

(iv) Using the values from parts (a) (ii) and (a) (iii), calculate the molar enthalpy change in kJ mol^{-1} for the mixing process.

_____

_____

(2)

(b) The students deduced that the heat change was due only to the formation of intermolecular forces between ethyl ethanoate molecules and trichloromethane molecules.

Ignoring all experimental errors, give **one** reason why the students may have made an incorrect deduction.

_____

_____

(1)

(Total 6 marks)

Q23.

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

_____

_____

_____

(3)

(b) Use the data in the table to calculate the standard enthalpy of formation of liquid methylbenzene, C_7H_8

Substance	C(s)	$H_2(g)$	$C_7H_8(l)$
Standard enthalpy of combustion, $\Delta H_c^{\ominus}$ /kJ mol^{-1}	–394	–286	–3909

$7C(s) + 4H_2(g) \rightarrow C_7H_8(l)$

_____

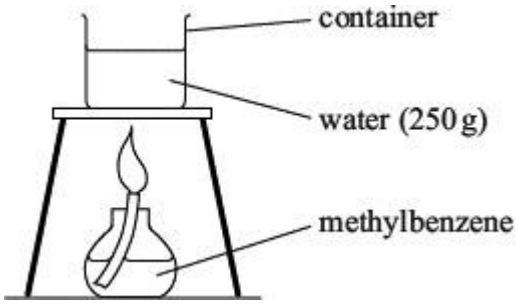
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(3)

(c) An experiment was carried out to determine a value for the enthalpy of combustion of liquid methylbenzene using the apparatus shown in the diagram.



Burning 2.5 g of methylbenzene caused the temperature of 250 g of water to rise by 60°C. Use this information to calculate a value for the enthalpy of combustion of methylbenzene, C_7H_8

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

_____

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(4)

(d) A 25.0 cm^3 sample of 2.00 mol dm^{-3} hydrochloric acid was mixed with 50.0 cm^3 of a 1.00 mol dm^{-3} solution of sodium hydroxide. Both solutions were initially at 18.0 °C.

After mixing, the temperature of the final solution was 26.5°C.

Use this information to calculate a value for the standard enthalpy change for the following reaction.

$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

In your calculation, assume that the density of the final solution is 1.00 g cm^{-3} and that its specific heat capacity is the same as that of water. (Ignore the heat capacity of the container.)

_____

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_____

(4)

(e) Give **one** reason why your answer to part (d) has a much smaller experimental error than your answer to part (c).

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_____

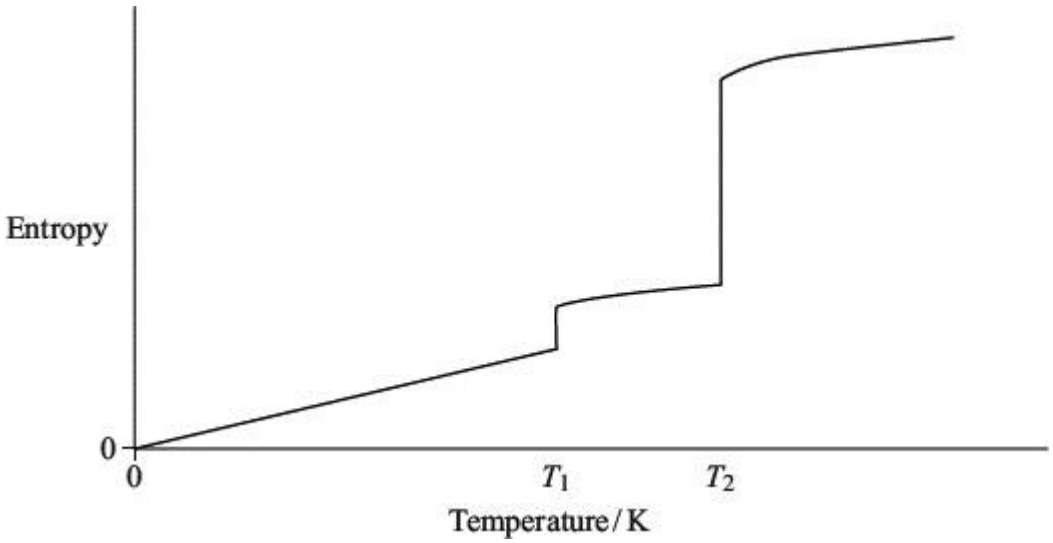
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(1)

(Total 15 marks)

Q24.

The sketch graph below shows how the entropy of a sample of water varies with temperature.



(a) Suggest why the entropy of water is zero at 0 K.

_____

(1)

(b) What change of state occurs at temperature T_1?

_____

(1)

(c) Explain why the entropy change, ΔS, at temperature T_2 is much larger than that at temperature T_1.

_____

_____

_____

(2)

(d) It requires 3.49 kJ of heat energy to convert 1.53 g of liquid water into steam at 373 K and 100 kPa.

(i) Use these data to calculate the enthalpy change, ΔH, when 1.00 mol of liquid water forms 1.00 mol of steam at 373 K and 100 kPa.

_____

_____

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_____

_____

(ii) Write an expression showing the relationship between free-energy change, ΔG, enthalpy change, ΔH, and entropy change, ΔS.

_____

(iii) For the conversion of liquid water into steam at 373 K and 100 kPa, $\Delta G = 0$ kJ mol^{-1}

Calculate the value of ΔS for the conversion of one mole of water into steam under these conditions. State the units.

(If you have been unable to complete part (d)(i) you should assume that $\Delta H = 45.0$ kJ mol^{-1}. This is not the correct answer.)

Calculation _____

_____

_____

Units _____

(6)

(Total 10 marks)

Q25.

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*.

_____

_____

_____

_____

_____

_____

(3)

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

_____

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_____

_____

_____

_____

_____

_____

_____

(4)

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

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

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

(i) Explain why, in *Stage 1*, a higher yield of hydrogen and carbon monoxide is **not** obtained if the pressure is increased.

_____

_____

_____

_____

(2)

(ii) *Stage 2* is carried out at a compromise temperature of 500K. By considering what would happen at higher and lower temperatures, explain why 500 K is considered to be a compromise for *Stage 2*.

_____

_____

_____

_____

_____

_____

(3)

(c) 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.

_____

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(3)

(Total 15 marks)

Q26.

(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

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(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)

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(Total 15 marks)

Q27.

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

_____

(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.

_____

_____

(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})

_____

_____

_____

_____

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

_____

_____

(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.

_____

(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 _____

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_____

(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

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

_____

_____

_____

_____

(3)

(Total 12 marks)

Q28.

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.

_____

(1)

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

_____

_____

(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})

_____

_____

(2)

(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.

_____

_____

(1)

(Total 8 marks)

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Q1.

(a) **M1** moles (= $\frac{25}{1000}$ × 2.0) = 0.050

1

M2 heat released = 0.050 × 56.1 (= 2.805 kJ or 2805 J)

1

M3 $\Delta T = \frac{q}{mc}$

1

M4 $\Delta T = \frac{2805}{50 \times 4.18}$ or $\frac{1000 \times 0.050 \times 56.1}{50 \times 4.18}$ = 13(.4) (°C)

Correct answer (to at least 2 sig fig) scores 4 marks

*27 or 26.8°C (from moles of two reagents being added together for **M2**, or use of 25 cm^3 in **M4**) scores 3 marks*

*0.013(.4)°C (from not converting kJ to J) scores 3 marks (loses **M4**) [0.027 or 0.0268°C would score 2 marks (loses **M2** and **M4**)*

M1** moles can be shown for either substance or without specifying the substance; if it is shown for both substances, must be correct for both for **M1

*Allow ECF from **M1** to **M2***

*Allow ECF from **M2** to **M4** (providing an attempt to calculate q has been made – no ECF if 56100 or 56.1 is used as q)*

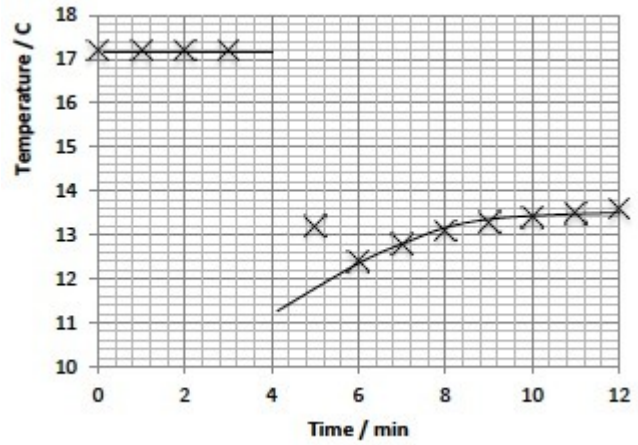
*Correct **M4** scores **M3**. If error made in **M4**, **M3** could score from substituted values in this expression in **M4***

***M4** final answer to at least 2 sig fig.*

*Penalise **M4** for negative temperature rise*

1

(b) **M1** draws suitable best fit curve to 4 minutes



***M1** line must be a curve and ignore value at 5 minutes*

***M1** line should not go to times before 4 minutes*

1

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M2 (17.2 – value read from graph line at 4 minutes) ± 0.2 (°C)

M2 *allow use of any curved or straight line that is an attempt to draw a line through the values after 4 minutes (that may include the point at 5 minutes)*

M2 *allow negative values*

1

[6]

Q2.

(a) Aldehyde/propanal has dipole-dipole forces (between molecules)

If any 'covalent bonds broken' CE=0 for clip.

Ignore Van der Waal forces

M1

Alcohol/propan-1-ol AND Carboxylic acid/ propanoic acid have hydrogen bonding (between molecules).

Ignore reference to energy

M2

The forces between the molecules in aldehyde are weaker (than those in alcohol and acid so it will evaporate first.)

M3 only awarded following correct M1 OR M2

Allow converse for M3

M3

(b) Keep the temperature of the reaction mixture below the boiling point of propan-1-ol/below 97 °C

Allow temperature in range 49-96 inclusive

Allow description of cooling the vessel

M1

Cool the distillate / collecting vessel

Ignore reference to oxidising agents

Penalise lid / sealed container

M2

(c) Add named carbonate/hydrogencarbonate OR magnesium to a sample of the distillate.

Incorrect chemical CE=0

Allow formula (mark on for incorrect formula)

Allow blue litmus or correct named indicator

M1

Effervescence/fizz/bubbles would confirm presence of acid or converse

Blue litmus turns red confirms acid present or converse

Allow gas/CO_2 produced which turns lime water cloudy OR gas/H_2 produced which burns with a squeaky pop

M2

(d) (Temperature difference = 15.1 °C)

If ΔT wrong – AE mark on otherwise can only award M2

If use 457 in M1, can only score M2

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q = 150 × 4.18 × 15.1 or 9467.7 J or 9.4677kJ

M1

amount ethanol burned = 0.457/46.0 = 9.93×10^{-3} mol

If use 457 in M2 can score 2 for - 0.953 kJ mol-1

M2

Heat change per mole = (M1/1000)/M2 = 952.99 kJ mol-1

ΔH = – 953 kJ mol^{-1} must be 3sfs and must be negative

(allow range -953 to -954)

BEWARE if they miss conversion to kJ and also miss conversion to g, they get answer = - 953 which scores 1
+953 can score M1 and M2
Allow -950 or -960 for rounding to 2sf

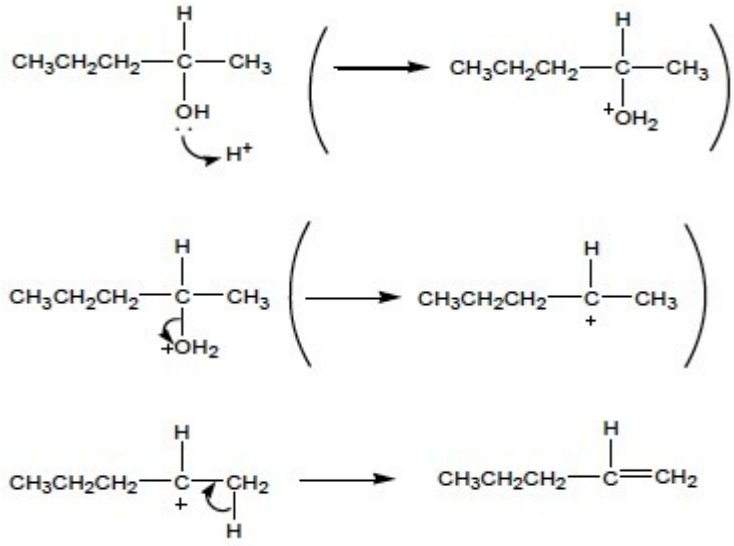
M3

(e) Elimination

Penalise base elimination

M1

Mechanism : Either (E1)

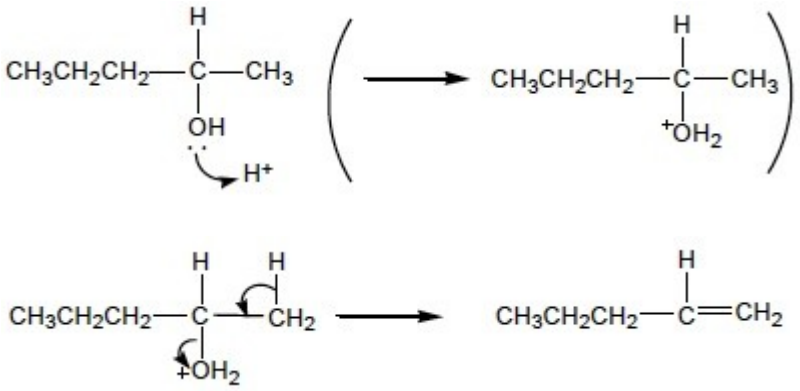


M2 for protonation of alcohol, i.e. lp plus arrow to H^+
or to H of H–O– in H_2SO_4 and from H-O bond to O
M3 for protonated alcohol plus arrow showing loss of water
M4 for arrow showing loss of H^+
From correct carbocation (E1)
wrong alcohol used / alkene formed loses M4

3

OR (E2)

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M2 for protonation of alcohol, i.e. lp plus arrow to H^+ or to H of H–O– in H_2SO_4 and from H-O bond to O
M3 for protonated alcohol plus arrow showing loss of water
M4 for arrow showing simultaneous loss of H^+
wrong alcohol used / alkene formed loses M4

3

(f) *E*-pent-2-ene

Allow trans

M1

C=C bond cannot rotate **and**

Each carbon in the double bond has (2) different groups attached.

Allow (two) different groups on each/either side of the double bond.

M2

[16]

Q3.

(a) **M1** Temperature on the y-axis and uses sensible scales (i.e. minimum 20 little squares for each °C on y-axis)

Lose mark if temperature scale starts at 0°C

*This mark scores if all points fit on the grid. Do not penalise M1 if extrapolation to 4 mins goes off the grid – this is penalised in **M3**.*

1

M2 Plots all the points correctly (± half a small square)

Lose mark if the points go off the grid Ignore a plotted point at 4 mins used to work out ΔT

1

M3 Draws two best fit lines (0-3 mins) and (6-12 mins)

Both lines must be straight and through all points except 5th minute; lose mark if the lines are kinked/doubled. Any line through 5th minute loses mark

*"S-shaped curve" through points loses **M3** and **M4***

1

M4 Extrapolates both lines to at least the 4th minute

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Lose mark if the extrapolation goes off the grid.

1

M5 21.9 – 19.8 = 2.1 (°C)

Allow calculation of ∆T from S-shaped curve as: Value at 4th minute – 19.8 but not if 0 (°C)

∆T value ecf from incorrect lines/extrapolation

∆T must be to at least 1dp

If value of ∆T = 2.1, then award M5

1

(b) 0.2 / 2.1 × 100 = 9.5 %

Conseq on (a)

Ignore no of sfs.

1

(c) Replace the glass beaker with a polystyrene cup / insulate the glass beaker / use a lid

Ignore use more dilute solutions

Ignore suggested materials for insulation

Do not allow copper calorimeter / bomb calorimeter

1

(d) Increase magnitude of temperature change

Ignore references to volume changes

1

by increasing the <u>concentration</u> of the acid/alkali

Mark independently

1

(e) **M1** $HOOCCOOH + 2KOH \rightarrow K_2(OOCCOO) + 2H_2O$

***M1** – equation (allow ionic KOH / $_2C_2O_4$)*

$H_2C_2O_4 + 2KOH \rightarrow K_2C_2O_4 + 2H_2O$

ignore state symbols

allow multiples

Mark independently

M2 q (= mc∆T) = 100 × 4.2 × 3.2 = 1344 J

***M2** – process*

(ignore sign here)

(allow calculations involving 4.18 which leads to 1338 J)

1

M3 n HOOCCOOH = 25 × 0.800 / 1000 = <u>0.020</u>
n KOH = 75 × 0.6 / 1000 = <u>0.045</u>

M3 – calculations of amounts, in moles, of both the ethanedioic acid and potassium hydroxide (both calculations needed)

1

M4 Moles of water = <u>0.040</u> moles

***M4** – answer (stated or used in calculation of ∆H)*

1

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M5 $\Delta H = -1.344/0.04$

$= -33.6$ (kJ mol^{-1})

M5 *– ecf on* ***M2*** *and* ***M4***

Answer must be negative and to at least 2sf

ΔH = – ***M2*** *(in kJ) / M4*

*–32.5 - –34 scores 4/4 (****M2-M5*** *+ equation)*

*+32.5 - +34 scores 3/4 (****M2****,* ***M3****,* ***M4*** *+ equation)*

–65 - –68 scores 3/4 (+ equation)

+65 - +68 scores 2/4 (+ equation)

–52 - –54 scores 3/4 (+ equation)

+52 - +54 scores 2/4 (+ equation)

2

(f) HOOCCOOH is a weak acid / not fully dissociated

H_2SO_4 is a strong(er)acid / fully dissociated / dissociates more

1

(more) energy needed to break bonds/complete dissociation / dissociation is endothermic

So less energy is needed for dissociation of sulfuric acid

Ignore references to heat loss

1

[16]

Q4.

(a) M1 Amount $ZnSO_4 = 1.0 \times \frac{50}{1000}$ mol or Amount $ZnSO_4 = 0.050$ mol

Mark M1 and M2 independently

1

M2 Amount Mg = $\frac{2.08}{24.3}$ mol or Amount Mg = 0.0856 mol
(Hence Mg in excess)

1

M3 $Q = mc\Delta T$

M3 could be scored in M4

1

M4 $Q = 50.0 \times 4.18 \times 37.3$
or $Q = 7795.7$ J

If an error in M4, lose M4 and M5 and only award M6 for correct use of their incorrect M4 and division by their correct limiting reagent

1

M5 (Energy released per mole) $\frac{7.796}{0.05}$ kJ mol^{-1} or $\frac{7.796}{0.05}$ J mol^{-1}

M5 division by their limiting reagent

1

M6 $\Delta H = -156$ kJ mol^{-1}

1

(b) Heat loss (from the apparatus would mean the experimental value is smaller / lower / less exothermic than the data source)

1

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(c) Marks awarded for this answer will be determined by the quality of the communication as well as the standard of the scientific response. Examiners should apply a 'best-fit' approach to the marking.

Level 3 (5 – 6 marks)
Covers 3 Stages with matching justifications
Answer is full and detailed and is supported by an appropriate range of relevant points such as those given below:
- argument is well structured with minimum repetition or irrelevant points
- accurate and clear expression of ideas with only minor errors in the use of technical terms, spelling and punctuation and grammar

Level 2 (3 – 4 marks)
Covers 2 Stages with matching justification. OR covers 3 Stages with incomplete justification
Answer has some omissions but is generally supported by some of the relevant points below:
- the argument shows some attempt at structure
- the ideas are expressed with reasonable clarity but with a few errors in the use of technical terms, spelling, punctuation and grammar

Level 1 (1 – 2 marks)
Covers 1 Stage with matching justification. OR covers 2 Stages with incomplete justification
Answer is largely incomplete. It may contain valid points which are not clearly linked to an argument structure. Unstructured answer. Errors in the use of technical terms, spelling, punctuation and grammar or lack of fluency

Level 0 (0 marks)

Insufficient correct chemistry

Indicative Chemistry Content

Stage 1 Improved insulation
1a Insulate the beaker or use a polystyrene cup or a lid
1b To reduce heat loss

Stage 2 Improved temperature recording
2a Record the temperature for a suitable time before adding the metal
2b To establish an accurate initial temperature
OR
2c Record temperature values at regular time intervals
2d To plot the temperature results against time on a graph

Stage 3 Improved analysis of results
3a Extrapolate the cooling back to the point of addition
3b To establish a (theoretical) maximum temperature OR temperature change (e.g. at the 4th minute) OR adjust for the cooling /apply a cooling correction
3a and 3b could be seen on an extrapolated sketch graph

(Note– IGNORE use of measuring equipment with greater precision)

6

[13]

Q5.

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(a) Not possible to prevent some dissolving

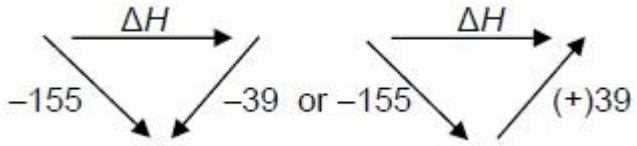
ALLOW It is soluble / dissolves / other hydrates may form / suggestions related to difficulty of measuring T (change) of a solid

1

(b) ($\Delta_{hyd}H$ =) –155 – (–39)

OR labelled cycle

Minimum needed for 'labelled cycle'



1

–116 (kJ mol^{-1})

1/2 for (+)116 or for –29 or for seeing –116 that has then be processed further

1

(c) This question is marked using levels of response. Refer to the Mark Scheme Instructions for examiners for guidance on how to mark this question

Level 3 (5 – 6 marks)

All stages are covered and the explanation of each stage is correct and virtually complete.
Stage 2 must include use of a graphical method for Level 3 (i.e. 'highest T reached' method is max Level 2)

Answer communicates the whole explanation, including reference to enthalpy, coherently and shows a logical progression through all three stages.Answer is full and detailed and is supported by an appropriate range of relevant points such as those given below:
For the answer to be coherent there must be some indication of **how** the graph is used to find ΔT

Level 2 (3 – 4 marks)

All stages are covered (NB 'covered' means min 2 from each of stage 1 and 3) but the explanation of each stage may be incomplete or may contain inaccuracies
OR two stages covered and the explanations are generally correct and virtually complete

Answer is coherent and shows some progression through all three stages. Some steps in each stage may be out of order and incomplete

Level 1 (1 – 2 marks)

Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies
OR only one stage is covered but the explanation is generally correct and virtually complete

Answer shows some progression between two stages

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Level 0 (0 marks)

Insufficient correct Chemistry to warrant a mark

Indicative Chemistry Content

Stage 1 Method

(1a) Measures water with named appropriate apparatus
(1b) Suitable volume/mass / volume/mass in range 10 – 200 cm^3/g
(1c) Into insulated container / polystyrene cup (NOT just 'lid')
(1d) Add known mass of $MgCl_2(s)$
(1e) Use of 'before and after' weighing method. NOT 'added with washings'

Stage 2 Measurements (could mark from diagram)

(2a) Record initial temperature (min 2 measurements)
(2b) Record T at regular timed intervals for 5+ mins / until trend seen
(2c) Plot T vs time

Stage 3 Use of Results (3a and 3b could come from diagram)

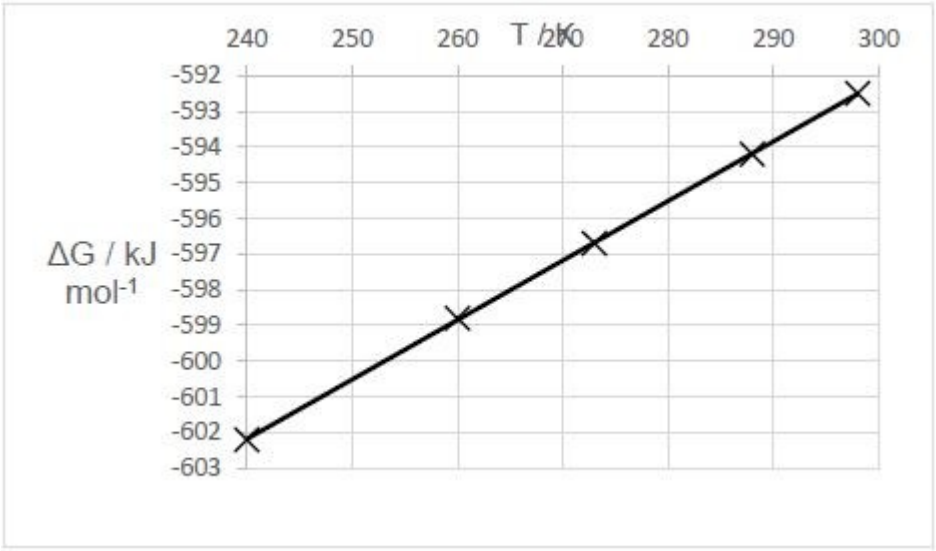
(3a) Extrapolate lines to when solid added (to find initial and final T)
(3b) $T_{final} - T_{initial} = \Delta T$ / idea of finding ΔT from graph at point of addition
(3c) $q = mc\Delta T$
(3d) amount = mass/Mr ($0.80/95.3 = 8.39 \times 10^{-3}$ mol)
(3e) ΔH_{soln} = –q/8.39×10^{-3} or in words

This could all be described in words without showing actual calculations but describing stages

If method based on 'combustion' Max Level 1

6

(d)



M1 *= 5 points correctly plotted*
M2 *= line drawn correctly (NOT if curved, doubled or kinked)*
(Check line of best fit –
if through 250, -600.5 and 280, -595.5 +/- one small square

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*then award **M2**, if all crosses on line award **M1** as well)*

2

Gradient = $\Delta(\Delta G)/\Delta T$ = 0.167 (kJ K^{-1} mol^{-1})

1

($\Delta G = \Delta H - T\Delta S$ so gradient = $-\Delta S$)

ΔS = –167 (J K^{-1} mol^{-1})

***M4** = unit conversion i.e. **M3** × 1000; M5 = –sign (process marks)*

*Correct answer with sign gets **M3**, **M4** and M5*

ALLOW –163 to –171

1+1

[14]

Q6.

TWO correct extrapolations of best fit straight lines

***Max 5/7** if no extrapolations or best fit straight lines drawn*

1

Use of their lines to calculate the temperature change at the 4th minute

1

(17 °C)

Q = mcΔT

Q = 10 × 4.18 × [student's temperature change]

Q = [710.6 J]

Correct numbers inserted into expression.

1

Moles of Mg = 0.24 / 24.3 = 0.00988 mol

1

ΔH = 710.6 / 0.00988 = 71923.07 J mol^{-1}

1

ΔH = –72 (kJ mol^{-1})

Must be negative to score M6

1

Answer to 2 significant figures

1

[7]

Q7.

B

[1]

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Q8.

(a) $C_6H_{11}OH + 8\frac{1}{2}O_2 \longrightarrow 6CO_2 + 6H_2O$

1

(b) Temperature rise = 20.1

$q = 50.0 \times 4.18 \times 20.1 = 4201$ (J)

1

Mass of alcohol burned = 0.54 g and M_r alcohol = 100.0

$\therefore$ mol of alcohol = $n = 0.54 / 100 = 0.0054$

1

Heat change per mole = $q / 1000n$ **OR** q / n

= 778 kJ mol^{-1} **OR** 778 000 J mol^{-1}

1

ΔH = –778 kJ mol^{-1} **OR** –778 000 J mol^{-1}

M4 is for answer with negative sign for exothermic reaction
Units are tied to the final answer and must match

1

(c) Less negative than the reference

1

Heat loss **OR** incomplete combustion **OR** evaporation of alcohol **OR** heat transferred to beaker not taken into account

1

(d) Water has a known density (of 1.0 g cm^{-3})

1

Therefore, a volume of 50.0 cm^3 could be measured out

1

[9]

Q9.

(a) Start a clock when KCl is added to water

1

Record the temperature every subsequent minute for about 5 minutes

Allow record the temperature at regular time intervals until some time after all the solid has dissolved for M2

1

Plot a graph of temperature vs time

1

Extrapolate back to time of mixing = 0 and determine the temperature

1

(b) Heat taken in = $m \times c \times \Delta T = 50 \times 4.18 \times 5.4 = 1128.6$ J

Max 2 if 14.6 °C used as ΔT

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1

Moles of KCl = 5.00 / 74.6 = 0.0670

1

Enthalpy change per mole = +1128.6 / 0.0670 = 16 839 J mol^{-1}

1

= +16.8 (kJ mol^{-1})

Answer must be given to this precision

1

(c) $\Delta H_{solution} = \Delta H_{lattice} + \Delta H$(hydration of calcium ions) + 2 × ΔH(hydration of chloride ions)

$\Delta H_{lattice} = \Delta H_{solution} - \Delta H$(hydration of calcium ions) –2 ×ΔH(hydration of chloride ions)

1

$\Delta H_{lattice}$ = –82–9 – (–1650 + 2 × –364) = +2295 (kJ mol^{-1})

1

(d) Magnesium ion is smaller than the calcium ion

1

Therefore, it attracts the chloride ion more strongly / stronger ionic bonding

1

[12]

Q10.

(a) Weigh the spirit burner (alcohol) before and after combustion **M1**

Do not allow "a known mass of alcohol" owtte

1

Water in a calorimeter / beaker **M2**

1

Measure volume of water (or mass) **M3**

1

Burn the alcohol to heat the water **M4**

1

Measure temperature rise <u>in water</u> **M5**

1

(b) Incomplete combustion

Evaporation of alcohol

Heat capacity of / heat absorption by the apparatus

Inadequate stirring

Any two correct

1
1

(c) Acidified potassium dichromate / manganate(VII) (Heat)

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Allow sodium in place of potassium with appropriate colour change)

If reagent incomplete lose M1 but mark on.

If reagent incorrect, CE = 0/3

1

butan-1-ol orange to green / purple to colourless

1

2-methylpropan-2-ol NVC / orange / purple

1

(d) $C_4H_9OH + 2O_2 \rightarrow 4C + 5H_2O$
OR
$C_4H_9OH + 4O_2 \rightarrow 4CO + 5H_2O$

Allow any correct balanced equations which include combinations of C, CO and/or CO_2 in the products but must be incomplete combustion.

1

Engine would not run as efficiently / would need to use more fuel / would release less energy

Allow build-up of carbon in engine costly to remove

1

CO / Particulates of carbon toxic

Allow global dimming if carbon given as product

1

[13]

Q11.

(a) M1 ($q = mc\Delta T = 100 \times 4.18 \times 38(.0)$)
= 15 884 / 15 880 / 15 900 / 16 000 (J)
(OR 15.884 / 15.88 / 15.9 / 16 (kJ))

Award full marks for correct answer

Mark is for value not expression (at least 2sf); penalise incorrect units here only if M1 is the only potential scoring point in M1-M3

1

M2 Moles (methanol = 1.65 / 32.0) = 0.0516 or 0.052

At least 2sf

1

M3 Heat change per moles = M1/M2
(15 884 / 0.0516 / 1000 = 308 (kJ mol^{-1})
(allow 305 to 310)

At least 2sf; answer must be in kJ mol^{-1}

1

M4 Answer = −308 (kJ mol^{-1}) (allow −305 to −310)

This mark is for – sign (mark independently)

1

(b) Heating up copper / calorimeter / container / thermometer /
heat capacity of copper / calorimeter / thermometer not taken into account

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OR
Evaporation of alcohol/methanol
OR
Experiment not done under standard conditions

Not human errors (e.g. misreading scales)

Not impure methanol

Allow evaporation of water

1

(c) (100 × 0.5 / 38 =) 1.3 or 1.32 or 1.316% (minimum 2 sf)

Allow correct answer to at least 2sf;

Allow 1.31 or 1.315%

1

(d) Idea that heat loss is more significant issue OR
Idea that temperature change/rise is (significantly / much) bigger than uncertainty

One of these two ideas only and each one must involve a comparison

1

(e) M1 Mass of ethanol = 500 × 0.789 (= 394.5 or 395 (g))

1

M2 Moles of ethanol = M1 / 46.0 (= 8.576 or 8.58)

1

M3 Heat released = M2 × 1371 = 11800 (kJ) must be 3 sf

1

Correct answer to 3sf scores 3; correct value to 2sf or more than 3sf scores 2

Answers that are a factor of 10^x out score 2 if given to 3sf or 1 if given to a different number of sf

M3 ignore units, but penalise incorrect units

M3 ignore sign

M2 and M3 – allow consequential marking

[10]

Q12.

(a) (i) $\mathbf{2}C_6H_{12}O_6 \longrightarrow \mathbf{3}CH_3COCH_3 + \mathbf{3}CO_2 + \mathbf{3}H_2O$

Or multiples

1

(ii) to speed up the reaction
OR
(provide a) catalyst or catalyses the reaction or biological catalyst
OR
release / contain / provides an enzyme

Ignore "fermentation"

Ignore "to break down the glucose"

Not simply "enzyme" on its own

1

(b) (i) $CH_3CH(OH)CH_3 + [O] \longrightarrow CH_3COCH_3 + H_2O$

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Any <u>correct</u> representation for the two organic structures.
Brackets not essential.
Not "sticks" for the structures in this case

1

(ii) Secondary (alcohol) OR 2° (alcohol)

1

(c) **M1** q = m c ΔT

OR q =150 × 4.18 × 8.0

Award full marks for <u>correct answer</u>
*In **M1**, do not penalise incorrect cases in the formula*

M2 = (±) 5016 (J) ***OR*** 5.016 (kJ) ***OR*** 5.02 (kJ)
(also scores M1)

M3 This mark is for dividing correctly the number of kJ by the number of moles and arriving at a final answer in the range shown.
Using 0.00450 mol

therefore ΔH = **<u>− 1115</u>** (kJ mol^{-1})

OR **<u>− 1114.6</u> to <u>− 1120</u>** (kJ mol^{-1})

Range (+)1114.6 to (+)1120 gains 2 marks

BUT − 1110 gains 3 marks and +1110 gains 2 marks

AND − 1100 gains 3 marks and +1100 gains 2 marks

Award full marks for correct answer
*In **M1**, do not penalise incorrect cases in the formula*
*Penalise **M3** ONLY if correct numerical answer but sign is incorrect; **(+)1114.6 to (+)1120 gains 2 marks***
*Penalise **M2** for arithmetic error and mark on*
If ΔT = 281; score q = m c ΔT only
*If c = 4.81 (leads to 5772) penalise **M2** ONLY and mark on for **M3** = − 1283*
*Ignore incorrect units in **M2***
*If units are given in **M3** they <u>must be either kJ or kJ mol^{-1}</u> in this case*

3

(d) **M1** The <u>enthalpy change</u> / <u>heat change at constant pressure</u> when <u>1 mol</u> of a compound / substance / element

M2 is <u>burned / combusts / reacts</u> <u>completely</u> in <u>oxygen</u>
OR
<u>burned / combusted / reacted in excess oxygen</u>

M3 with (all) <u>reactants and products /</u> (all) <u>substances in standard / specified states</u>

OR
(all) <u>reactants and products /</u> (all) <u>*substances in normal states under standard conditions*</u> / 100 kPa / 1 bar <u>and</u> specified T / 298 K

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*For **M3***

Ignore reference to 1 atmosphere

3

(e) **M1**

$\sum$ B **(reactants)** − $\sum$ B **(products)** = Δ*H*

OR

Sum of bonds broken − Sum of bonds formed = Δ*H*

OR

2B(C−C) + B(C=O) + 6B(C−H) + 4B(O=O) (LHS)

− 6B(C=O) − 6B(O−H) (RHS) = Δ*H*

M2 (also scores **M1**)

2(348)+805+6(412)+4(496) [LHS = **5957**]

(696) (2472) (1984)

− 6(805) − 6(463) [RHS = (−) **7608**] = Δ*H*

(4830) (2778)

OR using only bonds broken and formed (**5152 − 6803**)

M3

Δ*H*= **− 1651** (kJ mol^{-1})

Candidates may use a cycle and gain full marks.

Correct answer gains full marks

Credit 1 mark for (+) 1651 (kJ mol^{-1})

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication / addition error; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with $4O_2$, $3CO_2$ and $3H_2O$ OR a clear statement of **M1** which could be in words and scores **only M1***

Allow a maximum of one mark if the only scoring point is LHS = 5957 (or 5152) OR RHS = 7608 (or 6803)

Award 1 mark for + 1651

3

(f) **For the two marks M1 and M2, any two from**

- heat loss or not all heat transferred to the apparatus or heat absorbed by the apparatus or (specific) heat capacity of the apparatus not considered
- incomplete combustion / not completely burned / reaction is not complete
- The idea that the water may end up in the gaseous state (rather than liquid)
- reactants and / or products may not be in standard states.
- MBE data refers to gaseous species but the enthalpy of combustion refers to liquids in their standard states / liquid propanone and liquid water in standard states
- MBE do not refer to specific compounds OR MBE values vary with different compounds / molecules OR are average / mean values taken

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from a range of compounds / molecules

Apply the list principle but ignore incomplete reasons that contain correct chemistry

Ignore "evaporation"

Ignore "faulty equipment"

Ignore "human error"

Not enough simply to state that "MBE are mean / average values"

2

[15]

Q13.

Increase in volume

If a volume is quoted it must be less than 300

1

Smaller increase in T above room temperature
Or increased contact between calorimeter and water
Or smaller heat loss by evaporation / from the surface

1

[2]

Q14.

(a)

M1 $C_6H_{12}O_6 \longrightarrow$ **2**CH_3CH_2OH ($2C_2H_5OH$) + **2**CO_2

*Penalise C_2H_6O for ethanol in **M1**.*

M2 and **M3**

*Mark **M2** and **M3** independently.*

Any **two** conditions **in any order** for **M2** and **M3** from

- (enzymes from) yeast or zymase
- 25 °C ≤ T ≤ 42 °C OR 298 K ≤ T ≤ 315 K
- anaerobic / no oxygen / no air OR neutral pH

  A lack of oxygen can mean either without oxygen or not having enough oxygen and does not ensure no oxygen, therefore only credit "lack of oxygen" if it is qualified.

  Penalise 'bacteria', 'phosphoric acid', 'high pressure' using the list principle.

M4 (fractional) distillation or GLC

Ignore reference to 'aqueous' or 'water' (ie not part of the list principle).

M5 Carbon-neutral **in this context** means

There is no net / overall (annual) carbon dioxide / CO_2 emission to the atmosphere

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OR

There is no change in the <u>total amount / level</u> of <u>carbon dioxide / CO_2</u> present <u>in the atmosphere</u>

*For **M5** – must be about CO_2 <u>and</u> the atmosphere.*

The idea that the <u>carbon dioxide / CO_2</u> given out equals the <u>carbon dioxide / CO_2</u> that was taken in from <u>the atmosphere.</u>

5

(b) **M1** q = m c ∆T (this mark for correct mathematical formula)

*Full marks for **M1**, **M2** and **M3** for the <u>correct answer</u>.*

*In **M1**, do not penalise incorrect cases in the formula.*

M2 = (75 × 4.18 × 5.5)

1724 (J) **OR** 1.724 (kJ) **OR** 1.72 (kJ) **OR** 1.7 (kJ)

(also scores **M1**)

*Ignore incorrect units in **M2**.*

M3 Using 0.0024 mol

therefore ∆H = **<u>− 718</u>** (kJ mol^{-1})

(Accept a range from −708 to −719 but do not penalise more than 3 significant figures)

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect. Therefore **+718 gains two marks**.*

*If units are quoted in **M3** they must be correct.*

*If ∆T = 278.5, CE for the calculation and penalise **M2** and **M3**.*

M4 and **M5** in any order

Any **two** from

- incomplete combustion
- heat loss
- heat capacity of Cu not included
- some ethanol lost by evaporation
- not all of the (2.40 × 10^{-3} mol) ethanol is burned / reaction is incomplete

*If c = 4.81 (leads to 1984) penalise **M2** ONLY and mark on for **M3** = − 827*

5

(c) (i) **M1** enthalpy / heat / energy change (at constant pressure) or enthalpy / heat / energy needed in <u>breaking / dissociating (a) covalent bond(s)</u>

Ignore bond making.

M2 <u>averaged</u> for that type of bond over <u>different / a range of molecules / compounds</u>

Ignore reference to moles.

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2

(ii) **M1**

∑ B(**reactants**) − ∑ B(**products**) = ΔH

OR

Sum of bonds broken − Sum of bonds formed = ΔH

OR

B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O)
– 4B(C=O) – 6B(O–H) = ΔH = −1279

Correct answer gains full marks.

*Credit **1 mark for − 496** (kJ mol^{-1})*

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**).*

*If no AE, check for a correct method; this requires either a correct cycle with $2CO_2$ and $3H_2O$ OR a clear statement of **M1** which could be in words and scores **only M1**.*

M2 (also scores **M1**)
348+360+463+5(412)+ 3B(O=O)

(**3231**) (or **2768** if O–H cancelled)
− 4(805) − 6(463) = ΔH = − 1279

(**5998**) (or **5535** if O–H cancelled)

3B(O=O) = **1488** (kJ mol^{-1})

*Credit a maximum of one mark if the only scoring point is bonds formed adds up to **5998 (or 5535) OR** bonds broken includes the calculated value of **3231 (or 2768)**.*

M3

B(O=O) = **496** (kJ mol^{-1})

Award 1 mark for −496

Students may use a cycle and gain full marks

3

[15]

Q15.

(a) (Q = mcΔT)

= 50 × 4.18 × 27.3

*If incorrect (eg mass = 0.22 or 50.22 g) **CE = 0 / 2***

1

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= **5706 J** (accept 5700 and 5710)

Accept 5.7 kJ with correct unit. Ignore sign.

1

(b) M_r of 2-methylpropan-2-ol = 74(.0)

For incorrect M_r, lose M1 but mark on.

1

Moles = mass / M_r

= 0.22 / 74(.0)

= **0.00297 moles**

1

ΔH = –5706 / (0.002970 × 1000)

= **–1921 (kJ mol^{-1})**

If 0.22 is used in part (a), answer = –8.45 kJ mol^{-1} scores 3

(Allow –1920, –1919)

If uses the value given (5580 J), answer = –1879 kJ mol^{-1} scores 3

Answer without working scores M3 only.

Do not penalise precision.

Lack of negative sign loses M3

1

(c) ΔH = ΣΔH products – ΣΔH reactants
OR a correct cycle

Correct answer with no working scores 1 mark only.

1

ΔH = −(−360) + (4 × −393) + (5 × −286)

M2 also implies M1 scored.

1

ΔH = **–2642** (kJ mol^{-1}) This answer only.

Allow 1 mark out of 3 for correct value with incorrect sign.

1

(d) (–2422 – part (b)) × 100 / –2422

Ignore negative sign.

Expect answers in region of 20.7

If error carried forward, 0.22 allow 99.7

If 5580 J used earlier, then allow 22.4

1

(e) Reduce the distance between the flame and the beaker / put a sleeve around the flame to protect from drafts / add a lid / use a copper calorimeter rather than a pyrex beaker / use a food calorimeter

Any reference to insulating material around the beaker must be on top.

Accept calibrate the equipment using an alcohol of known enthalpy of combustion.

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1

(f) Incomplete combustion

1

[11]

Q16.

(a) Chloride (ions) are smaller (than bromide ions)

Must state or imply ions.

Allow chloride has greater charge density (than bromide).

Penalise chlorine ions once only (max 2 / 3).

1

So the force of attraction between chloride ions and water is stronger

This can be implied from M1 and M3 but do not allow intermolecular forces.

1

Chloride ions attract the δ+ on H of water / electron deficient H on water

Allow attraction between ions and polar / dipole water.

*Penalise H^+ (ions) and mention of hydrogen bonding for **M3***

Ignore any reference to electronegativity.

Note: If water not mentioned can score M1 only.

1

(b) $\Delta H_{solution} = \Delta H_L + \Delta H_{hyd}$ K^+ ions + ΔH_{hyd} Br^- ions / = 670 − 322 − 335

Allow $\Delta H_{solution} = \Delta H_L + \Sigma \Delta H_{hyd}$

1

= (+)13 (kJ mol^{-1})

Ignore units even if incorrect.

+13 scores M1 and M2

−13 scores 0

−16 scores M2 only (transcription error).

1

(c) (i) The entropy change is positive / entropy increases

ΔS is negative loses M1 and M3

1

Because 1 mol (solid) → 2 mol (aqueous ions) / no of particles increases

Allow the aqueous ions are more disordered (than the solid).

Mention of atoms / molecules loses M2

1

Therefore $\underline{T\Delta S > \Delta H}$

1

(ii) Amount of KCl = $5/M_r = 5/74.6 =$ 0.067(0) mol

If moles of KCl not worked out can score M3, M4 only (answer to M4 likely to be 205.7 K)

1

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Heat absorbed = 17.2 × 0.0670 = 1.153 kJ

Process mark for M1 × 17.2

1

Heat absorbed = mass × sp ht × Δ*T*

(1.153 × 1000) = 20 × 4.18 × Δ*T*

If calculation uses 25 g not 20, lose M3 only (M4 = 11.04, M5 = 287)

1

Δ*T* = 1.153 × 1000 / (20 × 4.18) = 13.8 K

If 1000 not used, can only score M1, M2, M3

M4 is for a correct ΔT

Note that 311.8 K scores 4 (M1, M2, M3, M4).

1

T = 298 − 13.8 = 284(.2) K

If final temperature is negative, M5 = 0

Allow no units for final temp, penalise wrong units.

1

[13]

Q17.

(a) The <u>enthalpy change / heat (energy) change</u> (at constant pressure) in a reaction is independent of the route / path taken (and depends only on the initial and final states)

Ignore the use of ΔH for enthalpy

1

(b) $\Delta H_{exp} + \Delta H_2 - \Delta H_1 = 0$

Any correct mathematical statement that uses <u>all three terms</u>

OR

$\Delta H_{exp} + \Delta H_2 = \Delta H_1$ ***OR*** $\Delta H_1 = \Delta H_{exp} + \Delta H_2$

OR

$\Delta H_{exp} = \Delta H_1 - \Delta H_2$ ***OR*** $\Delta H_{exp} = \Delta H_1 + (- \Delta H_2)$

1

(c) $\Delta H_{exp} = \Delta H_1 - \Delta H_2$

$\Delta H_{exp} = -156 - 12 =$ ***−168*** *(kJ mol^{-1})*

Ignore units

Award the mark for the correct answer without any working

1

(d) (i) M1 q = m c ΔT OR calculation (25.0 x 4.18 x 14.0)

Award full marks for correct answer

M2 = **1463**J OR **1.46** kJ (This also scores **M1**)

*In **M1**, do not penalise incorrect cases in the formula*

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M3 must have both the correct value within the range specified **and** the minus sign

*Penalise **M3** ONLY if correct numerical value but sign is incorrect; e.g. **+69.5 to +69.7 gains 2 marks** (ignore +70 after correct answer)*

For 0.0210 mol, therefore

ΔH_1 = **− 69.67** to **− 69.52** (kJ mol^{-1})

OR ΔH_1 = **− 69.7** to **− 69.5** (kJ mol^{-1})

*Penalise **M2** for arithmetic error but mark on*

Accept answers to 3sf or 4sf in the range − 69.7 to − 69.5

ΔT = 287, score q = m c ΔT only

Ignore -70 after correct answer

*If c = 4.81 (leads to 1684J) penalise **M2** ONLY and mark on for **M3** = − 80.17 (range − 80.0 to − 80.2)*

Ignore incorrect units

3

(ii) The idea of heat loss

NOT impurity

OR

Incomplete reaction (of the copper sulfate)

NOT incompetence

OR

Not all the copper sulfate has dissolved

NOT incomplete combustion

1

(e) Impossible to add / react the exact / precise amount of water

Not just "the reaction is incomplete"

OR

Very difficult to measure the temperature rise of a solid

OR

Difficult to prevent solid dissolving

OR

(Copper sulfate) solution will form

1

[8]

Q18.

(a) (i) **M1 (could be scored by a correct mathematical expression which must**

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have

all ΔH**symbols and the** $\sum$ or SUM)

M1 $\Delta H_r = \Sigma \Delta H_f$ **(products)** - $\Sigma \Delta H_f$ **(reactants)**

OR a correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$

M2 $\Delta H_r = -201 + (-242) - (-394)$
$\Delta H_r = -201 - 242 + 394$
$\Delta H_r = -443 + 394$
(This also scores M1)

M3 = – **49** (kJ mol^{-1})
(Award 1 mark ONLY for + 49)
Correct answer gains full marks
Credit 1 mark ONLY for + 49 (kJ mol^{-1})
For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either*
  correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$
  *OR a clear statement of **M1** which could be in words and*
  *scores only **M1***

3

(ii) It is an element / elemental
Ignore reference to "standard state"

OR

By definition

1

(b) **M1** (The yield) increases / goes up / gets more
*If M1 is given as "decreases" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank M1*

M2 There are more moles / molecules (of gas) on the left / of reactants
OR fewer moles / molecules (of gas) on the right / products
OR there are 4 moles /molecules (of gas) on the left and 2 moles / molecules on the right.
OR (equilibrium) shifts / moves to the side with less moles / molecules
*Ignore "volumes", "particles" "atoms" and "species" for **M2***

M3: Can only score M3 if M2 is correct

The (position of) equilibrium shifts / moves (from left to right) to oppose the increase in pressure
*For **M3**, not simply "to oppose the change"*

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*For **M3** credit the <u>equilibrium shifts / moves</u> (to right) to <u>lower / decrease the pressure</u>*

(There must be a <u>specific</u> reference to the change that is opposed)

3

(c) **M1** Yield increases goes up

M2 The (forward) reaction / to the right is <u>endothermic</u> OR <u>takes in/ absorbs heat</u>

OR

The reverse reaction / to the left is <u>exothermic</u> OR <u>gives out / releases heat</u>

*If M1 is given as "decrease" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank **M1***

Can only score M3 <u>if M2 is correct</u>

M3 The (position of) <u>equilibrium shifts / moves</u> (from left to right) <u>to oppose the increase in temperature</u> **(QoL)**

*For **M3**, <u>not</u> simply "to oppose the change"*

*For **M3**, credit the (position of) <u>equilibrium shifts / moves</u> **(QoL)***

*to <u>absorb the heat</u> **OR***

*to <u>cool the reaction</u> **OR***

to <u>lower the temperature</u>

(There must be a <u>specific</u> reference to the change that is opposed)

3

(d) (i) An activity which has no <u>net / overall</u> (annual) carbon emissions <u>to the atmosphere</u>

OR

An activity which has no <u>net / overall</u> (annual) greenhouse gas emissions <u>to the atmosphere</u>.

OR

There is no change in the <u>total amount / level</u> of carbon dioxide /CO_2 carbon /greenhouse gas present <u>in the atmosphere</u>.

The idea that the carbon /CO_2 given out equals the carbon /CO_2 that was taken in from <u>the atmosphere</u>

1

(ii) $CH_3OH + \mathbf{1}½\ O_2 \rightarrow CO_2 + \mathbf{2}H_2O$

Ignore state symbols

Accept multiples

1

(iii) $\mathbf{3}H_2 + \mathbf{1}½\ O_2 \rightarrow \mathbf{3}H_2O$

Ignore state symbols

OR

Accept multiples

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2H_2 + O_2 **2**H_2O

Extra species must be crossed through

1

(e) **M1** q = m c ∆T

Award full marks for correct answer

Ignore the case for each letter

OR q = 140 × 4.18 × 7.5

M2 = 4389 (J) OR 4.389 (kJ) OR 4.39 (kJ) OR 4.4 (kJ)(also scores M1)

M3 Using 0.0110 mol
therefore ∆H = **– 399** ($kJmol^{-1}$)
OR **– 400**

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect; +399 **gains 2 marks***

*Penalise **M2** for arithmetic error and mark on*

*In **M1**, do not penalise incorrect cases in the formula*

If ∆T = 280.5; score q = m c ∆T only

*If c = 4.81 (leads to 5050.5) penalise **M2** ONLY and mark on for **M3** = – 459*

+399 or +400 gains 2 marks

Ignore incorrect units

3

[16]

Q19.

(a) Temperature on *y*-axis

*If axes unlabelled use data to decide that temperature is on *y*-axis.*

1

Uses sensible scales

*Lose this mark if the **plotted points** do not cover half of the paper.*

Lose this mark if the temperature axis starts at 0 °C.

1

Plots **all** of the points correctly ± one square

Lose this mark if the graph plot goes off the squared paper.

1

Draws two best-fit lines

*Candidate must draw **two** correct lines.*

Lose this mark if the candidate's line is doubled or kinked.

1

Both extrapolations are correct to the 4th minute

Award this mark if the candidate's extrapolations are within one square of your extrapolations of the candidate's best-fit lines at the 4th minute.

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1

(b) 19.5 (°C)

Accept this answer only.

1

(c) 26.5 ± 0.2 (°C)

Do not penalise precision.

1

(d) (c) – (b)

*Only award this mark if temperature rise is recorded to **1 d.p.***

1

(e) Uses $mc\Delta T$ equation

Allow use of this equation with symbols or values for M1 even if the mass is wrong.

1

Correct value using 25 × 4.18 × (d)

7.0 gives 732 J.

Correct answer with no working scores one mark only.

Do not penalise precision.

Allow answer in J or kJ.

Ignore sign of enthalpy change.

1

(f) $9.0(1) \times 10^{-3}$

Do not allow 0.01

Allow 9×10^{-3} or 0.009 in this case.

1

(g) If answer to (e) in J, then (e) / (1000 × (f))

or

If answer to (e) in kJ, then (e) / (f)

7.0 and 9.01×10^{-3} gives 81.2 kJ mol^{-1}

If answer to (e) is in J must convert to kJ mol^{-1} correctly to score mark.

1

Enthalpy change has negative sign

Award this mark independently, whatever the calculated value of the enthalpy change.

1

(h) The idea that this ensures that all of the solution is at the same temperature

Do not allow 'to get an accurate reading' without qualification.

1

(i) (i) Chlorine is <u>toxic / poisonous / corrosive</u>

Do not allow 'harmful'.

1

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(ii) Explosion risk / apparatus will fly apart / stopper will come out

Ignore 'gas can't escape' or 'gas can't enter the tube'.

1

[16]

Q20.

(a) q = 500 × 4.18 × 40

Do not penalise precision.

1

= 83600 J

Accept this answer only.
Ignore conversion to 83.6 kJ if 83600 J shown.
Unit not required but penalise if wrong unit given.
Ignore the sign of the heat change.
An answer of 83.6 with no working scores one mark only.
An answer of 83600 with no working scores both marks.

1

(b) Moles (= 83.6 / 51.2) = 1.63

Using 77400 alternative gives 1.51 mol
Allow (a) in kJ / 51.2
Do not penalise precision.

1

Mass = 1.63 × 40(.0) = 65.2 (g)

Allow 65.3 (g)
Using 77400 alternative gives 60.4 to 60.5
Allow consequential answer on M1.
1 mark for M_r (shown, not implied) and 1 for calculation.
Do not penalise precision.

2

(c) Molarity = 1.63 / 0.500 = 3.26 mol dm–3

Allow (b) M1 × 2
Using 1.51 gives 3.02

1

(d) Container splitting and releasing irritant / corrosive chemicals

*Must have reference to both aspects; splitting or leaking (can be implied such as contact with body / hands) **and** hazardous chemicals.*
Allow 'burns skin / hands' as covering both points
Ignore any reference to 'harmful'.
Do not allow 'toxic'.

1

(e) (i) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$

Allow fractions / multiples in equation.
Ignore state symbols.

1

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(ii) Iron powder particle size could be increased / surface area lessened

Decrease in particle size, chemical error = 0 / 3

Change in oxygen, chemical error = 0 / 3

1

Not all the iron reacts / less reaction / not all energy released / slower release of energy / lower rate of reaction

Mark points M2 and M3 independently.

1

Correct consequence of M2

An appropriate consequence, for example

- *too slow to warm the pouch effectively*
- *lower temperature reached*
- *waste of materials*

1

(f) (i) Conserves resources / fewer disposal problems / less use of landfill / fewer waste products

Must give a specific point.

Do not allow 'does not need to be thrown away' without qualification.

Do not accept 'no waste'.

1

(ii) Heat to / or above 80 °C (to allow thiosulfate to redissolve)

Accept 'heat in boiling water'.

If steps are transposed, max 1 mark.

1

Allow to cool before using again

Reference to crystallisation here loses this mark.

1

[14]

Q21.

(a) **Three conditions <u>in any order</u> for M1 to M3**

M1 yeast or zymase

M2 30 °C ≥ T ≤ 42 °C

M3 anaerobic/no oxygen/no air OR neutral pH

M4 $C_6H_{12}O_6 \longrightarrow \mathbf{2}C_2H_5OH + \mathbf{2}CO_2$
OR
$\mathbf{2}C_6H_{12}O_6 \longrightarrow \mathbf{4}C_2H_5OH + \mathbf{4}CO_2$

Mark independently

Penalise "bacteria" and "phosphoric acid" using the list principle

Ignore reference to "aqueous" or "water" (i.e. not part of the list principle)

Or other multiples

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4

(b) **M**1 Carbon-neutral

Ignore "biofuel"

1

M2 6 (mol/molecules) CO_2/carbon dioxide taken in/used/used up (to form glucose or in photosynthesis)

1

M3 6 (mol/molecules) CO_2/carbon dioxide given out due to **2** (mol/molecules) CO_2/carbon dioxide from fermentation/ Process 2 and **4** (mol/molecules) CO_2/carbon dioxide from combustion/Process 3

It is NOT sufficient in M2 and M3 for equations alone without commentary or annotation or calculation

1

(c) **M1 (could be scored by a correct mathematical expression)**

(Sum of) bonds broken – (Sum of) bonds made/formed = Δ*H*

OR

(Σ) $B_{reactants}$ – (Σ) $B_{products}$ = Δ*H*

(where B = bond enthalpy/bond energy)

For M1 there must be a correct mathematical expression using ΔH or "enthalpy change"

M2 Reactants = (+) 4719
OR
Products = (–) 5750

M3 Overall + 4719 – 5750 = **–1031** (kJ mol^{-1}) **(This is worth 3 marks)**

Award full marks for correct answer.

Ignore units.

M2 is for either value underlined

M3 is NOT consequential on M2

3

Award 1 mark ONLY for +1031

Candidates may use a cycle and gain full marks.

M4 Mean bond enthalpies are not specific for this reaction *OR* they are average values from many different compounds/molecules

Do not forget to award this mark

1

(d) **M1** q = m c ΔT (this mark for correct mathematical formula)

M2 = 6688 (J) OR 6.688 (kJ) OR 6.69 (kJ) OR 6.7 (kJ)

M3 0.46g is 0.01 mol
therefore ΔH = **– 669** kJ mol^{-1} OR – **670** $kJmol^{-1}$

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OR **–668.8** kJ mol^{-1}

Award M1, M2 and M3 for correct answer to the calculation
Penalise M3 ONLY if correct answer but sign is incorrect
In M1, do not penalise incorrect cases in the formula
If m = 0.46 or m = 200.46 OR if ΔT = 281, CE and penalise M2 and M3
If c = 4.81 (leads to 7696) penalise M2 ONLY and mark on for M3 = –769.6 OR –770
Ignore incorrect units in M2

M4 Incomplete combustion

Do not forget to award this mark. Mark independently

4

[15]

Q22.

(a) (i) q = mc ΔT

Ignore case except T

1

(ii) 8.80 × 1.92 × 9.5 = **161** (J) to 160.5(12) (J)

Credit 0.161 provided it is clear that it is kJ.
Penalise wrong units

1

(iii) 11.95 × 0.96 × 9.5 = **109** (J) to 108.98(4) (J)

Credit 0.109 provided it is clear that it is kJ.
Penalise wrong units.

1

(iv) **M1** Addition of (a)(ii) and (a)(iii)

M2 Multiply by 10 and convert to kJ (divide by 1000) leading to an answer

Consequential on (a)(ii) and (a)(iii)
Penalise wrong units
Ignore the sign

Therefore ΔH = **(–) 2.69** ***OR*** **(–) 2.7(0)** (kJ mol^{-1})

Ignore greater numbers of significant figures (2.69496)
Subtraction in M1 is CE

2

(b) One from:

- No account has been taken of the intermolecular forces initially in the two liquids OR each liquid has its own intermolecular forces in operation before mixing.
- The liquids may react or reference to reaction or reference to bonds broken or formed

Any statement which shows that there are other intermolecular forces to consider.

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Ignore heat loss and ignore poor mixing.

1

[6]

Q23.

(a) Enthalpy change when 1 mol of compound (1)

Is formed from it's elements (1)

All substances in their standard state (1)

3

(b) $\Delta H = \Sigma \Delta H^{e}c$ (reactants) – $\Sigma \Delta H^{e}c$ (products) (1)

$= (7x - 394) + (4x - 286) - (-3909)$ (1)

$= +7$ kJmol^{-1} (1)

3

(c) Heat change = m c ΔT (1)

$= 250 \times 4.18 \times 60 = 62700\text{J} = 62.7\text{kJ}$ (1)

Moles $C_7H_8 = 2.5 / 92 = 0.0272$ (1)

$\Delta H = 62.7 / 0.0272 = -2307$ kJ mol^{-1} (1)

(allow –2300 to –2323)

4

(d) Mass of water heated = 25 + 50 = 75g
Temp rise = 26.5 – 18 = 8.5 °C

*both for **(1)** mark*

Heat change = $75 \times 4.18 \times 8.5 = 2665$ J = 2.665 kJ (1)

Moles HCl = 0.05 (1)

$\Delta H = -2.665 / 0.05 = -53.3$ kJmol^{-1} (1)

(allow –53 to –54)

4

(e) Less heat loss (1)

1

[15]

Q24.

(a) Particles are in maximum state of order

(or perfect order or completely ordered or perfect crystal or minimum disorder or no disorder)

(entropy is zero at 0 k by definition)

1

(b) (Ice) melts

(or freezes or changes from solid to liquid or from liquid to solid)

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1

(c) Increase in disorder

1

Bigger (at T_2)

1

Second mark only given if first mark has been awarded

(d) (i) Moles of water = 1.53/18 (= 0.085)

1

Heat change per mole = 3.49/0.085 = 41.1 (kJ mol^{-1})

(allow 41 to 41.1, two sig. figs.)

(penalise –41 (negative value), also penalise wrong units but allow kJ only)

1

(ii) $\Delta G = \Delta H - T\Delta S$

1

(iii) $\Delta H = T\Delta S$ or $\Delta S = \Delta H/T$

(penalise if contradiction)

1

ΔS = 41.1/373 = 0.110 kJ K^{-1} (mol^{-1}) (or 110 (J K^{-1} (mol^{-1}))

(allow 2 sig. figs.)

(if use value given of 45, answer is 0.12 (or 120 to 121)

(if ΔH is negative in (d) (i), allow negative answer)

(if ΔH is negative in (d) (i), allow positive answer)

(if ΔH is positive in (d) (i), penalise negative answer)

1

Correct units as above (mol^{-1} not essential)

1

[10]

Q25.

(a) (i) <u>enthalpy change</u> when 1 mol of a substance (or compound) (QL mark)

1

is (completely) burned in oxygen (or reacted in <u>excess</u> oxygen)

1

at 298 K and 100 kPa (or under standard conditions)

1

(ii) heat produced = mass of water × Sp heat capacity × ΔT (or $mc\Delta T$)

1

= 150 × 4.18 × 64 (note if mass = 2.12 lose first 2 marks then conseq) = 40100 J or = 40.1 kJ (allow 39.9 - 40.2 must have correct units)

1

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moles methanol = mass/M_r = 2.12/32 (1)
= 0.0663

1

ΔH = – 40.1/0.0663 = – 605 kJ (mol^{-1})

1

(allow –602 to –608 or answer in J)

(note allow conseq marking after all mistakes but note use of 2.12 g loses 2 marks

(b) (i) equilibrium shifts to left at high pressure

1

because position of equilibrium moves to favour fewer moles (of gas)

1

(ii) at high temperature reaction yield is low (or at low *T* yield is high)

1

at low temperature reaction is slow (or at high *T* reaction is fast)

1

therefore use a balance (or compromise) between rate and yield

1

(c) $\Delta H = \Sigma \Delta H_c^{\ominus}$(reactants) – $\Sigma \Delta H_c^{\ominus}$(products) (or correct cycle)

1

$\Delta H_c^{\ominus}(CH_3OH) = \Delta H_c^{\ominus}(CO) + 2 \times \Delta H_c^{\ominus}(H_2) - \Delta H$

1

= (–283) + (2 × –286) – (–91) (mark for previous equation or this)
= –764 (kJ mol^{-1}) (*units not essential but lose mark if units wrong)*
(note + 764 scores 1/3)

1

[15]

Q26.

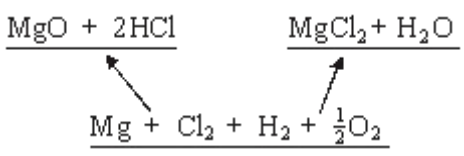
(a) (i) enthalpy (or heat or heat energy) change when
1 mol of a substance **(1)** (QL mark) is formed from its elements **(1)**
all substances in their standard states **(1) (**or normal states at 298K, 100 kPa or std condits)

not *STP, NTP*

3

(b) enthalpy change (or enthalpy of reaction) is independent of route **(1)**

$\Delta H = \Sigma \Delta H_f^{\ominus}$ prods - $\Sigma \Delta H_f^{\ominus}$ reactants (or cycle) **(1)**
minimum correct cycle is:



ΔH = -642 – 286 – (–602 + 2 × –92) **(1)**

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= –142 (kJ mol^{-1}) **(1)**

penalise this mark for wrong units

+142 scores 1 mark out of the last three

4

(c) $\Delta H = mcT$ **(1)** (or $mc\Delta T$)

$= 50 \times 4.2 \times 32 = 6720$ J $= 6.72$J **(1)**

mark is for 6720 J or 6.72 kJ

moles HCl $= \frac{\text{vol}}{1000} \times \text{conc} = \frac{50}{1000} \times 3$ **(1)**

$= 0.15$ **(1)**

if error here mark on conseq.

Therefore moles of MgO reacted = moles HCl/2 **(1)**
(mark is for/2, CE if not/2)
$= 0.15/2 = 0.075$

Therefore $\Delta H = 6.72/0.075$ **(1)**

= –90 kJ (mol^{-1})

kJ must be given, allow 89 to 91

*value **(1)***

*sign **(1)**; this mark can be given despite CE for /2*

8

Note various combinations of answers to part (c) score as follows:

–89 to –91 kJ **(8)** (or –89000 to 91000J)

*no units **(7)***

+89 to +91 kJ **(7)** (or + 89000 to +91000J)

*no units **(6)***

–44 to –46 kJ **(5)** (or -44000 to -46000J)

*no units **(4)** if units after 6.72 or 6720 (5)*

+44 to +46 kJ **(4)** (or +44000 to + 46000)

if no units and
*if no units after 6.72 or 6720 **(3)***
*otherwise check, could be **(4)***

[15]

Q27.

(a) $C_3H_6O + 4O_2 \rightarrow 3CO_2 + 3H_2O$ **(1)** (or multiple) 1

(b) (i) $\frac{1.45}{58}$ **(1)** = 0.0250 **(1)**

allow 0.025

allow conseq on wrong M_r

1.45/100, CE; $\frac{1.45}{58.1}$ *C.E.*

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(ii) heat released = mcΔT
= 100 × 4.18 × 58.1 **(1)**
if 1.45 used in place of 100 CE = 0

= 24300 J **(1)** (or 24.3kJ)
allow 24200 to 24300
ignore decimal places
units tied to answer
If use 0.1 × 4.18 × 51.8 allow ½ for 24.3 with no units

(iii) $\frac{24.3}{0.0250}$ = –972 (kJ mol^{-1}) **(1)**
allow –968 to –973
allow +972
allow conseq
allow no units
penalise wrong units

5

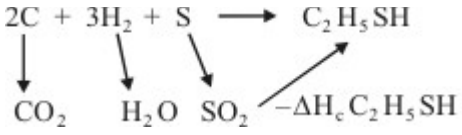
(c) (i) Heat loss **(1)** or energy loss
do not allow incomplete combustion

(ii) *Difference*: more negative **(1)** (or more exothermic)
QoL mark

Explanation: heat (*or energy*) released when water vapour condenses **(1)**
or heat/energy required to vaporise water
or water molecules have more energy in the gaseous state

3

(d) $\Delta H = \Sigma \Delta H_{reactants} - \Sigma \Delta H_{products}$ **(1)**

(or cycle 

)

= (2 × –394) + (3 × –286) + (–297) – (–1170) **(1)**
= –773 **(1)**
ignore units even if wrong
Allow 1/3 *for +773*

3

[12]

Q28.

(a) $2AgNO_3 + Zn \rightarrow Zn(NO_3)_2 + 2Ag$ **(1)**
Accept an ionic equation i.e. $2Ag^+ + Zn \rightarrow 2Ag + Zn^{2+}$

1

(b) Moles = mv / 1000 **(1) =** 0.20 × 50/1000 = 1.00 × 10^{-2}

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2

(c) Heat energy change = mCΔT **(1)** = 50 × 418 × 3.2 J

= 669 J (Ignore signs) **(1)**

Allow 668, 67.0 0.67kJ

Penalise wrong units if given

2

(d) $\frac{2 \times 669}{1 \times 10^{-2}}$ = 134 kJ mol^{-1}

Mark one : 2 × (answer to (c))

Mark two : Dividing by answers to (b)

Allow 133 – 134

Penalise incorrect units

Mark conseq to equation in (a) for full marks, also to that in (c)

If No working is shown and answer is incorrect zero

2

(e) Incomplete reaction or Heat loss **(1)**

1

[8]

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Q1.

(a) Many students struggled with this question, though it did discriminate well. The main problem stemmed from an inability to find the heat released using the enthalpy change (per mole) and the amount in moles of the acid or alkali reacting. Many believed that q was the same as the enthalpy change. Some students also incorrectly thought that amount in moles reacting' was the amount in moles of acid + moles of alkali.

(b) Very few students realised that the best-fit line was a curve and not a straight line. Some students also extrapolated to a time before the time of mixing. Only 3.8% of students gained both marks.

Q2.

(a) This question discriminated well: 28.3% of students correctly identified the types of intermolecular forces and noted that hydrogen bonding in the alcohol and the acid was stronger than dipole-dipole attractions between propanal molecules. Despite the request in the question to consider intermolecular forces, a few students still discussed the breaking of bonds in the molecules and so gained no marks, although fewer did this than is often the case in this type of question.

(b) Very few students (4%) scored both marks in this question and only 39.2% scored at least one mark, despite the question being based on one of the required practical activities.

(c) This part was answered well by nearly two-thirds of the students. The main error was to test for the aldehyde rather than the acid.

(d) This question discriminated well and there was a good spread of marks. Sadly, some students did not quote their answers to three significant figures and/or remember the negative sign for their exothermic enthalpy change of combustion.

(e) The major errors in the answers to this acid-catalysed elimination of water were where students confused this mechanism with the elimination of HX from a halogenoalkane using a base. However, just under a third of students scored full marks in a correct mechanism, either via the formation of a carbocation or by showing the simultaneous loss of water and H+ from a protonated alcohol.

(f) This part was challenging and a surprising proportion of students (8%) made no attempt. A large number scored no marks as they discussed the formation of different alkenes, rather than why pent-2-ene shows E-Z isomerism. Sadly, some of those who did gain the first mark failed to gain the second as this required two statements, not only that the C=C bond cannot rotate, but also that each carbon in the double bond has two different groups attached to it.

Q3.

(a) The usual advice is that a scale on a graph is 'suitable' if the plotted points take up more than half of the available space. In this case, the decision about the suitability of the scale was more 'relaxed' due to the need for students to allow space for the extrapolation to go higher than the highest plotted point. However, a significant number of students still managed to miss the mark by choosing scales that led to the plotted points being squeezed in to only a couple of squares on the vertical axis.

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There still seems to be a misconception amongst some students that all scales need to start at zero. Having plotted the points, most students recognised that their lines of best fit should ignore the point at 5 minutes. Although a lot of 'S-shaped' curves were seen (the reminder clue in the question was that candidates should draw suitable *lines* of best fit), some students failed to draw any line between 0 and 3 minutes, and the lines were sometimes not extrapolated to the 4th minute. A surprising number of students quoted the 'final' temperature at the 4th minute rather than giving ΔT. Pleasingly, 34.3% of students scored all five marks.

(b) Far more students than expected failed to double the uncertainty given in the question to reflect the fact that two temperature readings are taken with the thermometer. As a result, only 19.3% of students were awarded this mark.

(c) As expected, this was the easiest question on the paper with the vast majority of candidates (90.7%) able to suggest a way to reduce heat loss.

(d) This was another example of a question where some students were let down by not reading the question, which clearly asked for a change that would reduce the percentage uncertainty *in the use of the same thermometer*. Given that percentage uncertainty is calculated as apparatus uncertainty divided by measurement made, it was hoped that more students would recognise the need to increase the size of the measurement made, i.e. the temperature change. Many students who did recognise the need to generate a bigger temperature change suggested doing so by using smaller volumes; they thus failed to appreciate that this would reduce the amounts of reactants as well as the volume, so that less heat would be given out and the change in temperature would be the same as in the larger scale experiment. 58% of students scored zero.

(e) Despite the formula and name being given in the question, many students failed to recognise that ethanedioic acid is diprotic, which affected their equation and subsequent calculation. In the calculation, most were able to calculate the initial amounts of each reactant, but many then failed to recognise the idea that one is present in excess so that the other would be the limiting reagent and so determine the amount of water formed. Calculations involving adding 0.02 to 0.045, or subtracting 0.02 from 0.045, were frequently seen, although it was not always clear what students thought they were calculating when they did so, due to poor layout of calculations. There were also a lot of variations seen in the mass used for the mcΔT calculation. In any enthalpy change or calorimetry experiment of this type, it is the solution that is increasing in temperature, so it is the mass of solution that needs to be used (100 g here as 25 cm^3 of one solution was added to 75 cm^3 of another and all have a density of 1.00 g cm^{-3}). This calculation discriminated extremely well between students of different abilities; 21.2% scored maximum marks and only 6.4% failed to score anything.

(f) This was expected to be a high-level discriminator and that certainly proved to be the case for the second mark (achieved by only 3.3% of students). Although many gained a mark for referring to the fact that sulfuric acid is a stronger acid than ethanedioic acid, the second half of their answer often then incorrectly referred to ideas such as "it therefore reacts with more KOH", "more water is produced", and "bonds between K^+ and sulfate are stronger than between K^+ and ethanedioate". Only the best students recognised that the overall enthalpy change is the net result of the difference between 'energy supplied' and 'energy released'. In this case, the 'energy released' will be the same for both acids. Therefore, the difference in the enthalpies of neutralisation must be due to ethanedioic acid needing more energy to be supplied, in order to break O−H bonds during the neutralisation reaction (whereas the sulfuric acid is already fully dissociated).

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Q4.

(a) In this extended calculation the correct limiting reagent had to be used to gain full marks. This proved difficult for many students. The less able students were expected to be able to calculate the numbers of moles of the two reagents and/or state that q = mcΔT, but this was not always the case.

(b) 58.1% of students gained the mark for this question about a well-known practical issue.

(c) This practical question was marked using a levels of response mark scheme. There was a wide range of answers, showing that most had done this sort of practical during their course. Nearly all students were aware that insulation is the most obvious improvement to the technique but many students failed to read the question carefully. Many answers, even from the best students, described a technique but did not suggest clearly and then justify how the method given in the question could be improved.

Q5.

(a) This proved to be a much tougher starter question than had been anticipated, with only 12% of students earning the mark. Students did not recognise that enthalpy change could not be measured directly. In this case, the enthalpy change was for the formation of a hydrated salt from an anhydrous one, with the expected answer being that it would be impossible to prevent some salt dissolving during the addition of water to the anhydrous salt. An alternative answer, related to the difficulty in measuring the temperature of a solid, was also allowed.

Some students' answers revealed confusion between calorimetry and colorimetry, with suggested answers including the lack of colour change during the reaction. Some students also seemed to believe that calorimetry is only possible if something is being burned.

(b) This calculation was answered reasonably well, with less than 20% of students failing to score. There was confusion about the 'direction' around the Hess Cycle, and evidence of many students thinking that an equation of the form $\Delta H = \Sigma \Delta H_f$(products) - $\Sigma \Delta H_f$(reactants) can be used universally, when it only applies to the specific use of enthalpies of formation.

(c) Most students' encounter with this 'extended response' style of question produced a good spread of marks, although 37% of students failed to score. This was usually due to a completely inappropriate method being described, with incorrect answers such as: "making a solution of magnesium chloride", "using it to fill a spirit burner and lighting it under a beaker of water" and "putting a solution of magnesium chloride in a polystyrene cup and heating it over a Bunsen burner". Other incorrect answers included descriptions of the preparation of a standard solution followed by a titration and the addition of magnesium chloride to acid instead of to water.

This question was marked using a 'levels of response' mark scheme. The key to success was for students to concentrate first on the inclusion of as much correct chemistry as possible to ensure access to Level 3 (worth 5 or 6 marks). Within a level, the mark awarded depended on the clarity and coherence of an answer, together with a clear, logical progression through the description. Appropriate apparatus and quantities should have been mentioned as necessary. For example, rather than writing 'add water to a container', a good start to the answer would be to write 'A measuring cylinder was used to measure 50 cm^3 of water into a polystyrene cup'.

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Despite the fact that many students suggested in part (a), that it is difficult to measure the temperature of a solid, many then suggested putting the magnesium chloride into the polystyrene cup first and then recording its initial temperature, before adding the water.

(d) This was a challenging question, but one for which it proved relatively easy to score two marks; nearly 20% of students scored full marks here. Most students could successfully plot the points and draw a best fit line, although the negative scale on the y-axis confused some. Most students were also able to calculate the gradient of their line, although, as mentioned previously, it was not always clear what their suggested answer was. The calculation of ΔS proved trickier, with many trying to use the relationship $\Delta G = \Delta H - T\Delta S$, and either ignoring their calculated gradient or substituting it in for ΔH. Relatively few students recognised that this equation can be taken as $y = mx + c$ ($y = c - xm$ in this case) so that this graph of ΔG (y) vs T (x) gives a straight line with a gradient of $-\Delta S$.

Q10.

Part (a) - Only the best candidates were able to gain all five marks. Worryingly, many candidates seemed to attempt to measure the specific heat capacity of the alcohol by heating it in a water bath. Vague descriptions such as “burn some alcohol to heat some water” with a failure to state what variables need to be measured were also fairly common. Some wanted to use a polystyrene cup to hold the water. There were some very good answers too, though.

Part (b) - Generally well done.

Part (c) - Generally well answered. An incomplete reagent such as missing the condition “acidified” lost M1 but subsequent marks were available. Tollens’ reagent and Benedict’s reagent were favourite incorrect answers.

Part (d) - Only the best candidates were able to score full marks. There were many correct equations although some gave an unbalanced chemical equation forgetting the “O” in the alcohol and some gave only an equation for complete combustion. A common mistake was to give two environmental concerns or two economic concerns even though the question required one of each.

Q11.

Enthalpy of combustion & calorimetry

In the calculation of the enthalpy of combustion from the experimental data, many students used the mass of the fuel (rather than the water) when using $q = mc\Delta T$. Others incorrectly added 273 to the temperature rise. When finding the moles of methanol burned, some students rounded this to 1 significant figure which gave inaccurate answers. Some students failed to include the minus sign on their final answer to show that the reaction is exothermic. In (b) many students referred to the problems already stated in the question rather than an additional one. Many students suggested mistakes made during the experiment rather than design features. Many students scored the mark for (c) but many others did not know where to start. The calculation of apparatus percentage uncertainties should be an important and routine part of practical work. Few students realised that (d) related to the size of the uncertainty in the temperature rise compared to the actual temperature rise and/or heat loss in the experiment. Many students were uncertain how to start the calculation in (e), namely by using the density to find the mass of the ethanol. Others struggled to convert the volume in dm^3 to cm^3.

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Q12.

This question was answered well. Balancing the equation in part (a)i looks straightforward when you know the answer, but it is quite demanding if you have to work it out, and impressively half the students gave the correct answer. In part (b)i, it was necessary to draw unambiguous structures both for propan-2-ol (not given in the question) and propanone (given in part (a)i). The calculation in part (c) was well answered with the focus on correct chemistry rather than on the number of significant figures and the mathematics of rounding the final answer. The definition in part (d) was expected to be straightforward and yet still resulted in only 40% gaining all three marks. As many as 45% gained all three marks and 80% gained at least one mark from the very straightforward calculation in part (e), with errors occurring because some students did not know the bonding either in propanone or in carbon dioxide and used the unnecessary C−O that was given in the data set. It was decided that the very straightforward idea of “heat loss”, in whatever context, was worth only one mark in part (f) and that students needed to come up with other reasons why the values in part (c) and part (e) differed; many were able to do so and this led to 54% scoring both marks.

Q13.

In this question, the first mark (more water) was gained by many, although some suggested a volume larger than the calorimeter. Few managed to give a clear explanation, even though some seemed to have the right kind of idea but couldn’t express it sufficiently clearly.

Q14.

Part (a) discriminated almost as well as the earlier mechanism questions with well over half of the students scoring at least 3 of the 5 marks. Relatively few recognised that (fractional) distillation is a process used to produce a much more concentrated solution of ethanol and many referred to the hydration of ethene, having missed the requirement to start “from a dilute aqueous solution”. The concept of carbon-neutral “in the context of this biofuel” required reference both to carbon dioxide **and** the atmosphere. Part (b) was well answered with over half of all students scoring 4 out of 5 marks. By comparison, part (c) proved more demanding. The definition in part (c)(i) most often yielded only 1 of the 2 marks. Too often in part (c)(ii) it proved difficult to decipher the jumble of numbers that some students recorded on the page and only about one-third of students scored all 3 marks.

Q15.

(a) This part was mostly well answered, with the exception of those who chose to use the wrong mass.

(b) In this part, failure to give the negative sign was the most common error where students did not score full marks.

(c) This part was usually done very well.

(d) In contrast, this part was very poorly answered, almost always because –2642 was used from (c) rather than their answer to (b).

(e) Many vague answers were seen in response to this part. Simply adding insulation was insufficient and use of a polystyrene cup was wrong in this situation.

(f) The idea of incomplete combustion seemed to be poorly understood in this part, with quite a few students stating that ’not all the alcohol had burned’. Comments about

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heat loss etc were disqualified by the question.

Q16.

This question proved to be difficult. In part (a), most students scored one mark for mentioning that the ionic radius of the chloride ion is less than that for the bromide ion. However, many weaker students lost this mark because they did not make reference to a chloride ion; often, just chlorine was mentioned. Only the best students went on to discuss how a chloride ion is attracted to the partially positive hydrogen atom in a water molecule. Others referred incorrectly to intermolecular forces or to hydrogen bonding. About 60% of students gained both marks for the calculation in part (b). In part (c)(i), most students stated that the entropy would increase but many did not clearly explain why and also that the TΔS term would outweigh the positive enthalpy change. Although about a quarter of all students scored at least 4 marks in part (c)(ii), less than 10% went on to score full marks by subtracting the temperature change from 298 K. Marks were generally low because many students did not recognise that the heat absorbed could be calculated by multiplying the enthalpy of solution by the amount in moles of potassium chloride. Weak students also used a wrong value for the mass of water heated – usually 25 g or 5.00 g.

Q17.

Almost 85% of students were able to give a correct statement for Hess's Law and then attempted to apply it in parts (b) and (c), with over 70% success. No credit was given for a value calculated in part (c), consequent on an incorrect expression in part (b), since that is a chemical error.

Part (d) was generally well-answered although the negative sign was often missed in the answer leading to only 35% gaining all three marks. Only 7% were able to deduce a correct answer to part (e).

Q18.

The standard enthalpy change calculation in part (a) was straightforward and high scoring. In parts (b) and (c), good discrimination occurred and a great many well–articulated responses were seen. It is worth noting that no marks were scored in either of parts (b) or (c), if the effect on the yield was assigned incorrectly. The meaning of *carbon–neutral* in part (d) is spelled out in the specification and needs to refer to <u>net</u> emissions of carbon dioxide to the atmosphere. Parts (d)(ii) and (d)(iii) were challenging and only the best students were able to arrive at the equation for the overall reaction between hydrogen and oxygen to make water. Most students scored at least one mark in part (e); the commonest error was a failure to give the final answer a negative sign for this exothermic process.

Q19.

(a) In this part, most students completed the graph successfully. The usual problem was a mark being wrongly awarded for plotted points which did not cover half the grid because the student started the y-axis at zero. Some schools and colleges were very generous when awarding the mark for drawing a line of best fit. In graph questions where the points contain one or more anomalies, the line of best fit must ignore these anomalies to score the mark. The line of best fit mark cannot be awarded when the line itself is poorly drawn or doubled in places. A few schools and colleges did not allow the mark for extrapolation when the line of best fit was poor. As long as the line is extended correctly the mark for extrapolation can be awarded. If the line becomes kinked when extrapolated the mark for extrapolation cannot be awarded.

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(b) A few teachers failed to realise that the marks for part (b) and (c) were essentially for drawing the graph correctly rather than for reading from a poorly drawn graph.

(c) A few teachers failed to realise that the marks for part (b) and (c) were essentially for drawing the graph correctly rather than for reading from a poorly drawn graph.

(d) Few students lost the mark in this part for incorrect precision.

(e) In this part proved straightforward but a fair number of students used an incorrect mass in the equation.

(f) In this part, a good number of students were incorrectly allowed the second mark for the answer 0.01. This answer, being to one significant figure only, was disallowed in the Marking Guidelines.

(g) In this part was well answered, although a surprising number of students omitted the negative sign in their final answer.

(h) Answers to this part were generally good; the common error was to suggest that stirring ensured that the mixture was homogeneous.

(i) In this part (ii) a number of students thought that heat was the danger to the equipment and lost the mark.

The above notes are intended for that minority of schools and colleges experiencing difficulty in meeting the criteria. They must not be allowed to unduly detract from the very healthy overall picture. Given the pressures on teachers to deliver the teaching programme, this was once again a very positive and encouraging session. Schools and colleges are again warmly commended for the trouble taken to assemble a sample which proved to be easy to moderate. Their efforts continue to be much appreciated by the moderator team.

Q20.

Section B proved more demanding. In part (a), the calculation had similar faults to Question 5 but some students failed to read that the answer was to be in Joules - an answer in kJ was penalized unless there was a clear correct answer in the working. Part (b) and part (c) were well done though the alternative answer to part (a) was frequently used in these. In part (d), only a few students failed to highlight the need for the bag to split or the chemicals to come into contact with skin / hands. Part (e)(i) indicated that a considerable number of students found difficulties with the equation; common errors were the wrong formula for iron (III) oxide, the inclusion of ions on the reagent side of the equation and using Fe2 for the metal. Part (e)(ii) contained many good partial answers but there was a significant failure to focus finally on why longer times might not be an advantage. In part (f)(i), the main errors were to re-state the question about being reusable or to indicate that there would be no waste following use of these handwarmers. There were some vague answers to part (f)(ii) which referred to 'heating' the bag or 'keeping it in a warm place' and, for some, the contents were removed before further treatment. Nevertheless, sensible answers were frequently seen.

Q21.

Most candidates seem to know something about fermentation and part (a) discriminated extremely well.

In part (b), only the best candidates were able both to state that such a fuel is carbon-neutral and also to demonstrate that the six moles of CO_2 taken in during photosynthesis

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are later released in the fermentation process followed by the combustion of ethanol. Failure to recognise that two moles of ethanol were burning resulted in only four moles of CO_2 and left candidates confused. A few candidates seemed to think that a balanced equation with six carbon atoms on each side is carbon-neutral.

The calculation in part (c) proved demanding as candidates failed to count up accurately how many of each bond were broken and how many were formed. They were able quite often to get only one of these correct. The idea that mean bond enthalpies are average values obtained from many different compounds was not well known.

In part (d) the equation used to calculate the heat change was well known but conversion to enthalpy change proved difficult for all but the best. The idea of incomplete combustion was often missed.

Q22.

This was generally a well-answered question suggesting that the students were able to apply their knowledge in a novel context provided they had sufficient information. More than 70% of candidates scored full marks in all three parts (a)(i), (a)(ii) and (a)(iii) and almost half the candidates were able to use the calculated data for each liquid to arrive at some credit in part (a)(iv). Almost a third of the candidates gave plausible reasons for why the students may have made an incorrect deduction.

Q23.

Part (a) was generally well done by most candidates. The most common error was not referring to standard states. The calculation in part (b) proved more demanding for students than some previous enthalpy calculations with many candidates giving the incorrect answer of –7kJmor\ A large number of candidates did not give the correct mass or correct temperature rise in part (c) and therefore only scored the mark for the $Q = mc\Delta t$ equation. Many of the candidates who did calculate the heat evolved then failed to calculate molar quantities. The calculation in part (d) proved very difficult for candidates with very few scoring full marks. Common errors were incorrect mass, incorrect temperature rise and lack of conversion to molar quantities. Candidates should know that exothermic reactions are shown by a negative sign e.g. $–53.3kJmol^{-1}$. In part (e) many candidates failed to make the comparison regarding heat loss between the two experiments.

Q24.

This question also produced a wide range of marks. A major misconception was to relate entropy directly to the energy of particles rather than to their disorder. Most candidates gave a correct answer to part (b). In part (c) weak candidates often discussed the breaking of bonds rather than referring to disorder. Others just reiterated the question by stating that the entropy would increase. Good candidates usually gained one mark by stating that the disorder of particles increases when a liquid changes to a gas but only the best candidates answered the question fully by referring also to the smaller change in order on melting. It was pleasing to note that part (d) was answered correctly by many candidates. Marks were sometimes lost when giving units in part (d)(iii) that did not tally with the numerical answer. For example, when the numerical answer should have corresponded to $J\ K^{-1}\ mol^{-1}$ the units were frequently given as $kJ\ K^{-1}\ mol^{-1}$.

Q25.

In this question, good candidates were able to score full marks. Weaker candidates were less successful though they were usually able to pick up at least five or six marks.

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Answers to part (a) usually gained all three marks. Answers to part (b) by weaker candidates were less successful. One common error in the expression $mc\Delta T$ was to use the mass of methanol (2.12 g) instead of the mass of water (100 g). Another common error was to give an incorrect sign for the final value of the enthalpy of combustion. Candidates were expected to recognise that this exothermic process should lead to a negative value for the enthalpy of combustion of methanol. Weaker candidates also lost marks for incorrect units or for giving no units. It is important for candidates to give correct units for intermediate values in the calculation as well as for the answer. In this case, if a candidate gave a wrong final answer, it was still possible to gain an intermediate mark for the heat released to the 100 g of water. However, if the candidate did not make it clear whether the intermediate value was expressed in Joules or in kJ, it was not possible to give any credit.

Answers to part (b) were of a good standard and in part (b) (i) almost all candidates were awarded the two marks. Answers to part (b) (ii) were not quite so accurate and, in particular, only the best candidates stated that 500 K achieves the best balance between rate of reaction and yield.

Good candidates found part (c) straightforward but weaker candidates often omitted to allow for two moles of hydrogen and also used the wrong sign for the enthalpy of reaction (-91 kJ mol^{-1}) relative to the enthalpies of combustion of carbon monoxide and hydrogen.

Q26.

Most candidates answered this question well though it proved to be difficult to score maximum marks. The definition of standard enthalpy of formation in part (a) was usually correct though some candidates lost one mark because they did not make it clear that reactants and products should be in their standard states. In part (b) good candidates were able to score maximum marks but weaker candidates sometimes referred to energy rather than enthalpy when stating Hess's Law and such candidates often predicted an endothermic enthalpy change (+142 kJ mol^{-1}) rather than an exothermic one. Part (c) proved to be the most difficult part of this question. The major error was in the number of moles of magnesium oxide. Most candidates assumed that the number of moles of MgO would be the same as that of hydrochloric acid whereas it should have been half of that. This error led to a value for the enthalpy change that was too small by a factor of two. Such an answer resulted in the loss of three marks.

Q27.

This question proved accessible to most candidates; even the weaker candidates were able to score marks approaching half of those available. Answers to part (a) were usually correct.

Most candidates also gave a correct answer to part (b)(i) though there were a significant number of errors in the calculation of the relative molecular mass of propanone. Parts (b)(ii) and (b)(iii) were also answered well although there were some problems with units. The correct answer to part (c)(i) was known by most candidates but part (c)(ii) proved to be much more discriminating and only the best candidates were able to explain why the enthalpy of combustion is more negative when water is formed in the liquid state. A fair majority of candidates was able to give a correct answer to part (d) but as usual in this type of question, weaker candidates made an error in signs leading to an answer of +773 kJ mol^{-1} or made an error by omitting to multiply the relevant enthalpy of combustion by the number of moles of the substance involved.

Q28.

It was disappointing to find many wrong equations for the reaction between silver nitrate

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and zinc in part (a) especially as the use of silver nitrate solution to distinguish between halides ions forms part of this module and the formula of zinc nitrate was given.

Parts (b) and (c) were well answered and, as part (d) was marked consequentially to answers given in parts (a), (b) and (c), most candidates were also able to score full marks in part (d). Almost all candidates stated correctly in part (e) that loss of heat energy was the reason why the experimental value obtained was less than the correct value.

Q1.

This question is about energetics.

(a) Write an equation, including state symbols, for the reaction with an enthalpy change equal to the enthalpy of formation for iron(III) oxide.

_____

(1)

(b) **Table 1** contains some standard enthalpy of formation data.

Table 1

	$CO(g)$	$Fe_2O_3(s)$
$\Delta_f H^\ominus$ / kJ mol^{-1}	−111	−822

$Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(s) + 3CO_2(g)$ $\Delta H = -19$ kJ mol^{-1}

Use these data and the equation for the reaction of iron(III) oxide with carbon monoxide to calculate a value for the standard enthalpy of formation for carbon dioxide.

Show your working.

$\Delta_f H^\ominus$ _____ kJ mol^{-1}

(3)

(c) Some enthalpy data are given in **Table 2**.

Table 2

Process	**ΔH / kJ mol^{-1}**
$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$	−92
$N_2(g) \longrightarrow 2N(g)$	+944
$H_2(g) \longrightarrow 2H(g)$	+436

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Use the data from **Table 2** to calculate the bond enthalpy for N−H in ammonia.

N−H bond enthalpy _____ kJ mol^{-1}

(3)

(d) Give one reason why the bond enthalpy that you calculated in part (c) is different from the mean bond enthalpy quoted in a data book (388 kJ mol^{-1}).

_____

_____

_____

(1)

(Total 8 marks)

Q2.

When alkanes are burned in an excess of oxygen they produce carbon dioxide and water.

(a) Write an equation for the complete combustion of propane in oxygen.

_____

(1)

(b) An expression can be derived using bond enthalpy data to estimate the enthalpy of combustion ($\Delta_c H$) of an alkane.

For an alkane with ***n*** carbon atoms: $\Delta_c H = -(496\boldsymbol{n} + 202)$ kJ mol^{-1}

The enthalpy of combustion of an alkane was calculated to be −6650 kJ mol^{-1} using this expression.

Deduce the molecular formula of this alkane.

Show your working.

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Molecular formula of alkane _____

(2)

(c) Suggest **one** reason, other than the use of mean bond enthalpies, why a value for the enthalpy of combustion of a liquid alkane is different from the value obtained using the expression in part (b)

_____

_____

(1)

(d) Values of the enthalpy change for combustion of 1 g of some alkanes are shown in the table.

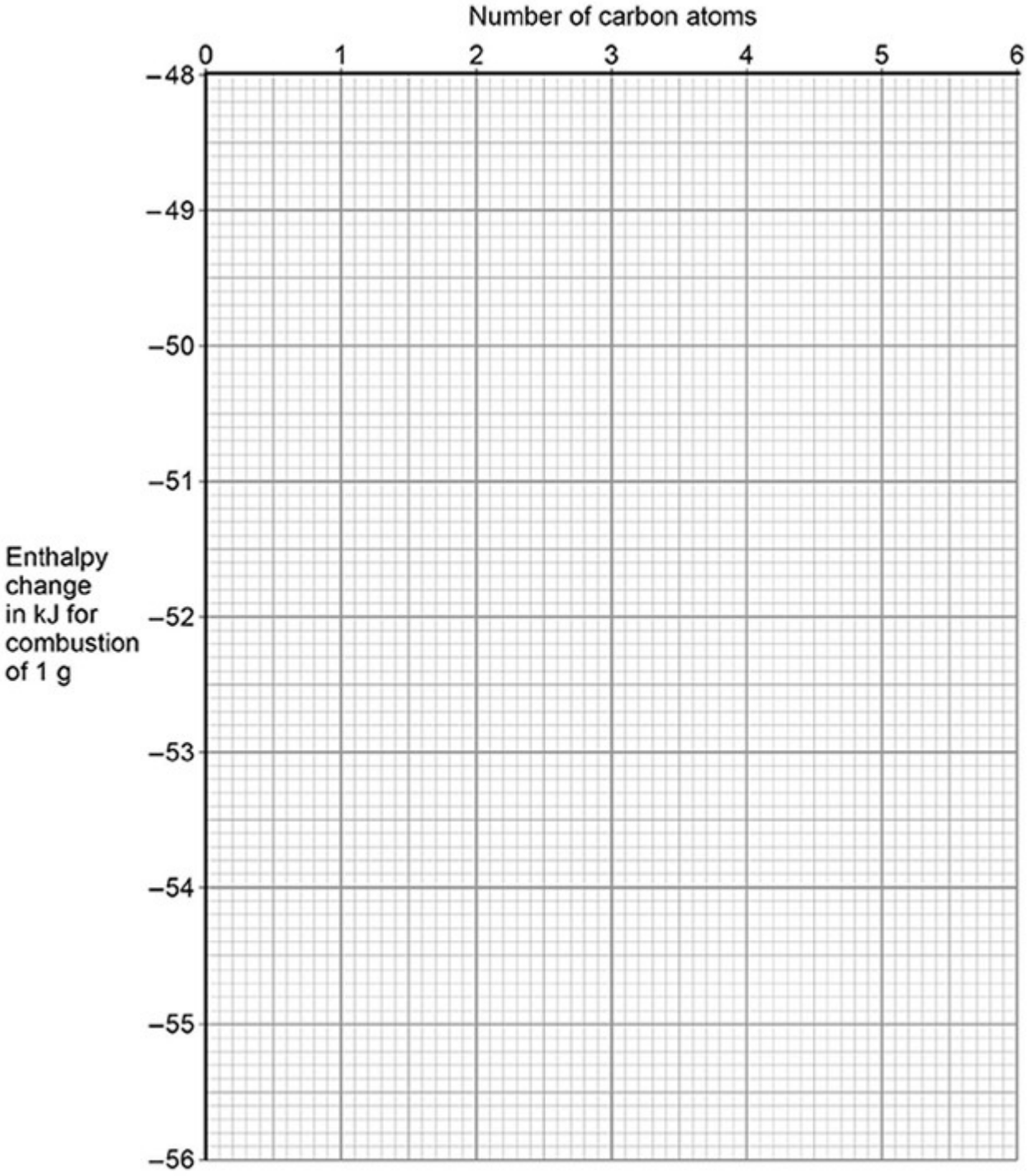
	methane	**ethane**	**propane**	**butane**	**pentane**
Enthalpy change in kJ for combustion of 1 g	−55.6	−52.0		−49.6	−48.7

Plot the enthalpy change for the combustion of 1 g against the number of carbon atoms in the alkanes in the table.

Draw a best fit line and use this to estimate the enthalpy change for combustion of 1 g of propane.

Write your answer in the table.

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(3)

(e) Isooctane (2,2,4-trimethylpentane) is an important component of petrol used in cars.

When isooctane is burned, the enthalpy change is −47.8 kJ g^{-1}

Isooctane is a liquid at room temperature with a density of 0.692 g cm^{-3}

Calculate the heat energy released, in kJ, when 1.00 dm^3 of isooctane burns in excess oxygen.

Give your answer to the appropriate number of significant figures.

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Heat energy released _____ kJ

(2)

(Total 9 marks)

Q3.

This question is about enthalpy changes.

(a) Write an equation, including state symbols, to show the reaction taking place when the standard enthalpy of combustion for ethanol is measured.

_____

(2)

(b) State the name given to the enthalpy change represented by the following chemical equation.

Explain why this enthalpy change would be difficult to determine directly.

$$C(s) + \frac{1}{2}O_2(g) \rightarrow CO(g)$$

Enthalpy change _____

Explanation _____

_____

_____

(2)

(c) Standard enthalpies of combustion for carbon and carbon monoxide are −393 kJ mol^{-1} and −283 kJ mol^{-1}, respectively.

Use these data to calculate the enthalpy change for the reaction in part **(b)**.

Enthalpy change = _____ kJ mol^{-1}

(2)

(d) Use the following data to calculate a value for the Xe–F bond enthalpy in XeF_4

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$$Xe(g) + 2F_2(g) \rightarrow XeF_4(g) \quad \Delta H = -252 \text{ kJ mol}^{-1}$$
$$F_2(g) \rightarrow 2F(g) \quad \Delta H = +158 \text{ kJ mol}^{-1}$$

Xe–F bond enthalpy = _____ kJ mol^{-1}

(3)

(e) Suggest a reason why the value calculated in part **(d)** differs from the mean Xe–F bond enthalpy quoted in a data source.

_____

_____

_____

(1)

(Total 10 marks)

Q4.

Calculate the enthalpy change, in kJ, for this dissociation of mole of propan-1-ol.

$$C_3H_7OH(g) \longrightarrow 3C(g) + 8H(g) + O(g)$$

	C—H	C—C	C—O	O—H
Mean bond dissociation enthalpy / kJ mol^{-1}	412	348	360	463

A −4751 ○

B −4403 ○

C +4403 ○

D +4751 ○

(Total 1 mark)

Q5.

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

_____

(1)

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

_____

_____

_____

_____

_____

(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

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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.

_____

_____

(4)

(Total 10 marks)

Q6.

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}.

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

_____

_____

_____

(1)

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

_____

_____

_____

(1)

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

_____

_____

_____

_____

_____

_____

(3)

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

_____

_____

_____

(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.

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K_p = _____ Units = _____

(7)

(Total 16 marks)

Q7.

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)

Q8.

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.

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

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.

(3)

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

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

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

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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.

_____

_____

_____

_____

_____

_____

_____

_____

(3)

(Total 9 marks)

Q9.

(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.

_____

(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.

_____

(1)

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

_____

(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.

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

(3)

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

(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 _____

_____

_____

Reason 2 _____

_____

_____

(2)

(Total 15 marks)

Q10.

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)

Q11.

Ethanol is an important fuel.

(a) A dilute aqueous solution of ethanol can be produced by the fermentation of an aqueous solution of glucose.
It is claimed that the ethanol obtained from this solution is a carbon-neutral biofuel.

Write an equation for this fermentation reaction.

Give **two** other essential conditions for this reaction to produce a good yield of ethanol.

Name a process used to produce a much more concentrated solution of ethanol from a dilute aqueous solution.

State the meaning of the term **carbon-neutral** in the context of this biofuel.

_____

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(5)

(b) 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}.

(5)

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

(i) Give the meaning of the term **mean bond enthalpy**.

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(2)

(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 15 marks)

Q12.

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

$H_2C=CH_2(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g)$ $\Delta H = -42$ 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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(2)

(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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(3)

(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.

_____

(2)

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

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

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(3)

(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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(3)

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

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

_____

(1)

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

(1)

(Total 17 marks)

Q13.

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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(1)

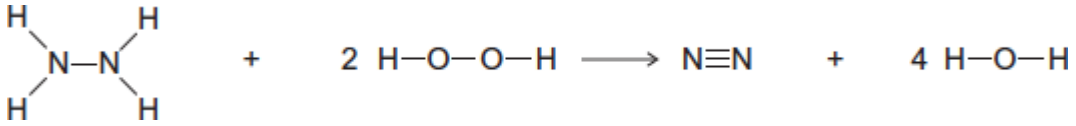
(b) State the meaning of the term *mean bond enthalpy*.

(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.



(3)

(Total 6 marks)

Q14.

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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_____

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(2)

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

_____

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(1)

(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

_____

(1)

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

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(2)

(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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(3)

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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.

_____

_____

(1)

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

_____

_____

(1)

(Total 11 marks)

Q15.

Ammonia can be manufactured by the Haber Process.

The equation for the reaction that occurs is shown below.

$$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$$

(a) The table below contains some bond enthalpy data.

	N ≡ N	H–H	N–H
Mean bond enthalpy / kJ mol^{-1}	944	436	388

(i) Use data from the table to calculate a value for the enthalpy of formation for one mole of ammonia.

_____

_____

_____

_____

_____

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(3)

(ii) A more accurate value for the enthalpy of formation of ammonia is –46 kJ mol^{-1}.
Suggest why your answer to part (a) (i) is different from this value.

_____

_____

(1)

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(b) The table below contains some entropy data.

	$H_2(g)$	$N_2(g)$	$NH_3(g)$
$S\ominus$ / J K^{-1} mol^{-1}	131	192	193

Use these data to calculate a value for the entropy change, with units, for the formation of one mole of ammonia from its elements.

_____

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(3)

(c) The synthesis of ammonia is usually carried out at about 800 K.

(i) Use the ΔH value of –46 kJ mol^{-1} and your answer from part (b) to calculate a value for ΔG, with units, for the synthesis at this temperature.
(If you have been unable to obtain an answer to part (b), you may assume that the entropy change is –112 J K^{-1} mol^{-1}. This is not the correct answer.)

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(3)

(ii) Use the value of ΔG that you have obtained to comment on the feasibility of the reaction at 800 K.

_____

(1)

(Total 11 marks)

Q16.

Glucose, produced during photosynthesis in green plants, is a renewable source from which ethanol can be made. Ethanol is a liquid fuel used as a substitute for petrol.
The processes involved can be summarised as follows.

Process **1** Photosynthesis in green plants

$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

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Process **2** Fermentation of glucose to form ethanol

Process **3** Complete combustion of ethanol
$CH_3CH_2OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

(a) State **three** essential conditions for the fermentation of aqueous glucose in Process **2**.

Write an equation for the reaction that takes place during this fermentation.

(4)

(b) It has been claimed that there is no net carbon (greenhouse gas) emission to the atmosphere when ethanol made by Process **2** is used as a fuel.

State the term that is used to describe fuels of this type.

Use the equations for Processes **1, 2** and **3** to show why it can be claimed that there is no net emission of carbon-containing greenhouse gases.

(3)

(c) Use the information from the equation for Process **3** above and the mean bond enthalpies from the table below to calculate a value for the enthalpy change for this process.

	C–H	C–C	C–O	O–H	C=O	O=O
Mean bond enthalpy / kJ mol^{-1}	+412	+348	+360	+463	+743	+496

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Give **one** reason why the value calculated from mean bond enthalpies is different from the value given in a data book.

(4)

(d) A student carried out a simple laboratory experiment to measure the enthalpy change for Process **3**. The student showed that the temperature of 200 g of water increased by 8.0 °C when 0.46 g of pure ethanol was burned in air and the heat produced was used to warm the water.

Use these results to calculate the value, in kJ mol^{-1}, obtained by the student for this enthalpy change. (The specific heat capacity of water is 4.18 J K^{-1} g^{-1})

Give **one** reason, other than heat loss, why the value obtained from the student's results is less exothermic than a data book value.

(4)

(Total 15 marks)

Q17.

Hydrogen gas is used in the chemical industry.

(a) Tungsten is extracted by passing hydrogen over heated tungsten oxide (WO_3).

(i) State the role of the hydrogen in this reaction.

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(1)

(ii) Write an equation for this reaction.

_____

(1)

(iii) State **one** risk of using hydrogen gas in metal extractions.

_____

_____

(1)

(b) Hydrogen is used to convert oleic acid into stearic acid as shown by the following equation.



oleic acid stearic acid

(i) Use your knowledge of the chemistry of alkenes to deduce the type of reaction that has occurred in this conversion.

_____

(1)

(ii) State the type of stereoisomerism shown by oleic acid.

_____

(1)

(c) Hydrogen reacts with nitrogen in the Haber Process. The equation for the equilibrium that is established is shown below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(i) State Le Chatelier's principle.

_____

_____

(1)

(ii) Use Le Chatelier's principle to explain why an increase in the total pressure of this equilibrium results in an increase in the equilibrium yield of ammonia.

_____

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_____

(2)

(d) Hydrogen reacts with oxygen in an exothermic reaction as shown by the following equation.

$$H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(g) \qquad \Delta H = -242 \text{ kJ mol}^{-1}$$

Use the information in the equation and the data in the following table to calculate a value for the bond enthalpy of the H–H bond.

	O–H	O=O
Mean bond enthalpy / kJ mol^{-1}	+ 463	+ 496

_____

_____

_____

_____

(3)

(Total 11 marks)

Q18.

A method of synthesising ammonia directly from nitrogen and hydrogen was developed by Fritz Haber. On an industrial scale, this synthesis requires a high temperature, a high pressure and a catalyst and is very expensive to operate.

(a) Use the data given below to calculate a value for the enthalpy of formation of ammonia

Bond	N ≡N	H – H	N – H
Mean bond enthalpy/kJ mol^{-1}	945	436	391

_____

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_____

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(3)

(b) A manager in charge of ammonia production wished to increase the daily production

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of ammonia and reduce the production costs. How would a chemist explain the factors that would influence the commercial efficiency of this production process?

(8)

(Total 11 marks)

Q19.

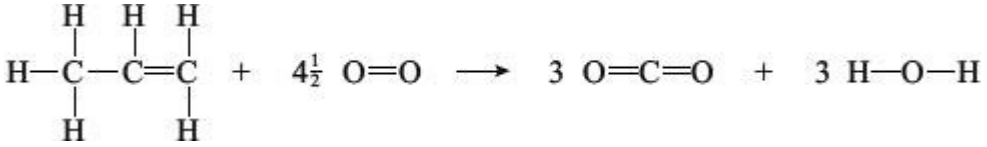
(a) Define the term *standard enthalpy of combustion*, ΔH_c⦵

(3)

(b) Use the mean bond enthalpy data from the table and the equation given below to calculate a value for the standard enthalpy of combustion of propene. All substances are in the gaseous state.

Bond	C == C	C—C	C—H	O == O	O == C	O—H
Mean bond enthalpy/ kJ mol^{-1}	612	348	412	496	743	463

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_____

(3)

(c) State why the standard enthalpy of formation, ΔH_f^o, of oxygen is zero.

_____

(1)

(d) Use the data from the table below to calculate a more accurate value for the standard enthalpy of combustion of propene.

Compound	$C_3H_6(g)$	$CO_2(g)$	$H_2O(g)$
Standard enthalpy of formation, ΔH_f^o/ kJ mol^{-1}	+20	–394	–242

_____

_____

_____

_____

_____

(3)

(e) Explain why your answer to part (b) is a less accurate value than your answer to part (d).

_____

_____

(2)

(Total 12 marks)

Q20.

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

Mean bond enthalpy _____

_____

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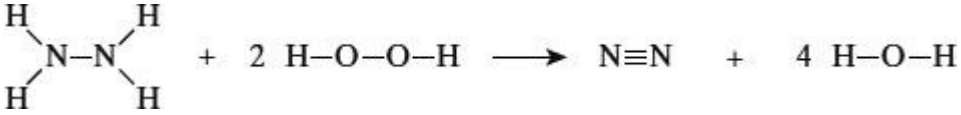
Standard enthalpy of formation _____

(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



(3)

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

	$N_2H_4(g)$	$H_2O_2(g)$	$H_2O(g)$
ΔH_f° /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 $N_2(g)$.

_____

(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).

_____

_____

(1)

(Total 13 marks)

Q21.

(a) The table below contains some mean bond enthalpy data.

Bond	H–O	O–O	O=O
Mean bond enthalpy/kJ mol^{-1}	463	146	496

The bonding in hydrogen peroxide, H_2O_2, can be represented by H–O–O–H. Use these data to calculate the enthalpy change for the following reaction.

$$H_2O_2(g) \rightarrow H_2O_2(g) + \tfrac{1}{2} O_2(g)$$

_____

_____

_____

_____

(3)

(b) The standard enthalpy of formation, $\Delta H_f^{\ominus}$ for methane, is –74.9 kJ mol^{-1}. Write an equation, including state symbols, for the reaction to which this enthalpy change applies.

_____

(2)

(c) The enthalpy changes for the formation of atomic hydrogen and atomic carbon from their respective elements in their standard states are as follows.

$\tfrac{1}{2} H_2(g) \rightarrow H(g)$ $\quad \Delta H^{\ominus} = +218$ kJ mol^{-1}

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

(i) By reference to its structure, suggest why a large amount of heat energy is required to produce free carbon atoms from solid carbon.

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(ii) Parts (b) and (c) give enthalpy data for the formation of $CH_4(g)$, H(g) and C(g). Use these data and Hess's Law to calculate the value of the enthalpy change for the following reaction.

$$CH_4(g) \rightarrow C(g) + 4H(g)$$

(iii) Use your answer from part (c)(ii) to calculate a value for the mean bond enthalpy of a C–H bond in methane.

(5)

(Total 10 marks)

Q22.

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.*

(2)

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

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

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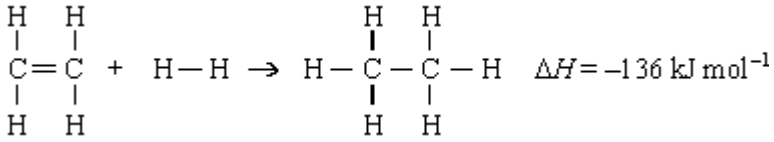
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_____

(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)

Q23.

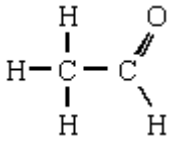
(a) State what is meant by the term *mean bond enthalpy*.

_____

_____

_____

(2)

(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

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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.

_____

_____

_____

_____

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

_____

_____

_____

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

_____

_____

(5)

(Total 7 marks)

Q24.

Given the following data

$C(s) + 2H_2(g) \rightarrow CH_4(g)$ $\Delta H = -75$ kJ mol^{-1}

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

which one of the following is the enthalpy change, in kJ mol^{-1}, of the reaction below?

$CH_4(g) \rightarrow C(s) + 4H(g)$

A −947

B +511

C +797

D +947

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(Total 1 mark)

Q1.

(a) $2Fe(s) + \frac{3}{2}O_2(g) \rightarrow Fe_2O_3(s)$ ONLY

Don't allow multiples. States must be shown

1

(b) M1 Correct cycle or equation

If M1 and M2 not awarded then M3 can be awarded for their M2 divided by 3

1

M2 $(3 \times \Delta_f H CO_2) = -19 + (-822) + 3(-111) - 0$

$(3 \times \Delta_f H CO_2) = -1174$

1

M3 $\Delta_f H CO_2 = -391$ kJ mol^{-1}

−317 for 1 mark

+391 for 1 mark

1

Allow 2 sig fig or more

(c) M1 Correct Hess's law cycle or equation

If M1 and M2 not awarded then M3 can be awarded for their M2 divided by 6

1

M2 $(6(N-H)) = 944 + 3(+436) + 92$

$(6(N-H)) = 2344$

−391 for 1 mark

1

M3 N−H = (+)391 kJ mol^{-1}

1

Allow 2 sig fig or more

(d) Data book value derived from (a number of) different compounds (not just different NH_3 molecules)

1

[8]

Q2.

(a) $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

allow fractions / multiples

allow any correct structural representation of molecules

ignore state symbols

1

(b) **M1** working that leads to n = 13

e.g. $-6650 = -(496\mathbf{n} + 202)$

and/or $496\mathbf{n} = 6650 - 202$

and/or $496\mathbf{n} = 6448$

$(\mathbf{n} = 13)$

1

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M2 $C_{13}H_{28}$

*$C_{13}H_{28}$ scores **M1** and **M2** if some correct working shown*

*$C_{13}H_{28}$ with no working scores **M2** only*

*allow error carried forward for **M2** for a correct formula of an alkane from the value of **n** worked out for **M1** (but there must be some working shown leading to this incorrect value of **n**); for example, allow $C_{14}H_{30}$ if error in **M1** stemming from error in rearranging equation*

1

(c) Idea that

- alkane is not gaseous or
- equation relates to gaseous alkanes or
- it takes energy to convert it into a gas or
- that water / alkane / substances are gaseous in calculations using bond enthalpies

ignore references to heat loss, incomplete combustion, loss of evaporation, not being in standard conditions or that it is not standard state

1

(d) **M1** plotting the four values correctly (allow one error where point is ±1 square out)

*If plotted points for wrong number of C atoms for two or more compounds, cannot score **M1** or **M2**, but could score **M3** if read value off for 3C atoms*

1

M2 smooth best fit curve

M2 *best fit curve for their four points for the correct number of C atoms*

1

M3 value from their best fit line for 3 C atoms (allow ± 1 square)

M3 *need – sign (but ignore units);*

*cannot score **M3** unless there is a line on the graph*

1

(e) **M1** mass of isooctane = 692 (g)

*correct answer scores **M1** and **M2***

1

M2 3.31×10^4 or 33100 (kJ) (**3sf only**)

M2 *correct value to incorrect number of sig figs is 1 mark;*

ignore sign ;

*no error carried forward for **M2***

1

[9]

Q3.

(a) $C_2H_5OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(l)$

1 mark for correct formulae and balancing

1

1 mark for all correct state symbols

1

(b) (Standard) enthalpy of formation

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1

Difficult to prevent C reacting with O_2 to form some CO_2

1

(c) $\Delta H = \Sigma \Delta H_c$ reactants − $\Sigma \Delta H_c$ products or a correct cycle

1

OR $\Delta H = -393-(-283)$

$\Delta H = -110$ (kJ $mol^{-1)}$

1

(d) Correctly drawn Hess's law cycle

1

4 (Xe–F) = 252 + (2 × 158) = 568

Xe–F = 568 / 4

1

Xe–F = 142 (kJ $mol^{-1)}$)

1

(e) Mean bond enthalpy found by taking an average for Xe–F in a range of compounds

1

[10]

Q4.

C

[1]

Q5.

(a) $C(s) + 2F_2(g) \longrightarrow CF_4(g)$

State symbols essential

1

(b) Around carbon there are 4 bonding pairs of electrons (and no lone pairs)

1

Therefore, these repel equally and spread as far apart as possible

1

(c) $\Delta H = \Sigma\ \Delta_f H$ products – $\Sigma\ \Delta_f H$ reactants or a correct cycle

1

Hence = (2 × –680) + (6 × –269) – (x) = –2889

1

x = 2889 – 1360 – 1614 = –85 (kJ mol^{-1})

1

Score 1 mark only for +85 (kJ mol^{-1})

(d) Bonds broken = 4(C–H) + 4(F–F) = 4 × 412 + 4 × F–F

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Bonds formed = 4(C–F) + 4(H–F) = 4 × 484 + 4 × 562

Both required

1

–1904 = [4 × 412 + 4(F–F)] – [4 × 484 + 4 × 562]

4(F–F) = –1904 – 4 × 412 + [4 × 484 + 4 × 562] = 632

1

F–F = 632 / 4 = 158 (kJ mol^{-1})

1

The student is correct because the F–F bond energy is much less than the C–H or other covalent bonds, therefore the F–F bond is weak / easily broken

Relevant comment comparing to other bonds

(Low activation energy needed to break the F–F bond)

1

[10]

Q6.

(a) Bonds broken = 2(C=O) + 3(H–H) = 2 × 743 + 3 × H–H

Bonds formed = 3(C–H) +(C–O) + 3(O–H) = 3 × 412 + 360 + 3 × 463

Both required

1

–49 = [2 × 743 + 3 × (H–H)] – [3 × 412 + 360 + 3 × 463]

3(H–H) = –49 – 2 × 743 + [3 × 412 + 360 + 3 × 463] = 1450

Both required

1

H–H = 483 (kJ mol^{-1})

Allow 483.3(3)

1

(b) Mean bond enthalpies are not the same as the actual bond enthalpies in CO_2 (and / or methanol and / or water)

1

(c) The carbon dioxide (produced on burning methanol) is used up in this reaction

1

(d) 4 mol of gas form 2 mol

1

At high pressure the position of equilibrium moves to the right to lower the pressure / oppose the high pressure

1

This increases the yield of methanol

1

(e) Impurities (or sulfur compounds) block the active sites

Allow catalyst poisoned

1

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(f) Stage 1: moles of components in the equilibrium mixture

Extended response question

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

Initial moles	1.0	3.0	0	0
Eqm moles	(1–0.86) = 0.14	(3–3×0.86) = 0.42	0.86	0.86

1

Stage 2: Partial pressure calculations

Total moles of gas = 2.28

Partial pressures = mol fraction × p_{total}

1

p_{CO2} = mol fraction × p_{total} = 0.14 × 500 / 2.28 = 30.7 kPa

p_{H2} = mol fraction × p_{total} = 0.42 × 500 / 2.28 = 92.1 kPa

M3 is for partial pressures of both reactants

Alternative M3 =

pp_{CO2} = 0.0614 × 500

pp_{H2} = 0.1842 × 500

1

p_{CH3OH} = mol fraction × p_{total} = 0.86 × 500 / 2.28 = 188.6 kPa

p_{H2O} = mol fraction × p_{total} = 0.86 × 500 / 2.28 = 188.6 kPa

M4 is for partial pressures of both products

Alternative M4 =

pp_{CH3OH} = 0.3772 × 500

pp_{H2O} = 0.3772 × 500

1

Stage 3: Equilibrium constant calculation

$K_p = p_{CH3OH} \times p_{H2O} / p_{CO2} \times (p_{H2})^3$

1

Hence $K_p = 188.6 \times 188.6 / 30.7 \times (92.1)^3 = 1.483 \times 10^{-3} = 1.5 \times 10^{-3}$

Answer must be to 2 significant figures

1

Units = $\underline{kPa}^{-2}$

1

[16]

Q7.

B

[1]

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Q8.

(a) The <u>enthalpy / heat energy change</u> when <u>1 mol</u> (of a substance)

If enthalpy of formation definition given CE=O

***NOT** just 'energy'*

***ALLOW** alternatives for substance e.g. molecule/compound/element*

1

Is <u>burned/reacts completely in oxygen</u>

***ALLOW** reacts in excess oxygen*

1

With all reactants and products in their <u>standard states</u>

OR

With all reactants and products in their normal states at 298K/given temp & 100kPa

***ALLOW** 'everything' for 'reactants and products'*

Penalise incorrect conditions if given

***ALLOW** 'normal states under standard conditions'*

1

(b) $\Delta H = \Sigma \Delta H_c$(reactants) - $\Sigma \Delta H_c$ (products)

OR

Correctly and fully balanced cycle

Correct answer scores 3

1

$\Delta H = [3(-394) + 4(-286)] – (-2010)$

OR

$\Delta H = -2326 + 2010$

M2 also scores M1

1

$\Delta H = -316$ (kJ mol^{-1})

+316 scores 1 mark only

***IGNORE** units*

Check for AE in working – can award M3 as ecf (error carried forward) from M2 if M2 not given due to AE

1

(c) $\Delta H/-1893 = \Sigma B$(reactants) - ΣB(products)

OR

$\Delta H/-1893 = \Sigma$Bonds broken - ΣBonds formed

OR

$\Delta H/-1893 = 2B(C-C) + 7B(C-H) + B(C-O) + B(O-H) + 4½\ B(O=O) – 6B(C=O) – 8B(O-H)$

Correct answer scores 3

1

$-1893= 2B(C-C) + 7(412) + 360 + 463 + 4½(496) – 6(805) – 8(463)$

OR

$-1893= 2B(C-C) +5939 – 8534$

OR

$-1893= 2B(C-C) -2595$

OR

$2B(C-C) = 702$

M2 also scores M1

May see no 463 in bonds broken and 7x463 in made (gives 5476 – 8071)

1

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B(C-C) = (+)351(kJ mol^{-1})

*If **NOT** 351 check for AE. This would lose M2, but could gain M1 and M3*

(+)234 scores 1 (due to 3(C-C))

***NOT** M3 from incorrect M2 unless incorrect M2 is due to AE*

***IGNORE** units*

If no other mark awarded then

***ALLOW** 1 if 5939 or 5476 or 8534 or 8071 seen*

1

[9]

Q9.

(a) (i) $\mathbf{2}C_6H_{12}O_6 \longrightarrow \mathbf{3}CH_3COCH_3 + \mathbf{3}CO_2 + \mathbf{3}H_2O$

Or multiples

1

(ii) to speed up the reaction
OR
(provide a) catalyst or catalyses the reaction or biological catalyst
OR
release / contain / provides an enzyme

Ignore "fermentation"

Ignore "to break down the glucose"

Not simply "enzyme" on its own

1

(b) (i) $CH_3CH(OH)CH_3 + [O] \longrightarrow CH_3COCH_3 + H_2O$

Any correct representation for the two organic structures. Brackets not essential.

Not "sticks" for the structures in this case

1

(ii) Secondary (alcohol) OR 2° (alcohol)

1

(c) **M1** $q = m\ c\ \Delta T$

OR $q = 150 \times 4.18 \times 8.0$

Award full marks for correct answer

*In **M1**, do not penalise incorrect cases in the formula*

M2 = (±) 5016 (J) ***OR*** 5.016 (kJ) ***OR*** 5.02 (kJ)
(also scores M1)

M3 This mark is for dividing correctly the number of kJ by the number of moles and arriving at a final answer in the range shown.
Using 0.00450 mol

therefore ΔH = **− 1115** (kJ mol^{-1})

***OR* − 1114.6 to − 1120** (kJ mol^{-1})

Range (+)1114.6 to (+)1120 gains 2 marks

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BUT − 1110 gains 3 marks and +1110 gains 2 marks

AND − 1100 gains 3 marks and +1100 gains 2 marks

Award full marks for correct answer

*In **M1**, do not penalise incorrect cases in the formula*

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect; **(+)1114.6 to (+)1120 gains 2 marks***

*Penalise **M2** for arithmetic error and mark on*

If ΔT = 281; score q = m c ΔT only

*If c = 4.81 (leads to 5772) penalise **M2** ONLY and mark on for **M3** = − 1283*

*Ignore incorrect units in **M2***

*If units are given in **M3** they must be either kJ or kJ mol^{-1} in this case*

3

(d) **M1** The enthalpy change / heat change at constant pressure when 1 mol of a compound / substance / element

M2 is burned / combusts / reacts completely in oxygen
OR
burned / combusted / reacted in excess oxygen

M3 with (all) reactants and products / (all) substances in standard / specified states

OR
(all) reactants and products / (all) *substances in normal states under standard conditions* / 100 kPa / 1 bar and specified T / 298 K

*For **M3***

Ignore reference to 1 atmosphere

3

(e) **M1**
$\sum$ B **(reactants)** − $\sum$ B **(products)** = Δ*H*
OR
Sum of bonds broken − Sum of bonds formed = Δ*H*
OR
2B(C−C) + B(C=O) + 6B(C−H) + 4B(O=O) (LHS)

− 6B(C=O) − 6B(O−H) (RHS) = Δ*H*

M2 (also scores **M1**)
2(348)+805+6(412)+4(496) [LHS = **5957**]

(696) (2472) (1984)

− 6(805) − 6(463) [RHS = (−) **7608**] = Δ*H*

(4830) (2778)

OR using only bonds broken and formed (**5152 − 6803**)

M3
Δ*H*= **− 1651** (kJ mol^{-1})

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Candidates may use a cycle and gain full marks.

Correct answer gains full marks

Credit 1 mark for (+) 1651 (kJ mol^{-1})

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication / addition error; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with $4O_2$, $3CO_2$ and $3H_2O$ OR a clear statement of **M1** which could be in words and scores **only M1***

Allow a maximum of one mark if the only scoring point is LHS = 5957 (or 5152) OR RHS = 7608 (or 6803)

Award 1 mark for + 1651

3

(f) **For the two marks M1 and M2, any two from**

- heat loss or not all heat transferred to the apparatus or heat absorbed by the apparatus or (specific) heat capacity of the apparatus not considered
- incomplete combustion / not completely burned / reaction is not complete
- The idea that the water may end up in the gaseous state (rather than liquid)
- reactants and / or products may not be in standard states.
- MBE data refers to gaseous species but the enthalpy of combustion refers to liquids in their standard states / liquid propanone and liquid water in standard states
- MBE do not refer to specific compounds OR MBE values vary with different compounds / molecules OR are average / mean values taken from a range of compounds / molecules

Apply the list principle but ignore incomplete reasons that contain correct chemistry

Ignore "evaporation"

Ignore "faulty equipment"

Ignore "human error"

Not enough simply to state that "MBE are mean / average values"

2

[15]

Q10.

(a) The enthalpy (change) to break 1 mol of H—O / bonds

Allow heat energy

1

Averaged over a range of compounds / molecules

Penalise energy but mark on

ignore states

CE = 0 for ionic bonds

1

(b) $H_2 + \frac{1}{2} O_2 \longrightarrow H_2O$

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ΔH = (H−H) + $\frac{1}{2}$ (O = O) − 2(H−O) / sum of (bonds broken) − sum of (bonds formed)

1

= 436 + 496 / 2 − 2 × 464

1

= −244 (kJ mol^{-1})

Allow 1 mark only for +244 and −488

Units not essential but penalise incorrect units

1

(c) (i) same reaction / same equation / same number / same reactants and same products / same number and type of bonds broken and formed

Do not allow similar

1

(ii) There must be a slight difference between the actual bond enthalpy (in water) and mean bond enthalpies for the O−H bond (in other molecules)

Allow bond enthalpy value for enthalpy of formation may not be under standard conditions.

Allow reference to bond energy rather than bond enthalpy

Do not allow heat loss or experimental error

Do not allow mean bond enthalpies are not accurate

1

[7]

Q11.

(a)

M1 $C_6H_{12}O_6 \longrightarrow$ **2**CH_3CH_2OH ($2C_2H_5OH$) + **2**CO_2

*Penalise C_2H_6O for ethanol in **M1**.*

M2 and **M3**

*Mark **M2** and **M3** independently.*

Any **two** conditions **in any order** for **M2** and **M3** from

- (enzymes from) yeast or zymase
- 25 °C ≤ T ≤ 42 °C OR 298 K ≤ T ≤ 315 K
- anaerobic / no oxygen / no air OR neutral pH

  A lack of oxygen can mean either without oxygen or not having enough oxygen and does not ensure no oxygen, therefore only credit "lack of oxygen" if it is qualified.

  Penalise 'bacteria', 'phosphoric acid', 'high pressure' using the list principle.

M4 (fractional) distillation or GLC

Ignore reference to 'aqueous' or 'water' (ie not part of the list principle).

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M5 Carbon-neutral **in this context** means

There is no net / overall (annual) carbon dioxide / CO_2 emission to the atmosphere

OR

There is no change in the total amount / level of carbon dioxide / CO_2 present in the atmosphere

*For **M5** – must be about CO_2 and the atmosphere.*

The idea that the carbon dioxide / CO_2 given out equals the carbon dioxide / CO_2 that was taken in from the atmosphere.

5

(b) **M1** q = m c ∆T (this mark for correct mathematical formula)

*Full marks for **M1**, **M2** and **M3** for the correct answer.*

*In **M1**, do not penalise incorrect cases in the formula.*

M2 = (75 × 4.18 × 5.5)

1724 (J) **OR** 1.724 (kJ) **OR** 1.72 (kJ) **OR** 1.7 (kJ)

(also scores **M1**)

*Ignore incorrect units in **M2**.*

M3 Using 0.0024 mol

therefore ∆H = **− 718** (kJ mol^{-1})

(Accept a range from −708 to −719 but do not penalise more than 3 significant figures)

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect. Therefore **+718 gains two marks**.*

*If units are quoted in **M3** they must be correct.*

*If ∆T = 278.5, CE for the calculation and penalise **M2** and **M3**.*

M4 and **M5** in any order

Any **two** from

- incomplete combustion
- heat loss
- heat capacity of Cu not included
- some ethanol lost by evaporation
- not all of the (2.40 × 10^{-3} mol) ethanol is burned / reaction is incomplete

*If c = 4.81 (leads to 1984) penalise **M2** ONLY and mark on for **M3** = − 827*

5

(c) (i) **M1** enthalpy / heat / energy change (at constant pressure) or enthalpy / heat / energy needed in breaking / dissociating (a) covalent bond(s)

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Ignore bond making.

M2 averaged for that type of bond over different / a range of molecules / compounds

Ignore reference to moles.

2

(ii) **M1**

∑ B(**reactants**) − ∑ B(**products**) = ΔH

OR

Sum of bonds broken − Sum of bonds formed = ΔH

OR

B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O)
– 4B(C=O) – 6B(O–H) = ΔH = −1279

Correct answer gains full marks.

*Credit **1 mark for − 496** (kJ mol^{-1})*

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**).*

*If no AE, check for a correct method; this requires either a correct cycle with $2CO_2$ and $3H_2O$ OR a clear statement of **M1** which could be in words and scores **only M1**.*

M2 (also scores **M1**)
348+360+463+5(412)+ 3B(O=O)

(**3231**) (or **2768** if O–H cancelled)
− 4(805) − 6(463) = ΔH = − 1279

(**5998**) (or **5535** if O–H cancelled)

3B(O=O) = **1488** (kJ mol^{-1})

*Credit a maximum of one mark if the only scoring point is bonds formed adds up to **5998 (or 5535) OR** bonds broken includes the calculated value of **3231 (or 2768)**.*

M3

B(O=O) = **496** (kJ mol^{-1})

Award 1 mark for −496

Students may use a cycle and gain full marks

3

[15]

Q12.

(a) (i) M1 c(oncentrated) phosphoric acid / c(onc.) H_3PO_4

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OR c(oncentrated) sulfuric acid / c(onc.) H_2SO_4

*In **M1**, the acid must be concentrated.*
Ignore an incorrect attempt at the correct formula that is written in addition to the correct name.

M2 Re-circulate / re-cycle the (unreacted) ethene (and steam) / the reactants
OR pass the gases over the catalyst several / many times

*In **M2**, ignore "remove the ethanol".*
Credit "re-use".

2

(ii) M1
(By Le Chatelier's principle) the equilibrium is driven / shifts / moves to the right / L to R / forwards / in the forward direction

M2 depends on a correct statement of M1
The equilibrium moves / shifts to

- oppose the addition of / increased concentration of / increased moles / increased amount of water / steam
- to decrease the amount of steam / water

Mark M3 independently
M3 Yield of product / conversion increase ***OR*** ethanol increases / goes up / gets more

3

(iii) M1 Poly(ethene) / polyethene / polythene / HDPE / LDPE

M2 At higher pressures
More / higher cost of electrical energy to pump / pumping cost
OR
Cost of higher pressure equipment / valves / gaskets / piping etc.
OR expensive equipment

*Credit all converse arguments for **M2***

2

(b) M1 for balanced equation

M2 for state symbols in a correctly balanced equation

$2C(s / graphite) + 3H_2(g) + ½O_2(g) \longrightarrow CH_3CH_2OH(l)$ (C_2H_5OH)

Not multiples but credit correct state symbols in a correctly balanced equation.

Penalise C_2H_6O but credit correct state symbols in a correctly balanced equation.

2

(c) (i) M1 The enthalpy change / heat change at constant pressure when 1 mol of a compound / substance / element

*If standard enthalpy of formation **CE=0***

M2 is burned / combusts / reacts completely in oxygen
OR burned / combusted / reacted in excess oxygen

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M3 with (all) reactants and products / (all) substances in standard / specified states
OR (all) reactants and products / (all) substances in normal states under standard conditions / 100 kPa / 1 bar and specified T / 298 K

*For **M3***
Ignore reference to 1 atmosphere

3

(ii) M1

Correct answer gains full marks

ΣB(**reactants**) − ΣB(**products**) = *ΔH*

Credit 1 mark for (+) 1279 (kJ mol^{-1})

OR
Sum of bonds broken − Sum of bonds formed = ΔH
OR
B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O) (LHS)
− 4B(C=O) − 6B(O−H) (RHS) = *ΔH*

M2 (also scores **M1**)
348+360+463+5(412)+3(496) [LHS = **4719**]
(2060) (1488)
− 4(805) − 6(463) [RHS = − **5998**] = *ΔH*
(3220) (2778)
OR using only bonds broken and formed (**4256 − 5535**)

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with 2C and 6H and 7O OR a clear statement of **M1** which could be in words and scores **only M1***

M3
ΔH= **− 1279** (kJ mol^{-1})

*Allow a maximum of one mark if the only scoring point is LHS = 4719 **OR** RHS = 5998*

Award 1 mark for +1279

Candidates may use a cycle and gain full marks

3

(d) (i) Reducing agent ***OR*** reductant ***OR*** electron donor
OR to reduce the copper oxide

Not "reduction".
Not "oxidation".
Not "electron pair donor".

1

(ii) CH_3COOH

1

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[17]

Q13.

(a) $3N_2H_4 \longrightarrow 4NH_3 + N_2$

Or multiples

Ignore state symbols

1

(b) M1 enthalpy / heat (energy) change / required / needed to break / dissociate a covalent bond (or a specified covalent bond)

Ignore bond making

Ignore standard conditions

M2** requires an attempt at **M1

M2 average / mean over different molecules / compounds / substances

2

(c) M1

Σ (bonds broken) − Σ (bonds formed) = ΔH

***M1** could stand alone*

OR

Sum of bonds broken − Sum of bonds formed = ΔH

Award full marks for correct answer

M2 (also scores **M1**)

Ignore units

4(+388) + 163 + 2(146) + 4(463) − 944 − 8(463) = ΔH
OR broken +3859 (2007) formed − 4648 (2796)

M3

ΔH = **− 789** (kJ mol^{-1})

Two marks can score with an arithmetic error in the working

Award 1 mark for + 789

*Credit **one mark only** for calculating either the sum of the bonds broken or the sum of the bonds formed provided this is the only mark that is to be awarded*

Students may use a cycle and gain full marks

3

[6]

Q14.

(a) (Enthalpy change to) break the bond in 1 mol of chlorine (molecules)

Allow (enthalpy change to) convert 1 mol of chlorine molecules into atoms
Do not allow energy or heat instead of enthalpy, allow heat energy

1

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To form (2 mol of) gaseous chlorine atoms / free radicals

Can score 2 marks for 'Enthalpy change for the reaction': $Cl_2(g) \rightarrow 2Cl(g)$

Equation alone gains M2 only

Can only score M2 if 1 mol of chorine molecules used in M1 (otherwise it would be confused with atomisation enthalpy)

Any mention of ions, CE = 0

1

(b) (For atomisation) only 1 mol of chlorine atoms, not 2 mol (as in bond enthalpy) is formed / equation showing ½ mol chlorine giving 1 mol of atoms

Allow breaking of one bond gives two atoms

Allow the idea that atomisation involves formation of 1 mol of atoms not 2 mol

Allow the idea that atomisation of chlorine involves half the amount of molecules of chlorine as does dissociation

Any mention of ions, CE = 0

1

(c) (i) $\frac{1}{2}F_2(g) + \frac{1}{2}Cl_2(g) \rightarrow ClF(g)$

1

(ii) $\Delta H = \frac{1}{2}E(F–F) + \frac{1}{2}E(Cl–Cl) – E(Cl–F)$

Allow correct cycle

1

$E(Cl–F) = \frac{1}{2}E(F–F) + \frac{1}{2}E(Cl–Cl) - \Delta H$

$= 79 + 121 - (-56)$

$= 256$ (kJ mol^{-1})

−256 scores zero

Ignore units even if wrong

1

(iii) $\frac{1}{2}Cl_2 + 3/2\ F_2 \rightarrow ClF_3$

If equation is doubled CE=0 unless correcr answer gained by / 2 at end
This would score M1

1

$\Delta H = \frac{1}{2}E(Cl–Cl) + 3/2\ E(F–F) - 3E(Cl–F)$

$= 121 + 237 - 768$ / (or 3 × value from (c)(ii))

This also scores M1 (note = 358 − 768)

1

$= -410$ (kJ mol^{-1})

If given value of 223 used ans = −311
Allow 1 / 3 for +410 and +311

1

(iv) (Bond enthalpy of) Cl−F bond in ClF is different from that in ClF_3

Allow Cl-F bond (enthalpy) is different in different compounds (QoL)

1

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(d) NaCl is ionic / not covalent

1

[11]

Q15.

(a) (i) $\Delta H = \Sigma$ bonds broken $-\Sigma$ bonds formed

1

= 944/2 + 3/2 × 436 –3 × 388

1

= –38 (kJ mol^{-1})

ignore units even if incorrect
correct answer scores 3
–76 scores 2/3
+38 scores 1/3

1

(ii) mean / average bond enthalpies are from a range of compounds
or
mean / average bond enthalpies differ from those in a single compound / ammonia

1

(b) $\Delta S = \Sigma S$ products $-\Sigma S$ reactants

1

= 193 – (192/2 + 131 × 3/2)

1

= –99.5 J K^{-1} mol^{-1}

units essential for M3
correct answer with units scores 3
–199 J K^{-1} mol^{-1} & –99.5 score 2/3
–199 and + 99.5 J K^{-1} mol^{-1} score 1/3

1

(c) (i) $\Delta G = \Delta H - T\Delta S$ = –46 + 800 × 99.5/1000

mark is for putting in numbers with 1000
if factor of 1000 used incorrectly CE = 0

1

= 33.6 or 33600

allow 33 to 34 (or 33000 to 34000)

1

kJ mol^{-1} with J mol^{-1}

correct units for answer essential
if answer to part (b) is wrong or if -112 used, mark consequentially e.g.
- *–199 gives 113 to 114 kJ mol^{-1} (scores 3/3)*
- *–112 gives 43 to 44 kJ mol^{-1} (scores 3/3)*

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1

(ii) If answer to (c) (i) is positive: not feasible / not spontaneous

If answer to (c) (i) is negative: feasible / spontaneous

if no answer to (c) (i) award zero marks

1

[11]

Q16.

(a) **Three conditions <u>in any order</u> for M1 to M3**

M1 yeast or zymase

M2 30 °C ≥ T ≤ 42 °C

M3 anaerobic/no oxygen/no air OR neutral pH

M4 $C_6H_{12}O_6 \longrightarrow \mathbf{2}C_2H_5OH + \mathbf{2}CO_2$
OR
$\mathbf{2}C_6H_{12}O_6 \longrightarrow \mathbf{4}C_2H_5OH + \mathbf{4}CO_2$

Mark independently

Penalise "bacteria" and "phosphoric acid" using the list principle

Ignore reference to "aqueous" or "water" (i.e. not part of the list principle)

Or other multiples

4

(b) **M**1 Carbon-neutral

Ignore "biofuel"

1

M2 <u>6 (mol/molecules) CO_2/carbon dioxide taken in/used/used up</u> (to form glucose or in photosynthesis)

1

M3 <u>6 (mol/molecules) CO_2/carbon dioxide</u> given out <u>due to **2** (mol/molecules) CO_2/carbon dioxide from fermentation/ Process 2 and **4** (mol/molecules) CO_2/carbon dioxide from combustion/Process 3</u>

It is NOT sufficient in M2 and M3 for equations alone without commentary or annotation or calculation

1

(c) **M1 (could be scored by a correct mathematical expression)**

(Sum of) <u>bonds broken</u> – (Sum of) <u>bonds made/formed = Δ*H*</u>

OR

(Σ) $\underline{B_{reactants} - (\Sigma)\ B_{products} = \Delta H}$

(where B = <u>bond</u> enthalpy/<u>bond</u> energy)

For M1 there must be a <u>correct</u> mathematical expression using ΔH or "enthalpy change"

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M2 Reactants = (+) 4719
OR
Products = (–) 5750

M3 Overall + 4719 – 5750 = **–1031** (kJ mol^{-1}) **(This is worth 3 marks)**

Award full marks for correct answer.
Ignore units.
M2 is for either value underlined
M3 is NOT consequential on M2

3

Award 1 mark ONLY for +1031

Candidates may use a cycle and gain full marks.

M4 Mean bond enthalpies are not specific for this reaction
OR they are average values from many different compounds/molecules

Do not forget to award this mark

1

(d) **M1** q = m c ΔT (this mark for correct mathematical formula)

M2 = 6688 (J) OR 6.688 (kJ) OR 6.69 (kJ) OR 6.7 (kJ)

M3 0.46g is 0.01 mol
therefore ΔH = **– 669** kJ mol^{-1} OR – **670** kJmol^{-1}
OR **–668.8** kJ mol^{-1}

Award M1, M2 and M3 for correct answer to the calculation
Penalise M3 ONLY if correct answer but sign is incorrect
In M1, do not penalise incorrect cases in the formula
If m = 0.46 or m = 200.46 OR if ΔT = 281, CE and penalise M2 and M3
If c = 4.81 (leads to 7696) penalise M2 ONLY and mark on for M3 = –769.6 OR –770
Ignore incorrect units in M2

M4 Incomplete combustion

Do not forget to award this mark. Mark independently

4

[15]

Q17.

(a) (i) Reducing agent

OR

Reduce(s) (WO_3/tungsten oxide)

OR

electron donor

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OR

to remove <u>oxygen</u> (from WO_3/tungsten oxide or to form water);

1

(ii) $WO_3 + \mathbf{3}H_2 \rightarrow W + \mathbf{3}H_2O$

Or multiples

1

(iii) *One from*

H_2 is

- explosive
- flammable or inflammable
- easily ignited

Ignore reference to pressure or temperature

1

(b) (i) Addition

Ignore "electrophilic"

Penalise "nucleophilic addition"

OR

(catalytic) hydrogenation

OR

Reduction

1

(ii) Geometric(al)

OR

cis/trans OR E Z OR E/Z

1

(c) (i) (If any factor is changed which affects an equilibrium), the position of <u>equilibrium</u> will <u>shift/move/change/respond/act</u> so as <u>to oppose the change</u>.

OR

(When a system/reaction in equilibrium is disturbed), the <u>equilibrium shifts/moves</u> in a direction which tends <u>to reduce the disturbance</u>

A variety of wording will be seen here and the key part is the last phrase and must refer to <u>movement of the equilibrium</u>.

QoL

1

(ii) **M1 – Statement of number of moles/molecules**

There are <u>more moles/molecules</u> (of gas) on the left/of reactants

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OR

fewer moles/molecules (of gas) on the right./products

OR

there are 4 moles/molecules (of gas) on the left and 2 moles/ molecules on the right.

Ignore "volumes" for M1

Mark independently

M2 – Explanation of response/movement in terms of pressure
Increase in pressure is opposed (or words to that effect)

OR

pressure is lowered by a shift in the equilibrium (from left) to right/favours forward reaction.

2

(d) ΣB(reactants) – ΣB(products) = Δ*H* (**M1**)

OR

Sum of bonds broken – Sum of bonds formed = ΔH (**M1**)

B(H–H) + ½B(O=O) – 2B(O–H) = – 242 (**M1**)

B(H–H) = – 242 – ½(+496) + 2(+463) (this scores **M1** and **M2**)

B(H–H) = (+)436 (kJ mol^{-1}) (**M3**)

Award 1 mark for – 436

Candidates may use a cycle and gain full marks.

M1 could stand alone

Award full marks for correct answer.

Ignore units.

Two marks can score with an arithmetic error in the working.

3

[11]

Q18.

(a) Equation $1/2N_2 + 3/2H_2 \rightarrow NH_3$

1

$\Delta Hf = [(945 \times 0.5) + (426 \times 1.5)] – (391 \times 3)$

1

$= –46.5$ kJ mol^{-1}

1

Mark Range	The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication

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	(QWC). There are no discrete marks for the assessment of QWC but the candidates' QWC in this answer will be one of the criteria used to assign a level and award the marks for this part of the question **Descriptor** an answer will be expected to meet most of the criteria in the level descriptor
4-5	– claims supported by an appropriate range of evidence – good use of information or ideas about chemistry, going beyond those given in the question – argument well structured with minimal repetition or irrelevant points – accurate and clear expression of ideas with only minor errors of grammar, punctuation and spelling
2-3	– claims partially supported by evidence – good use of information or ideas about chemistry given in the question but limited beyond this – the argument shows some attempt at structure – the ideas are expressed with reasonable clarity but with a few errors of grammar, punctuation and spelling
0-1	– valid points but not clearly linked to an argument structure – limited use of information or ideas about chemistry – unstructured – errors in spelling, punctuation and grammar or lack of fluency

(b) The higher the temperature the faster the reaction QWC **1**

but, since the reaction is exothermic **1**

the equilibrium yield is lower QWC **1**

The higher the pressure the greater the equilibrium yield QWC **1**

because there is a reduction in the number of moles of gas in the reaction **1**

but higher pressure is expensive to produce or plant is more expensive to build QWC **1**

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A better catalyst would lessen the time to reach equilibrium

1

and allow more ammonia to be produced in a given time QWC

1

[11]

Q19.

(a) enthalpy change/ heat energy change when 1 mol of a substance

1

is completely burned in oxygen

1

at 298K and 100 kPa or standard conditions

1

(not 1atm)

(b) $\Delta H = \sum$ bonds broken – $\sum$ bonds formed

1

= (6 × 412) + 612 +348 + (4.5 × 496) – ((6 × 743) + (6 × 463))

1

= – 1572 kJ mol^{-1}

1

(c) by definition ΔH_f is formation from an element

1

(d) $\Delta H_c = \sum \Delta H_f$ products -$\sum \Delta H_f$ reactants or cycle

1

= (3 × – 394) + (3 × –242) – (+20)

1

= − 1928 kJ mol^{-1}

1

(e) bond enthalpies are mean/average values

1

from a range of compounds

1

[12]

Q20.

(a) enthalpy (or energy) to break (or dissociate) a bond;

1

averaged over different molecules (environments);

1

enthalpy (or heat energy) change when one mole of a compound;

1

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is formed from its elements;

1

in their standard states;

1

(b) enthalpy change = Σ(bonds broken) – Σ(bonds formed) or cycle;

1

= 4 × 388 +163 + 2 × 146 + 4 × 463 – (944 + 8 × 463);
(or similar)

1

= –789;
(+ 789 scores 1 only)

1

(c) (i) zero;

1

(ii) ΔH = Σ (enthalpies of formation of products)
–Σ (enthalpies of formation of reactants)

1

= 4 × –242-(75 + 2 × –133);

1

= –777;
(+ 777 scores one only)

1

(d) mean bond enthalpies are not exact
(or indication that actual values are different from real values)

1

[13]

Q21.

(a) ΔH = Σ(bonds broken) – Σ(bonds formed) (or cycle)

1

= +146 – 496/2 (or 2 × 463 + 146 –(2 × 463 + 496/2)

1

= – 102 (kJ mol^{-1}) **(1)**
*(accept no units, wrong units loses a mark; +102 scores **(1)** only)*

1

(b) $C(s) + 2H_2(g) \rightarrow CH_4(g)$ equation **(1)** Correct state symbols **(1)**

2

(c) (i) Macromolecular
(accept giant molecule or carbon has many (4) bonds)

1

(ii) $\Delta H = \Sigma \Delta H_f$(products) – $\Sigma \Delta H_f$(reactants) (or cycle)

1

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= 715 + 4 × 218 – (–74.9)

1

= 1662 (kJ mol^{-1})

(accept no units, wrong units loses one mark, allow 1660 to 1663, –1662 scores one mark only)

1

(iii) 1662/4 = 415.5

(mark is for divide by four, allow if answer to (c)(ii) is wrong)

1

[10]

Q22.

(a) Enthalpy (Energy) to break a (covalent) bond **(1) OR dissociation energy**
Varies between compounds so average value used **(1) QL mark**

OR average of dissociation energies in a single molecule / e.g. CH_4

Do not allow mention of energy to form bonds but with this case can allow second mark otherwise 2nd mark consequential on first

2

(b) (i) 1/2 N_2 + 3/2 H_2 → NH_3 **(1)**

Ignore s s

(ii) ΔH = (Σ)bonds broken – (Σ)bonds formed **(1)**
= 1/2 × 944 + 3/2 × 436 – 3 × 388 **(1)**
= –38 kJ mol^{-1} **(1)**

Ignore no units, penalise wrong units
Score 2/3 for -76
1/3 for +38
Allow 1/3 for +76

4

(c) 4 (C–H) + (C=C) + (H–H) – (6 (C–H) + (C–C)) = –136 **(1)**
OR (C=C) + (H–H) – ((C–C) + 2 (C–H)) = –136
2 (C–H) = 836 **(1)**
(C–H) = 418 (kJ mol^{-1}) **(1)**

Note: allow (1) for –836
another (1) for –418

3

[9]

Q23.

(a) (Energy required) to break a given <u>covalent</u> bond **(1)**
averaged over a range of compounds **(1)**

Penalise first mark if 'energy' / 'enthalpy' evolved

2

(b) (i) 4 × C−H = 4 × 413 = +1652
1 × C−C = 1 × 347 = 347
1 × C=O = 1 × 736 = 736
2½ × O=O = 2.5 × 498 = 1245 **(1)**

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= 2735 + 1245 = +3980 **(1)**

first mark for 4 : 1: 1 or 2735 ignore sign

(ii) 4 × H−O = -4 × 464 = –1856
4 × C−O = -4 × 736 = –2944 **(1)**
= –4800 **(1)**

First mark for 4 : 4

(iii) ΔH_R = ΣBonds broken − ΣBonds made
= +3980 − 4800 = −820 **(1)**

Conseq Mark for incorrect answers in (i) and (ii) as (i) Answer + (ii) Answer =

5

[7]

Q24.

D

[1]

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Q1.

(a) This was poorly answered, with many students missing state symbols and balancing the equation incorrectly. Only the best students (24.6%) gained the mark here.

(b) This proved challenging compared to questions set in the previous specification from this topic area. 34.3% of students failed to pick up even one mark.

(c) Again challenging for all but the best students, only 26.3% scored more than one mark.

(d) This was not as well answered as might have been expected. The fact that mean bond enthalpies are calculated using a range of compounds was not well understood.

Q2.

(a) Most students could write the equation for the complete combustion of propane.

(b) This question required students to rearrange a mathematical expression, but many could not do this because they made errors with minus signs on rearrangement.

(c) Very few students appreciated that bond enthalpies are measured in the gaseous state and so the expression would not give an accurate value for a liquid alkane.

(d) Most students plotted the points on the graph correctly, but a very significant proportion of them drew a best fit line that was straight rather than a curve. Most students read the value for propane off the graph, but some did not include the negative sign to show it was exothermic. Worryingly, some students did not know how many C atoms the alkanes contained and failed to score.

(e) Many students failed to find the mass of 1 dm^3 of isooctane, not appreciating that the density value given was in g cm^{-3} rather than g dm^{-3}. Some students lost the second mark because they did not appreciate that the answer should be given to three significant figures.

Q7.

This question involved several steps and many went wrong as they effectively used ΔH = [Sum bond enthalpies products] – [Sum bond enthalpies reactants] instead of ΔH = [Sum bond enthalpies reactants] – [Sum bond enthalpies products].

Q8.

Two-thirds of the marks in this enthalpy-based question involved students being able to carry out calculations based on Hess' Law and, as always, there was a divide between those who could cope with such questions and those who couldn't.

In part (a) the importance of learning definitions was illustrated. Many students failed to make clear that <u>all</u> reactants and products need to be in their standard states.

In questions such as part (b) students are strongly advised to start with a clear and complete indication of the expression relating the enthalpy change of the reaction to the data given or to draw out a clearly labelled cycle. Students who relied on the use of a

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learned expression often got this wrong way round, possibly due to confusion with the use of enthalpies of formation whereas, in this case, the data provided were enthalpies of combustion.

In a question like part (c) students are strongly advised to sketch out the displayed formulae of all reactants and products when working with bond energies. Failing to do so in many cases meant that bonds were omitted or miscounted (3 × C-C in propan-1-ol was often seen) by students.

Q9.

This question was answered well. Balancing the equation in part (a)i looks straightforward when you know the answer, but it is quite demanding if you have to work it out, and impressively half the students gave the correct answer. In part (b)i, it was necessary to draw unambiguous structures both for propan-2-ol (not given in the question) and propanone (given in part (a)i). The calculation in part (c) was well answered with the focus on correct chemistry rather than on the number of significant figures and the mathematics of rounding the final answer. The definition in part (d) was expected to be straightforward and yet still resulted in only 40% gaining all three marks. As many as 45% gained all three marks and 80% gained at least one mark from the very straightforward calculation in part (e), with errors occurring because some students did not know the bonding either in propanone or in carbon dioxide and used the unnecessary C−O that was given in the data set. It was decided that the very straightforward idea of “heat loss”, in whatever context, was worth only one mark in part (f) and that students needed to come up with other reasons why the values in part (c) and part (e) differed; many were able to do so and this led to 54% scoring both marks.

Q10.

Answers to part (a) were often incomplete; many students lost a mark because only one bond was broken rather than 1 mol of bonds. Answers to part (b) were usually correct but a fairly common mistake was to omit to halve the O=O bond enthalpy or to calculate a value for the formation of 2 mol of water. Answers to part (c)(i) were usually correct but in part (c)(ii) most students did not score because they did not refer to the O-H bond and some inadvisably thought that experimental error was a sufficient answer.

Q11.

Part (a) discriminated almost as well as the earlier mechanism questions with well over half of the students scoring at least 3 of the 5 marks. Relatively few recognised that (fractional) distillation is a process used to produce a much more concentrated solution of ethanol and many referred to the hydration of ethene, having missed the requirement to start “from a dilute aqueous solution”. The concept of carbon-neutral “in the context of this biofuel” required reference both to carbon dioxide **and** the atmosphere. Part (b) was well answered with over half of all students scoring 4 out of 5 marks. By comparison, part (c) proved more demanding. The definition in part (c)(i) most often yielded only 1 of the 2 marks. Too often in part (c)(ii) it proved difficult to decipher the jumble of numbers that some students recorded on the page and only about one-third of students scored all 3 marks.

Q12.

In part (a)(i), some students missed either the fact that the catalyst has to be a concentrated strong acid or that the unreacted ethene is re-circulated to achieve an overall yield of 95% and this meant that only a small number of students scored both marks. Considerable latitude was allowed in the responses for part (a)(ii), since it was

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clear that many students did not really understand what was happening in this process and this approach to the marking enabled the majority of students to gain at least two marks out of three. In part (a)(iii), some students recognised the possibility of poly(ethene) being formed and approximately 17% of students gained both marks.

It has been a while since a question like part (b) has been asked and it was not well answered with few students gaining full marks and over half scoring zero. Balancing the correct equation and then including the correct state symbols were both needed for full marks. Parts (c) and (d) proved straightforward for many and full marks were seen from over a third of students in each of parts (c)(i) and (c)(ii), respectively.

Q13.

The formula for ammonia and that for nitrogen caused the most problems in part (a) and only 60% scored the mark. The definition of mean bond enthalpy has not been examined for some time and the idea that it is a measure of the enthalpy change when a **covalent** bond is broken was missed by most, although many knew that the mean value comes from an average of the values obtained for the same bond in a range of different compounds. In part (c), 51% of students scored full marks, however, many students made transposition and arithmetic errors.

Q14.

Answers to this question were disappointingly poor. In part (a), there was not much evidence that the precise meaning of the term **bond dissociation enthalpy** was understood or had been learned. Only 20% of students scored both marks and over 50% scored zero. This enthalpy change refers to the conversion of one mole of chlorine gas into two moles of chlorine atoms but this was not usually stated. Answers to part (b) did not usually convey the understanding that this process is exactly the same as bond dissociation but that it involves only half a mole of chlorine gas. There was also confusion between chlorine molecules, chlorine atoms and chloride ions. Part (c)(i) was answered better but many answers were incorrect because they did not show chlorine and fluorine molecules. In part (c)(iii), many students used incorrect cycles or formulae and obtained an exothermic rather than an endothermic answer. In part (c)(iv), most students did not read or did not understand the question. A statement that bond enthalpies are obtained by averaging values from different compounds may be a correct statement but it is not an answer to the question.

Q15.

Only 28% of candidates gained all three marks in part (a)(i). The usual error was a failure to follow the instruction in the question that required an enthalpy change for only one mole of ammonia. In part (a)(ii) many candidates were unable to explain clearly that individual bond enthalpies in a specific compound will differ from data book values of mean bond enthalpies that are an average of bond enthalpy values from a range of different compounds. The remainder of this question was well answered by most candidates.

Q16.

Most candidates seem to know something about fermentation and part (a) discriminated extremely well.

In part (b), only the best candidates were able both to state that such a fuel is carbon-neutral and also to demonstrate that the six moles of CO_2 taken in during photosynthesis are later released in the fermentation process followed by the combustion of ethanol. Failure to recognise that two moles of ethanol were burning resulted in only four moles of

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CO_2 and left candidates confused. A few candidates seemed to think that a balanced equation with six carbon atoms on each side is carbon-neutral.

The calculation in part (c) proved demanding as candidates failed to count up accurately how many of each bond were broken and how many were formed. They were able quite often to get only one of these correct. The idea that mean bond enthalpies are average values obtained from many different compounds was not well known.

In part (d) the equation used to calculate the heat change was well known but conversion to enthalpy change proved difficult for all but the best. The idea of incomplete combustion was often missed.

Q17.

This question took hydrogen as its theme and asked questions across the subject. Overall it was a high scoring question. The application of Le Chatelier's principle was done well with only 10% of candidates failing to score any marks. By contrast, the calculation of a value for the H-H bond enthalpy proved very demanding and half the candidates scored no marks.

Q19.

More able candidates were able to obtain high marks in this question but the weaker candidates found the calculations difficult. The definition in (a) was usually attempted well with the majority of candidates scoring 3 marks. Answers to (b) discriminated between candidates. There were several arithmetic errors in the calculation, and a few candidates who did not know to subtract the sum of the bonds made from the sum of the bonds broken leading to an incorrect sign in the final answer. Most candidates realised that oxygen was an element in (c). Again the calculation in (d) discriminated well. A common incorrect answer was 1888 $kJmol^{-1}$ which was usually due to doing the calculation the wrong way round. Weaker candidates also failed to take account of the 3 moles of water and carbon dioxide in their calculation. The explanation of why answers to (b) were less accurate than (a) was not done as well as expected with many candidates scoring one out of the 2 marks. Candidates should know that mean bond enthalpies are averaged over a range of compounds which contain the same bond, or from the same compound which contains several of the same type of bond. A common incorrect answer here was 'heat loss'.

Q20.

More able candidates were able to obtain high marks for this question but less able candidates found the calculations hard. In part (a) candidates lost a mark if they referred to bond-formation instead of bond-breaking. Less able candidates were unable to explain that mean bond enthalpy refers to an average of bonds where the environment is different, usually due to existence in different molecules. In part (b) many candidates provided incorrect answers because they did not work out the correct number of bonds being broken or formed. For example, only the best candidates recognised that two O—O bonds were broken. It was disappointing in part (c) (i) that many candidates did not understand the question. It was quite common to find candidates attempting a calculation using the equation, the enthalpy of formation values given in the table and an assumption that the enthalpy change for the equation was zero. Answers to part (c) (ii) were more usually correct though weaker candidates failed to take account of the two moles of hydrogen peroxide and the four moles of water. Answers to part (d) were usually incorrect. A common wrong answer was the statement 'Heat loss'.

Q21.

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Good candidates were able to obtain high marks for this question but weak candidates found it very difficult and marks of zero out of ten were not unusual. In part (a), a common mistake was to use the O—O single bond enthalpy rather than the correct value for the O=O double bond and also to use one mole of oxygen rather than half a mole. In part (b) the balanced equation was usually correct but the state symbol for carbon was frequently shown as gaseous rather than solid (or graphite). In Part (c) (i) only the best candidates appeared to notice the wording in the question which required a reference to the structure of solid carbon. Part (c) (ii) also proved to be a difficult question for weaker candidates who rarely multiplied the enthalpy of formation of hydrogen atoms by the factor four. Also, the enthalpy of formation of methane (–74.9 kJ mol^{-1}) was usually added rather than subtracted. Incorrect cycles and equations involving combustion of methane were also common errors. Part (c) (iii) was answered well; the mark was awarded for dividing the answer to part (c) (ii) by four.

Q22.

This question proved to be very difficult and good answers were extremely rare. Part (a) of the question was used to assess candidates' quality of language. Explanations were usually rather vague or imprecise and whereas one mark out of two was common, answers that were awarded two marks were very infrequent. In part (b)(i), despite a specific statement in the question referring to one mole of ammonia, most candidates wrote an equation giving two moles of ammonia. In part (b) (ii), only the best candidates gave the correct answer of –38 kJ mol^{-1}. Some credit was given for a method of calculation that was partly correct but which lead to an incorrect nswer as a result of using the wrong signs or the wrong number of moles of ammonia. The incorrect answers that gained some credit were –76, +76 and +38 kJ mol^{-1}. Correct answers to part (c) were seen rarely. Common errors were confusion over signs when breaking bonds then forming bonds and a failure to include the enthalpy change value of –136 kJ mol^{-1} in any equation that was set up.

Q23.

The meaning of the term mean bond enthalpy was not well understood and, as in the June 2001 paper, few candidates scored two marks in part (a). Part (b)(i), in which candidates were required to use mean bond enthalpy data, was generally well answered and only candidates who failed to deduce the correct number and type of bond lost marks. In part (b)(ii) many candidates lost one mark when they failed to recognise that bond formation is an exothermic process. Part(c)(iii) was marked consequentially to answers given in parts (i) and (ii).

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Q1.

The data below refer to the industrial production of nitric acid from ammonia.

Reaction 1 $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $\Delta H^{\ominus} = -909$ kJ mol^{-1}

Reaction 2 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H^{\ominus} = -115$ kJ mol^{-1}

Reaction 3 $3NO_2(g) + H_2O(l) \rightleftharpoons 2HNO_3(aq) + NO(g)$ $\Delta H^{\ominus} = -117$ kJ mol^{-1}

The direct oxidation of ammonia to nitrogen dioxide can be represented by the equation

$$4NH_3(g) + 7O_2(g) \rightarrow 4NO_2(g) + 6H_2O(g)$$

for which the standard enthalpy change, in kJ mol^{-1}, is

A −1139

B −1024

C −794

D −679

(Total 1 mark)

Q2.

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

_____

(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.

_____

_____

(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.

_____

_____

(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.

_____

(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

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

_____

_____

_____

_____

(3)

(Total 12 marks)

Q3.

Using the information below, answer this question.

$Fe_2O_3(s) + 3H_2(g) \rightarrow 2Fe(s) + 3H_2O(g)$ $\Delta H^{\ominus}$ = +96 kJ mol^{-1}, $\Delta S^{\ominus}$ = +138 J K^{-1} mol^{-1}

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	$Fe_2O_3(s)$	$H_2(g)$	Fe(s)
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	−822.0	0	0
$\Delta S^{\ominus}$ / J K^{-1} mol^{-1}	90.0	131.0	27.0

The standard enthalpy of formation of steam is

A +286 kJ mol^{-1}

B +242 kJ mol^{-1}

C −242 KJ mol^{-1}

D −286 kJ mol^{-1}

(Total 1 mark)

Q4.

The table below contains some standard enthalpy of formation data.

Substance	C(s)	$N_2(g)$	$H_2O(g)$	$CO_2(g)$	$NH_4NO_3(s)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	0	0	–242	–394	–365

(a) Why are the values of the standard enthalpy of formation for carbon and nitrogen zero?

_____

(1)

(b) State Hess's Law.

_____

_____

_____

(2)

(c) Use $\Delta H_f^{\ominus}$ data from the table to calculate a value for the enthalpy change for the following reaction.

$$NH_4NO_3(s) + \frac{1}{2}C(s) \rightarrow N_2(g) + 2H_2O(g) + \frac{1}{2}CO_2(g)$$

_____

_____

_____

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_____

(3)

(Total 6 marks)

Q5.

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

_____

_____

_____

(2)

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

_____

_____

_____

_____

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

_____

(5)

(c) State Hess's Law.

_____

_____

(1)

(d) 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)	$H_2(g)$
$\Delta H_c^{\ominus}$ / kJ mol^{-1}	–1356	–393.5	–285.8

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(3)
(Total 11 marks)

Q6.

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

(3)

(b) State Hess's law.

(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)

Q7.

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)

Q8.

When ethanamide (CH_3CONH_2) burns in oxygen the carbon is converted into carbon dioxide, the hydrogen is converted into water and the nitrogen forms nitrogen gas.

Substance	ethanamide	carbon dioxide	water
Enthalpy of formation ($\Delta H_f^{\ominus}$) / kJ mol^{-1}	−320	−394	−286

Using the data above, which one of the following is a correct value for the enthalpy of combustion of ethanamide?

A -1823 kJ mol^{-1}

B -1183 kJ mol^{-1}

C -1000 kJ mol^{-1}

D -360 kJ mo1^{-1}

(Total 1 mark)

Q9.

Consider the reactions

$C_2H_4(g) + 2O_2(g) \rightarrow 2CO(g) + 2H_2O(g)$ $\quad \Delta H^{\ominus} = -758$ kJ mol^{-1}

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$2C(s) + 2H_2(g) \rightarrow C_2H_4(g)$ $\Delta H^{\ominus} = +52$ kJ mol^{-1}

$H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(g)$ $\Delta H^{\ominus} = -242$ kJ mol^{-1}

The enthalpy of formation of carbon monoxide is

A −111 kJ mol^{-1}

B −163 kJ mol^{-1}

C −222 kJ mol^{-1}

D -464 kJ mol^{-1}

(Total 1 mark)

Q10.

Given the following data

$C(s) + 2H_2(g) \rightarrow CH_4(g)$ $\Delta H = -75$ kJ mol^{-1}

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

which one of the following is the enthalpy change, in kJ mol^{-1}, of the reaction below?

$CH_4(g) \rightarrow C(s) + 4H(g)$

A −947

B +511

C +797

D +947

(Total 1 mark)

Q11.

Nitric acid is produced industrially from ammonia, air and water using the following sequence of reactions:

(1) $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$ $\Delta H = -909$ kJ mol^{-1}

(2) $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$ $\Delta H = -115$ kJ mol^{-1}

(3) $3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(aq) + NO(g)$ $\Delta H = -117$ kJ mol^{-1}

Which is the enthalpy change (in kJ mol^{-1}) for the following reaction?

$4NH_3(g) + 7O_2(g) \rightarrow 4NO_2(g) + 6H_2O(g)$

A −679

B −794

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C −1024

D −1139

(Total 1 mark)

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Q1.

A

[1]

Q2.

(a) $C_3H_6O + 4O_2 \rightarrow 3CO_2 + 3H_2O$ **(1)** (or multiple) 1

(b) (i) $\frac{1.45}{58}$ **(1)** = 0.0250 **(1)**

allow 0.025
allow conseq on wrong M_r

1.45/100, CE; $\frac{1.45}{58.1}$ *C.E.*

(ii) heat released = mcΔT
= 100 × 4.18 × 58.1 **(1)**

if 1.45 used in place of 100 CE = 0

= 24300 J **(1)** (or 24.3kJ)

allow 24200 to 24300
ignore decimal places
units tied to answer
If use 0.1 × 4.18 × 51.8 allow ½ for 24.3 with no units

(iii) $\frac{24.3}{0.0250}$ = –972 (kJ mol^{-1}) **(1)**

allow –968 to –973
allow +972
allow conseq
allow no units
penalise wrong units

5

(c) (i) Heat loss **(1)** or energy loss

do not allow incomplete combustion

(ii) *Difference*: more negative **(1)** (or more exothermic)

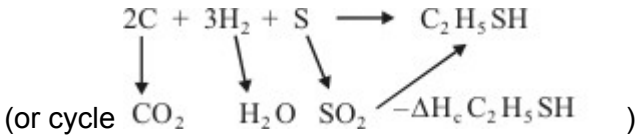
QoL mark

Explanation: heat (*or energy*) released when water vapour condenses **(1)**
or heat/energy required to vaporise water
or water molecules have more energy in the gaseous state

3

(d) $\Delta H = \Sigma\Delta H_{reactants} - \Sigma\Delta H_{products}$ **(1)**

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(or cycle)

= (2 × –394) + (3 × –286) + (–297) – (–1170) **(1)**
= –773 **(1)**

ignore units even if wrong

Allow 1/3 *for +773*

3

[12]

Q3.

C

[1]

Q4.

(a) They are elements **(1)**

Ignore irrelevant comments

1

(b) Enthalpy <u>change</u> **(1)**

or heat energy change or heat change or ΔH or any named enthalpy change C.E. if change not mentioned

Independent of route **(1)**

OR depends on initial and final <u>states</u>
Only give second mark if first mark awarded except allow if energy used instead of enthalpy

2

(c) $\Delta H = \Sigma \Delta H_f^{\ominus}$(products) - $\Sigma \Delta H_f^{\ominus}$(reactants) **(1) (Or a cycle)**
= 2 × –242 + ½ × –394 – (–365) **(1) (also implies first mark)**
= -316 kJ mol^{-1} **(1)**

3

Ignore no units penalise wrong units
+316 scores 1/3

[6]

Q5.

(a) Heat energy change **(1)**

Not energy on its own

measured at constant pressure **(1)**

Mark separately, ignore constant temperature statements

2

(b) (i) Enthalpy change when 1 mol of a substance (or compound / product) **(1)** is formed from its constituent elements **(1)** in their standard states **(1)**

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under standard conditions **(1)**

Mark separately

(ii) $2Na(s) + S(s) + 2O_2(g) \rightarrow Na_2SO_4(s)$

Balanced (1) State symbols (1), but only if all species are correct

Allow $\frac{1}{8} S_8(s)$

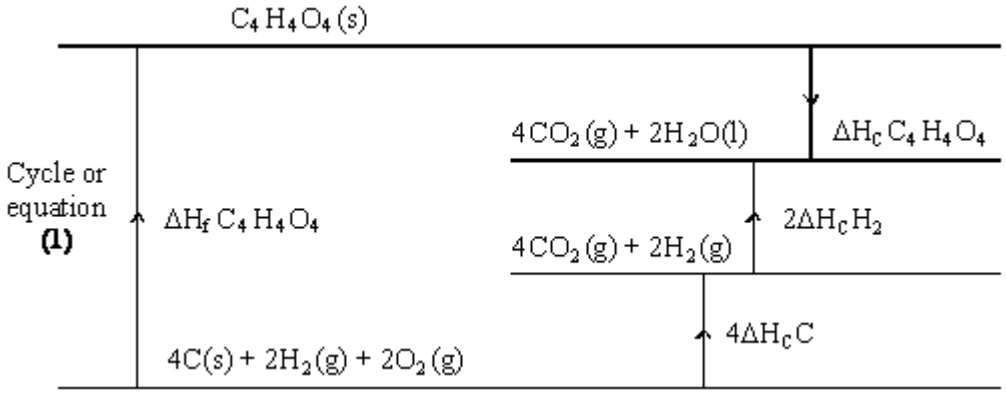
5

(c) Enthalpy change is independent of reaction route **(1)**

Penalise incorrect additional statements

1

(d)



$-1356 + (2 \times 285.8) + (4 \times 393.5) + \Delta H_f C_4H_4O_4 = 0$

$\Delta H_f = -789.6$ kJ mol^{-1}

If answer is incorrect:

Score +789.6 two marks

Score (× 1); (× 2) and (× 4) for species - one mark

If an incorrect negative answer given check for AE for loss of one mark

3

[11]

Q6.

(a) (Enthalpy change) when 1 mol **(1)** of a compound is formed from its constituent elements **(1)** in their standard states **(1)**

3

Allow energy or heat, Ignore evolved or absorbed

Mark each point independently

(b) (The enthalpy change for a reaction is) independent of the route **(1)**

1

(c) $\Delta H_R = \Sigma\Delta H_f$ products - $\Sigma\Delta H_f$ reactants **(1)**

= [(3 × -286) + (3 × -394)] - (-248) **(1)**

= -1792 **(1)** (kJ mol^{-1})

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Deduct one mark for each error to zero

3

[7]

Q7.

C

[1]

Q8.

B

[1]

Q9.

A

[1]

Q10.

D

[1]

Q11.

D

[1]

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Q2.

This question proved accessible to most candidates; even the weaker candidates were able to score marks approaching half of those available. Answers to part (a) were usually correct.

Most candidates also gave a correct answer to part (b)(i) though there were a significant number of errors in the calculation of the relative molecular mass of propanone. Parts (b)(ii) and (b)(iii) were also answered well although there were some problems with units. The correct answer to part (c)(i) was known by most candidates but part (c)(ii) proved to be much more discriminating and only the best candidates were able to explain why the enthalpy of combustion is more negative when water is formed in the liquid state. A fair majority of candidates was able to give a correct answer to part (d) but as usual in this type of question, weaker candidates made an error in signs leading to an answer of +773 kJ mol^{-1} or made an error by omitting to multiply the relevant enthalpy of combustion by the number of moles of the substance involved.

Q4.

This question was answered well by many candidates. Answers to part (a) were usually correct. Most candidates provided good answers to part (b) but some lost marks because they referred to energy or to enthalpy alone rather than to enthalpy change. In part (c) the most common error was to invert signs leading to an answer of 316 kJ mol-1 rather than to –316 kJ mol^{-1}.

Q5.

The meaning of the term enthalpy change, required in part (a), was not well stated and whilst many correctly referred to the heat energy change, most failed to state that this was measured at constant pressure. Part (b) was well answered with many correct definitions of the term standard enthalpy of formation of a compound though slightly fewer candidates gave a correct equation with state symbols in section (ii). Hess's Law was correctly stated by many candidates and it is particularly pleasing to report that the calculation required in part (d) was very well done.

Q6.

This question was very well answered and many candidates were able to score full marks. Happily, as candidates showed working in part (c), part marks could be awarded when incorrect answers were given.

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Q1.

Chlorine is used to decrease the numbers of microorganisms in water.

When chlorine is added to water, there is a redox reaction, as shown by the equation

$$Cl_2 + H_2O \rightleftharpoons HClO + HCl$$

(a) Deduce the oxidation state of chlorine in HClO and the oxidation state of chlorine in HCl

Oxidation state of chlorine in HClO _____

Oxidation state of chlorine in HCl _____

(1)

(b) Give two half-equations to show the oxidation and reduction processes that occur in this redox reaction.

Oxidation half-equation _____

Reduction half-equation _____

(2)

(c) Chlorine is reacted with cold, aqueous sodium hydroxide in the manufacture of bleach.

Give an equation for this reaction between chlorine and sodium hydroxide.

_____

(1)

(d) The concentration of ClO^- ions in bleach solution can be found by reaction with iodide ions.

The overall equation for this reaction is shown.

$$ClO^- + 2I^- + 2H^+ \rightarrow I_2 + Cl^- + H_2O$$

A sample of bleach solution was found to contain ClO^- ions with a concentration of 0.0109 mol dm^{-3}

Potassium iodide is added to a 20.0 cm^3 portion of this bleach solution.

Calculate the mass, in mg, of potassium iodide needed to react with all of the ClO^- ions in the sample of bleach.
Give your answer to the appropriate number of significant figures.
Give **one** observation during this reaction.

Mass of potassium iodide _____ mg

Observation _____

_____

_____

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_____

(4)

(e) Potassium chlorate(VII), $KClO_4$, is used in fireworks. When potassium chlorate(VII) decomposes, it produces potassium chloride and oxygen.

Give an equation for the decomposition of potassium chlorate(VII).
Use the data in the table to calculate the enthalpy change for this reaction.

Substance	**$\Delta_f H$ / kJ mol^{-1}**
$KClO_4(s)$	– 434
KCl(s)	– 436

Equation _____

Enthalpy change _____ kJ mol^{-1}

(2)

(Total 10 marks)

Q2.

What is the enthalpy of formation of buta-1,3-diene, $C_4H_6(g)$?

Substance	**Enthalpy of combustion / kJ mol^{-1}**
$C_4H_6(g)$	–2546
C(s)	–394
$H_2(g)$	–286

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A +112 kJ mol^{-1} ⬭

B –112 kJ mol^{-1} ⬭

C +746 kJ mol^{-1} ⬭

D –746 kJ mol^{-1} ⬭

(Total 1 mark)

Q3.

This question is about energetics.

(a) Write an equation, including state symbols, for the reaction with an enthalpy change equal to the enthalpy of formation for iron(III) oxide.

_____

(1)

(b) **Table 1** contains some standard enthalpy of formation data.

Table 1

	CO(g)	Fe_2O_3(s)
$\Delta_f H^\ominus$/ kJ mol^{-1}	−111	−822

$Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(s) + 3CO_2(g)$ $\Delta H = -19$ kJ mol^{-1}

Use these data and the equation for the reaction of iron(III) oxide with carbon monoxide to calculate a value for the standard enthalpy of formation for carbon dioxide.

Show your working.

$\Delta_f H^\ominus$ _____ kJ mol^{-1}

(3)

(c) Some enthalpy data are given in **Table 2**.

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Table 2

Process	**ΔH / kJ mol^{-1}**
$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$	−92
$N_2(g) \longrightarrow 2N(g)$	+944
$H_2(g) \longrightarrow 2H(g)$	+436

Use the data from **Table 2** to calculate the bond enthalpy for N−H in ammonia.

N−H bond enthalpy _____ kJ mol^{-1}

(3)

(d) Give one reason why the bond enthalpy that you calculated in part (c) is different from the mean bond enthalpy quoted in a data book (388 kJ mol^{-1}).

_____

_____

_____

(1)

(Total 8 marks)

Q4.

Anhydrous magnesium chloride, $MgCl_2$, can absorb water to form the hydrated salt $MgCl_2.4H_2O$

$$MgCl_2(s) + 4H_2O(l) \longrightarrow MgCl_2.4H_2O(s)$$

(a) Suggest **one** reason why the enthalpy change for this reaction cannot be determined directly by calorimetry.

_____

_____

(1)

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(b) Some enthalpies of solution are shown in Table 1.

Table 1

Salt	Enthalpy of solution / kJ mol^{-1}
$MgCl_2(s)$	−155
$MgCl_2.4H_2O(s)$	−39

Calculate the enthalpy change for the absorption of water by $MgCl_2(s)$ to form $MgCl_2.4H_2O(s)$.

Enthalpy change _____ kJ mol^{-1}

(2)

(c) Describe how you would carry out an experiment to determine the enthalpy of solution of anhydrous magnesium chloride.

You should use about 0.8 g of anhydrous magnesium chloride.

Explain how your results could be used to calculate the enthalpy of solution.

_____

_____

_____

_____

_____

_____

_____

_____

(6)

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(d) Anhydrous magnesium chloride can be formed by direct reaction between its elements.

$$Mg(s) + Cl_2(g) \longrightarrow MgCl_2(s)$$

The free-energy change, ΔG, for this reaction varies with temperature as shown in **Table 2**.

Table 2

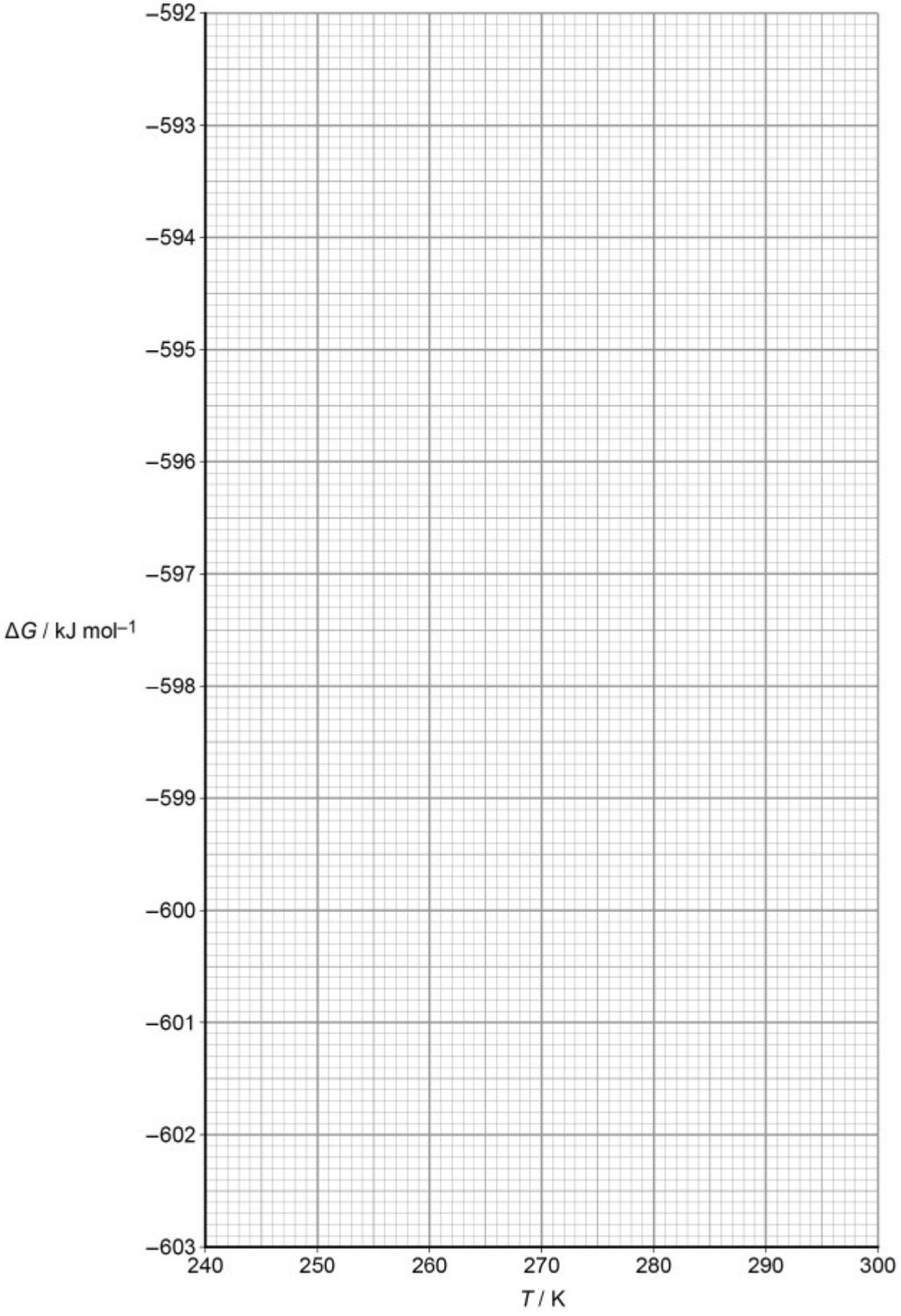
T / K	ΔG / kJ mol^{-1}
298	−592.5
288	−594.2
273	−596.7
260	−598.8
240	−602.2

Use these data to plot a graph of free-energy change against temperature on the grid below.

Calculate the gradient of the line on your graph and hence calculate the entropy change, ΔS, in J K^{-1} mol^{-1}, for the formation of anhydrous magnesium chloride from its elements.

Show your working.

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ΔS _____ $JK^{-1}mol^{-1}$

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(5)
(Total 14 marks)

Q5.

This question is about enthalpy changes.

(a) Write an equation, including state symbols, to show the reaction taking place when the standard enthalpy of combustion for ethanol is measured.

_____

(2)

(b) State the name given to the enthalpy change represented by the following chemical equation.

Explain why this enthalpy change would be difficult to determine directly.

$$C(s) + \frac{1}{2}O_2(g) \rightarrow CO(g)$$

Enthalpy change _____

Explanation _____

_____

_____

(2)

(c) Standard enthalpies of combustion for carbon and carbon monoxide are −393 kJ mol^{-1} and −283 kJ mol^{-1}, respectively.

Use these data to calculate the enthalpy change for the reaction in part **(b)**.

Enthalpy change = _____ kJ mol^{-1}

(2)

(d) Use the following data to calculate a value for the Xe–F bond enthalpy in XeF_4

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$$Xe(g) + 2F_2(g) \rightarrow XeF_4(g) \quad \Delta H = -252 \text{ kJ mol}^{-1}$$
$$F_2(g) \rightarrow 2F(g) \quad \Delta H = +158 \text{ kJ mol}^{-1}$$

Xe–F bond enthalpy = _____ kJ mol^{-1}

(3)

(e) Suggest a reason why the value calculated in part **(d)** differs from the mean Xe–F bond enthalpy quoted in a data source.

_____

_____

_____

(1)

(Total 10 marks)

Q6.

Hydrogen can be manufactured by the reaction of methane with steam. An equilibrium is established as shown by the equation.

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

(a) Use Le Chatelier's principle to predict the effect on the equilibrium yield of hydrogen if the overall pressure is increased.
Explain your answer.

Effect on yield _____

Explanation _____

_____

_____

_____

(3)

(b) Explain why the equilibrium yield of hydrogen is unchanged if a catalyst is used in

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the reaction.

_____

_____

_____

_____

_____

(2)

(c) The table shows the standard enthalpy of formation and the standard entropy for each substance in this equilibrium reaction.

	$CH_4(g)$	$H_2O(g)$	$CO(g)$	$H_2(g)$
$\Delta_f H^\theta$ / kJ mol^{-1}	−75	−242	−111	0
Sθ / J K^{-1} mol^{-1}	186	189	198	131

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

Standard enthalpy change _____ kJ mol^{-1}

(2)

Use your answer from part **(c)** and the entropy data from the table above to calculate the minimum temperature, in °C, needed for this reaction to be feasible. Give your answer to the appropriate number of significant figures.

(If you did not complete part **(c)** you should assume a value of 120 kJ mol^{-1} for the standard enthalpy change. This is **not** the correct value).

Minimum temperature _____ °C

(5)

(Total 12 marks)

Q7.

The table shows the standard enthalpy of formation, $\Delta_f H^\theta$, for some of the substances in the reaction

$$C_2H_6(g) + 6F_2(g) \longrightarrow C_2F_6(g) + 6HF(g) \qquad \Delta H^\theta = -2898 \text{ kJ mol}-1$$

	$C_2H_6(g)$	$C_2F_6(g)$
$\Delta_f H^\theta$ /kJ mol^{-1}	−84	−1344

What is the standard enthalpy of formation, in kJ mol^{-1}, for HF(g)?

A −1638 ○

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B −273 ⬭

C +273 ⬭

D +1638 ⬭

(Total 1 mark)

Q8.

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

_____

(1)

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

_____

_____

_____

_____

_____

(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)

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(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.

_____

_____

(4)

(Total 10 marks)

Q9.

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

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

_____

_____

_____

_____

(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)**

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$\Delta H_c^{\ominus}$ / 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.

(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.

(3)

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(Total 9 marks)

Q10.

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.

(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)

Q11.

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.

_____

(1)

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

_____

(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.

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(i) Write an equation for this reaction.

_____

(1)

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

_____

(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.

_____

(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)

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(Total 10 marks)

Q12.

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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(3)

(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.

(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.

(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.

_____

_____

_____

(1)

(Total 11 marks)

Q13.

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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(5)

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

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(2)

(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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(3)

(Total 10 marks)

Q14.

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.

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(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

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

(3)

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

(1)

(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.

(2)

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

(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 $\longrightarrow$ .....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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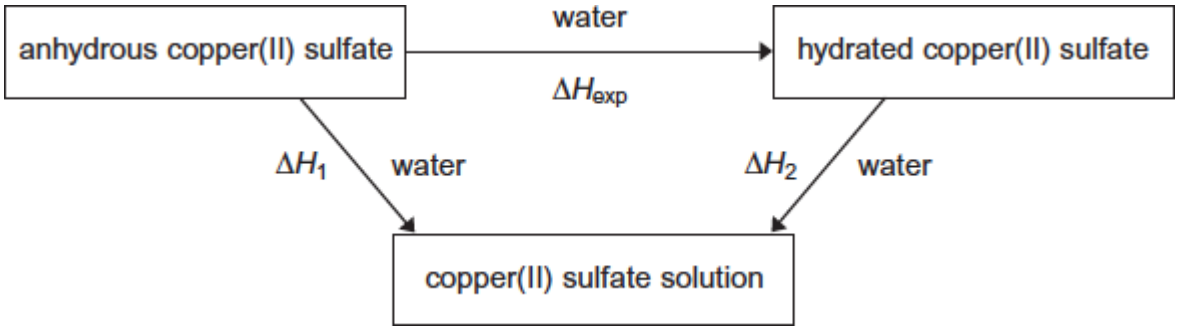
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(1)

(Total 10 marks)

Q15.

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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_____

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(1)

(b) Write a mathematical expression to show how ΔH_{exp}, ΔH_1 and ΔH_2 are related to each other by Hess's Law.

_____

(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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(1)

(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.

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(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}.

(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).

(1)

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

(1)

(Total 8 marks)

Q16.

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.

(2)

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

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dissociation enthalpy of chlorine.

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_____

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(1)

(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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(1)

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

_____

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(2)

(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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(3)

(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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(1)

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

_____

_____

(1)

(Total 11 marks)

Q17.

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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(3)

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

_____

_____

(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 _____

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Explanation _____

_____

_____

_____

_____

_____

(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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_____

_____

_____

(3)

(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.

_____

(1)

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

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

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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(3)

(Total 16 marks)

Q18.

(a) Iron is extracted from iron(III) oxide using carbon at a high temperature.

(i) State the type of reaction that iron(III) oxide undergoes in this extraction.

_____

(1)

(ii) Write a half-equation for the reaction of the iron(III) ions in this extraction.

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_____

(1)

(b) At a high temperature, carbon undergoes combustion when it reacts with oxygen.

(i) Suggest why it is **not** possible to measure the enthalpy change directly for the following combustion reaction.

$$C(s,graphite) + \frac{1}{2}O_2(g) \longrightarrow CO(g)$$

_____

_____

(1)

(ii) State Hess's Law.

_____

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(1)

(iii) State the meaning of the term *standard enthalpy of combustion.*

_____

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(3)

(c) Use the standard enthalpies of formation in the table below and the equation to calculate a value for the standard enthalpy change for the extraction of iron using carbon monoxide.

	$Fe_2O_3(s)$	$CO(g)$	$Fe(l)$	$CO_2(g)$
ΔH_f/ kJ mol^{-1}	- 822	- 111	+14	- 394

$$Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(l) + 3CO_2(g)$$

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(3)

(d) (i) Write an equation for the reaction that represents the standard enthalpy of formation of carbon dioxide.

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(1)

(ii) State why the value quoted in part (c) for the standard enthalpy of formation of $CO_2(g)$ is the same as the value for the standard enthalpy of combustion of carbon.

_____

_____

(1)

(Total 12 marks)

Q19.

This question is about the extraction of titanium from titanium(IV) oxide by a two-stage process.
The first stage in the process produces titanium(IV) chloride. In the second stage, titanium(IV) chloride is converted into titanium.
The enthalpy change for the second stage can be determined using Hess's Law.

(a) Give **one** reason why titanium is **not** extracted directly from titanium(IV) oxide using carbon.

_____

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(1)

(b) Give the meaning of the term *enthalpy change*.

_____

_____

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(1)

(c) State Hess's Law.

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(1)

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

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(3)

(e) The following standard enthalpy of formation data refer to the second stage in the extraction of titanium.

	$TiCl_4(g)$	Na(l)	NaCl(s)	Ti(s)
$\Delta H_f^\ominus$ / kJ mol^{-1}	–720	+3	–411	0

(i) State why the value for the standard enthalpy of formation of Na(l) is **not** zero.

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_____

(1)

(ii) Use data from the table to calculate a value for the standard enthalpy change of the following reaction.

$$TiCl_4(g) + 4Na(l) \longrightarrow 4NaCl(s) + Ti(s)$$

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(3)

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(iii) State the role of sodium in this reaction.

_____

(1)

(Total 11 marks)

Q20.

Hess's Law is used to calculate the enthalpy change in reactions for which it is difficult to determine a value experimentally.

(a) State the meaning of the term *enthalpy change*.

_____

(1)

(b) State Hess's Law.

_____

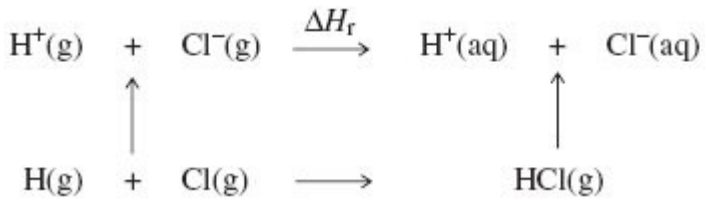
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(1)

(c) Consider the following table of data and the scheme of reactions.

Reaction	Enthalpy change / kJ mol^{-1}
$HCl(g) \rightarrow H^+(aq) + Cl^-(aq)$	–75
$H(g) + Cl(g) \rightarrow HCl(g)$	–432
$H(g) + Cl(g) \rightarrow H^+(g) + Cl^-(g)$	+963



Use the data in the table, the scheme of reactions and Hess's Law to calculate a value for ΔH_r

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(3)

(Total 5 marks)

Q21.

Barium can be extracted from barium oxide (BaO) in a process using aluminium.
A mixture of powdered barium oxide and powdered aluminium is heated strongly.
The equation for this extraction process is shown below.

$$3BaO(s) + 2Al(s) \rightarrow 3Ba(s) + Al_2O_3(s)$$

Some standard enthalpies of formation are given in the table below.

Substance	BaO(s)	$Al_2O_3(s)$
$\Delta H_f^{\⦵}$/kJ mol^{-1}	–558	–1669

(a) (i) State what is meant by the term *standard enthalpy of formation*.

_____

_____

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(3)

(ii) State why the standard enthalpy of formation of barium and that of aluminium are both zero.

_____

(1)

(iii) Use the data to calculate the standard enthalpy change for the reaction shown by the equation above.

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(3)

(b) (i) Suggest the major reason why this method of extracting barium is expensive.

_____

(1)

(ii) Using barium oxide and aluminium powders increases the surface area of the

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reactants. Suggest **one** reason why this increases the rate of reaction.

_____

(1)

(c) (i) Write an equation for the reaction of barium with water.

_____

(1)

(ii) A solution containing barium ions can be used to test for the presence of sulfate ions in an aqueous solution of sodium sulfate.

Write the **simplest ionic** equation for the reaction which occurs and state what is observed.

Simplest ionic equation

_____

Observation _____

(2)

(iii) State how barium sulfate can be used in medicine. Explain why this use is possible, given that solutions containing barium ions are poisonous.

Use _____

Explanation _____

_____

(2)

(Total 14 marks)

Q22.

The combustion of hydrocarbons is an important source of energy.

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

_____

_____

_____

(3)

(b) (i) Write an equation for the complete combustion of ethane, C_2H_6.

_____

(ii) Use the standard enthalpies of formation given below to calculate the standard enthalpy of combustion of ethane.

Formula and state of compound	$C_2H_6(g)$	$CO_2(g)$	$H_2O(l)$

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Standard enthalpy of formation (at 298 K)/kJ mol^{-1}	–85	–394	–286

(4)

(c) A container 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}.

(4)

(Total 11 marks)

Q23.

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

(3)

(b) Use the data in the table to calculate the standard enthalpy of formation of liquid methylbenzene, C_7H_8

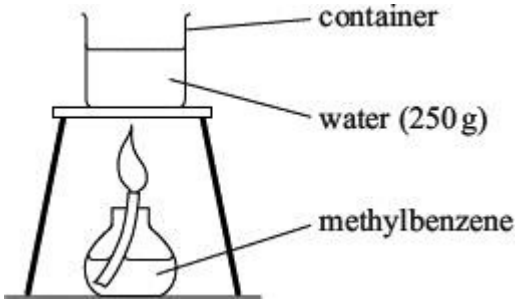
Substance	C(s)	$H_2(g)$	$C_7H_8(l)$
Standard enthalpy of combustion, $\Delta H_c^{\ominus}$ /kJ mol^{-1}	–394	–286	–3909

$7C(s) + 4H_2(g) \rightarrow C_7H_8(l)$

(3)

(c) An experiment was carried out to determine a value for the enthalpy of combustion of liquid methylbenzene using the apparatus shown in the diagram.

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Burning 2.5 g of methylbenzene caused the temperature of 250 g of water to rise by 60°C. Use this information to calculate a value for the enthalpy of combustion of methylbenzene, C_7H_8

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

(4)

(d) A 25.0 cm^3 sample of 2.00 mol dm^{-3} hydrochloric acid was mixed with 50.0 cm^3 of a 1.00 mol dm^{-3} solution of sodium hydroxide. Both solutions were initially at 18.0 °C.

After mixing, the temperature of the final solution was 26.5°C.

Use this information to calculate a value for the standard enthalpy change for the following reaction.

$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

In your calculation, assume that the density of the final solution is 1.00 g cm^{-3} and that its specific heat capacity is the same as that of water. (Ignore the heat capacity of the container.)

(4)

(e) Give **one** reason why your answer to part (d) has a much smaller experimental error than your answer to part (c).

(1)

(Total 15 marks)

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Q24.

(a) Define the term *standard enthalpy of combustion*, ΔH_c⦵

_____

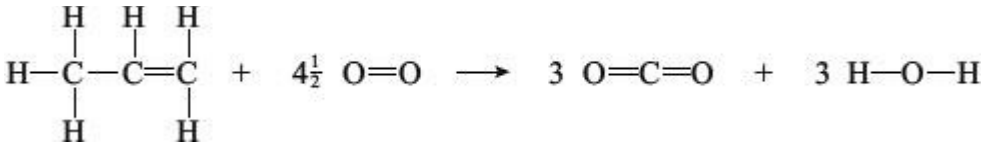
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(3)

(b) Use the mean bond enthalpy data from the table and the equation given below to calculate a value for the standard enthalpy of combustion of propene. All substances are in the gaseous state.

Bond	C == C	C—C	C—H	O == O	O == C	O—H
Mean bond enthalpy/ kJ mol^{-1}	612	348	412	496	743	463



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_____

_____

_____

(3)

(c) State why the standard enthalpy of formation, ΔH_f°, of oxygen is zero.

_____

(1)

(d) Use the data from the table below to calculate a more accurate value for the standard enthalpy of combustion of propene.

Compound	$C_3H_6(g)$	$CO_2(g)$	$H_2O(g)$
Standard enthalpy of formation, ΔH_f°/ kJ mol^{-1}	+20	–394	–242

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(3)

(e) Explain why your answer to part (b) is a less accurate value than your answer to part (d).

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_____

(2)

(Total 12 marks)

Q25.

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

Mean bond enthalpy _____

_____

_____

Standard enthalpy of formation _____

_____

_____

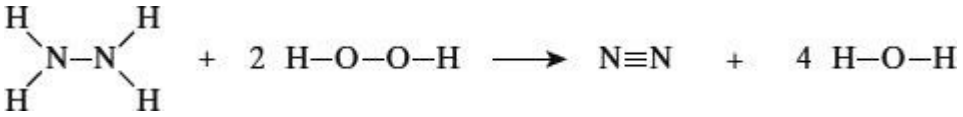
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(5)

(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



_____

_____

_____

_____

_____

(3)

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

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	$N_2H_4(g)$	$H_2O_2(g)$	$H_2O(g)$
ΔH_f° /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 $N_2(g)$.

_____

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

_____

_____

_____

_____

_____

(4)

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

_____

_____

(1)

(Total 13 marks)

Q26.

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*.

_____

_____

_____

_____

_____

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(3)

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

(4)

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

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

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

(i) Explain why, in *Stage 1*, a higher yield of hydrogen and carbon monoxide is **not** obtained if the pressure is increased.

(2)

(ii) *Stage 2* is carried out at a compromise temperature of 500K. By considering what would happen at higher and lower temperatures, explain why 500 K is considered to be a compromise for *Stage 2*.

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(3)

(c) 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 15 marks)

Q27.

This question is about the reaction given below.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

Enthalpy data for the reacting species are given in the table below.

Substance	CO(g)	$H_2O(g)$	$CO_2(g)$	$H_2(g)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	−110	−242	−394	0

The standard enthalpy change for this reaction of carbon monoxide and steam is

A +42 kJ mol^{-1}

B −42 kJ mol^{-1}

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C +262 kJ mol^{-1}

D −262 kJ mol^{-1}

(Total 1 mark)

Q28.

Use the information below to answer this question.

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

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

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

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

A −2880

B −2590

C −806

D −554

(Total 1 mark)

Q29.

(a) The table below contains some mean bond enthalpy data.

Bond	H–O	O–O	O=O
Mean bond enthalpy/kJ mol^{-1}	463	146	496

The bonding in hydrogen peroxide, H_2O_2, can be represented by H–O–O–H. Use these data to calculate the enthalpy change for the following reaction.

$$H_2O_2(g) \rightarrow H_2O_2(g) + \tfrac{1}{2}O_2(g)$$

_____

_____

_____

_____

(3)

(b) The standard enthalpy of formation, $\Delta H_f^{\ominus}$ for methane, is –74.9 kJ mol^{-1}. Write an equation, including state symbols, for the reaction to which this enthalpy change applies.

_____

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(2)

(c) The enthalpy changes for the formation of atomic hydrogen and atomic carbon from their respective elements in their standard states are as follows.

$\frac{1}{2}H_2(g) \rightarrow H(g)$ $\quad \Delta H^{\ominus} = +218$ kJ mol^{-1}

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

(i) By reference to its structure, suggest why a large amount of heat energy is required to produce free carbon atoms from solid carbon.

_____

_____

(ii) Parts (b) and (c) give enthalpy data for the formation of $CH_4(g)$, H(g) and C(g). Use these data and Hess's Law to calculate the value of the enthalpy change for the following reaction.

$CH_4(g) \rightarrow C(g) + 4H(g)$

_____

_____

_____

_____

_____

(iii) Use your answer from part (c)(ii) to calculate a value for the mean bond enthalpy of a C–H bond in methane.

_____

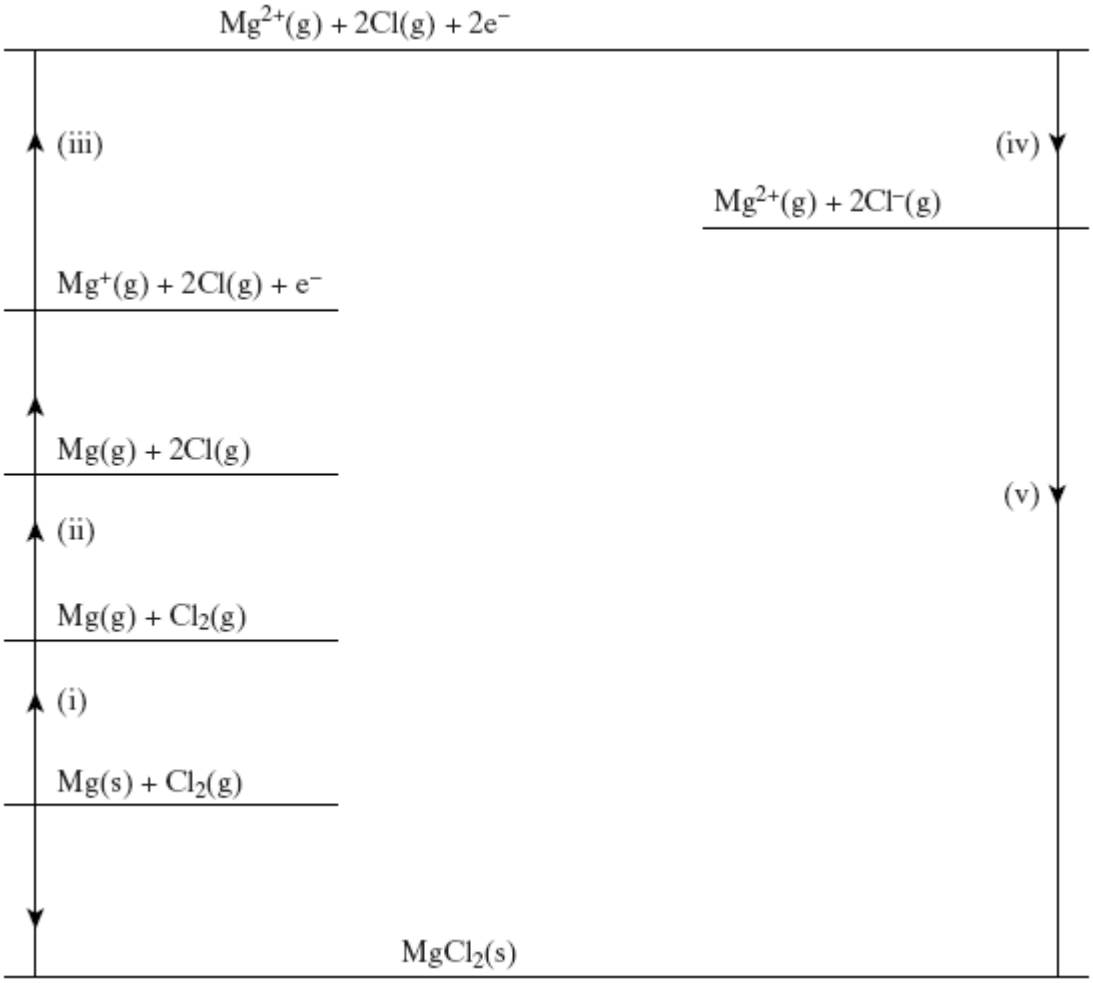
(5)

(Total 10 marks)

Q30.

(a) A Born–Haber cycle for the formation of magnesium(II) chloride is shown below.

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Taking care to note the direction of the indicated enthalpy change and the number of moles of species involved, give each of the enthalpy changes (i) to (v) above.

Enthalpy change (i) _____

Enthalpy change (ii) _____

Enthalpy change (iii) _____

Enthalpy change (iv) _____

Enthalpy change (v) _____

(5)

(b) Write an equation for the decomposition of MgCl(s) into $MgCl_2(s)$ and Mg(s) and use the following data to calculate a value for the enthalpy change of this reaction.

$\Delta H_f^{\ominus}$ MgCl(s) = –113 kJ mol^{-1}

$\Delta H_f^{\ominus}$ $MgCl_2(s)$ = –653 kJ mol^{-1}

Equation _____

Calculation _____

_____

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(4)

(c) Use the data below to calculate a value for the molar enthalpy of a solution of $MgCl_2(s)$.

Lattice formation enthalpy of $MgCl_2(s)$ = –2502 kJ mol^{-1}

$\Delta H^{\ominus}_{hydration}$ of $Mg^{2+}(g)$ = –1920 kJ mol^{-1}

$\Delta H^{\ominus}_{hydration}$ of $Cl^-(g)$ = –364 kJ mol^{-1}

(3)

(Total 12 marks)

Q31.

(a) The gaseous reactants **W** and **X** were sealed in a flask and the mixture left until the following equilibrium had been established.

$2W(g) + X(g) \rightleftharpoons 3Y(g) + 2Z(g)$ ΔH = –200 kJ mol^{-1}

Write an expression for the equilibrium constant, K_p, for this reaction.
State one change in the conditions which would both increase the rate of reaction and decrease the value of K_p. Explain your answers.

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(7)

(b) Ethyl ethanoate can be prepared by the reactions shown below.

Reaction 1

$CH_3COOH(l) + C_2H_5OH(l) \rightleftharpoons CH_3COOC_2H_5(l) + H_2O(l)$ $\Delta H^{\ominus} = -2.0$ kJ mol^{-1}

Reaction 2

$CH_3COCl(l) + C_2H_5OH(l) \rightarrow CH_3COOC_2H_5(l) + HCl(g)$ $\Delta H^{\ominus} = -21.6$ kJ mol^{-1}

(i) Give one advantage and one disadvantage of preparing ethyl ethanoate by **Reaction 1** rather than by **Reaction 2**.

(2)

(ii) Use the information given above and the data below to calculate values for the standard entropy change, $\Delta S^{\ominus}$, and the standard free-energy change, $\Delta G^{\ominus}$, for **Reaction 2** at 298 K.

	$CH_3COCl(l)$	$C_2H_5OH(l)$	$CH_3COOC_2H_5(l)$	$HCl(g)$
$S^{\ominus}$/JK^{1}mol^{1}	201	161	259	187

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_____

_____

(6)

(Total 15 marks)

Q32.

Use the information below to answer this question.

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H^{\ominus} = -393.5$ kJ mol^{-1}

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ $\Delta H^{\ominus} = -285.8$ kJ mol^{-1}

$3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$ $\Delta H^{\ominus} = -104.0$ kJ mol^{-1}

$4C(s) + 5H_2(g) \rightarrow C_4H_{10}(g)$ $\Delta H^{\ominus} = -125.2$ kJ mol^{-1}

The value in kJ mol^{-1} of the enthalpy of thermal dissociation when butane forms propane, hydrogen and carbon is

A −26.3

B −17.5

C +17.5

C +21.2

(Total 1 mark)

Q33.

Use the information below to answer this question.

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H^{\ominus} = -393.5$ kJ mol^{-1}

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ $\Delta H^{\ominus} = -285.8$ kJ mol^{-1}

$3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$ $\Delta H^{\ominus} = -104.0$ kJ mol^{-1}

$4C(s) + 5H_2(g) \rightarrow C_4H_{10}(g)$ $\Delta H^{\ominus} = -125.2$ kJ mol^{-1}

The value in kJ mol^{-1} for the enthalpy of combustion of propane is

A −211.7

B −419.7

C −2220

C −2878

(Total 1 mark)

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Q34.

(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.

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(8)

(Total 15 marks)

Q35.

Chlorine is formed in a reversible reaction as shown by the equation

$$4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$$

(a) Use the data below to calculate the standard enthalpy change, $\Delta H^{\ominus}$, and the standard entropy change, $\Delta S^{\ominus}$, for this reaction.

Substance	HCl(g)	O_2(g)	Cl_2(g)	H_2O(g)
$\Delta H_f^{\ominus}$/kJ mol^{-1}	–92	0	0	–242
$S^{\ominus}$/ J K^{-1} mol^{-1}	187	205	223	189

Standard enthalpy change, $\Delta H^{\ominus}$ _____

Standard entropy change, $\Delta S^{\ominus}$ _____

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_____

_____

_____

(6)

(b) The data below apply to a different gas phase reversible reaction.

Standard enthalpy change, $\Delta H^{\ominus}$ = +208 kJ mol^{-1}
Standard entropy change, $\Delta S^{\ominus}$ = +253 J K^{-1} mol^{-1}

(i) Deduce the effect of an increase in temperature on the position of the equilibrium in this reaction. Use Le Chatelier's principle to explain your answer.

Effect _____

Explanation _____

(ii) Calculate the minimum temperature at which this reaction is feasible.

_____

_____

_____

_____

(7)

(Total 13 marks)

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Q1.

(a) Two correct Cl ox states: HClO = +1 HCl = -1

1

(b) Oxidation:
$Cl_2 + 2H_2O \rightarrow 2HClO + 2H^+ + 2e^-$

Accept - $2e^-$ on the other side

Allow $Cl_2 + 2H_2O \rightarrow 2ClO^- + 2e^-$

1

Reduction:
$Cl_2 + 2H^+ + 2e^- \rightarrow 2HCl$

Allow $Cl_2 + 2e^- \rightarrow 2Cl^-$

If both equations correct but incorrect order, allow 1

Ignore state symbols

1

(c) $2NaOH + Cl_2 \rightarrow NaCl + NaClO + H_2O$

Allow

$2OH^- + Cl_2 \rightarrow Cl^- + ClO^- + H_2O$

Allow NaOCl

Ignore state symbols

1

(d) mol ClO^- = conc × vol = 0.0109 × 0.02
= <u>0.000218 / 2.18×10^{-4}</u> mol

1

mol KI = 0.000218 × 2 = 0.000436 mol

M2 = M1 x2

If incorrect ratio, M2 & M3 = 0

1

mass KI = Mr ×mol = 166.0 × 0.000436
= 0.072376 g
= 72.4 (mg)

M3 = M1 × 2 × 166.0 × 1000

Must be to <u>3 sig figs</u>

1

<u>black solid/ppt</u> appears/forms (in a colourless solution)
or (colourless solution) turns brown (solution)

Not purple. Not red. Not brown ppt/solid

Ignore grey.

1

(e) $KClO_4 \rightarrow KCl + 2O_2$

Ignore state symbols

Allow multiples

1

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ΔH = – 436 – – 434 = – 2 kJ mol^{-1}

Must be negative
Mark independently
Allow consequential for multiples

1

[10]

Q2.

A

[1]

Q3.

(a) $2Fe(s) + \frac{3}{2}O_2(g) \rightarrow Fe_2O_3(s)$ ONLY

Don't allow multiples. States must be shown

1

(b) M1 Correct cycle or equation

If M1 and M2 not awarded then M3 can be awarded for their M2 divided by 3

1

M2 $(3 \times \Delta_f HCO_2) = -19 + (-822) + 3(-111) - 0$
$(3 \times \Delta_f HCO_2) = -1174$

1

M3 $\Delta_f HCO_2 = -391$ kJ mol^{-1}

−317 for 1 mark
+391 for 1 mark

1

Allow 2 sig fig or more

(c) M1 Correct Hess's law cycle or equation

If M1 and M2 not awarded then M3 can be awarded for their M2 divided by 6

1

M2 $(6(N-H)) = 944 + 3(+436) + 92$
$(6(N-H)) = 2344$

−391 for 1 mark

1

M3 N−H = (+)391 kJ mol^{-1}

1

Allow 2 sig fig or more

(d) Data book value derived from (a number of) different compounds (not just different NH_3 molecules)

1

[8]

Q4.

(a) Not possible to prevent some dissolving

ALLOW It is soluble / dissolves / other hydrates may form / suggestions related to difficulty of measuring T (change) of a

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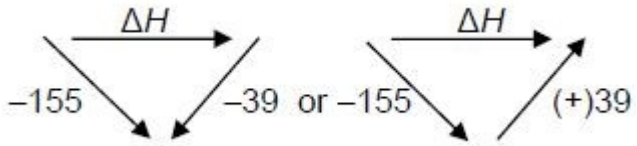
solid

1

(b) ($\Delta_{hyd}H$ =) –155 – (–39)

OR labelled cycle

Minimum needed for 'labelled cycle'



1

–116 (kJ mol^{-1})

1/2 for (+)116 or for –29 or for seeing –116 that has then be processed further

1

(c) This question is marked using levels of response. Refer to the Mark Scheme Instructions for examiners for guidance on how to mark this question

Level 3 (5 – 6 marks)

All stages are covered and the explanation of each stage is correct and virtually complete.
Stage 2 must include use of a graphical method for Level 3 (i.e. 'highest T reached' method is max Level 2)

Answer communicates the whole explanation, including reference to enthalpy, coherently and shows a logical progression through all three stages.Answer is full and detailed and is supported by an appropriate range of relevant points such as those given below:
For the answer to be coherent there must be some indication of **how** the graph is used to find ΔT

Level 2 (3 – 4 marks)

All stages are covered (NB 'covered' means min 2 from each of stage 1 and 3) but the explanation of each stage may be incomplete or may contain inaccuracies
OR two stages covered and the explanations are generally correct and virtually complete

Answer is coherent and shows some progression through all three stages. Some steps in each stage may be out of order and incomplete

Level 1 (1 – 2 marks)

Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies
OR only one stage is covered but the explanation is generally correct and virtually complete

Answer shows some progression between two stages

Level 0 (0 marks)

Insufficient correct Chemistry to warrant a mark

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Indicative Chemistry Content

Stage 1 Method

(1a) Measures water with named appropriate apparatus
(1b) Suitable volume/mass / volume/mass in range 10 – 200 cm^3/g
(1c) Into insulated container / polystyrene cup (NOT just 'lid')
(1d) Add known mass of $MgCl_2(s)$
(1e) Use of 'before and after' weighing method. NOT 'added with washings'

Stage 2 Measurements (could mark from diagram)

(2a) Record initial temperature (min 2 measurements)
(2b) Record T at regular timed intervals for 5+ mins / until trend seen
(2c) Plot T vs time

Stage 3 Use of Results (3a and 3b could come from diagram)

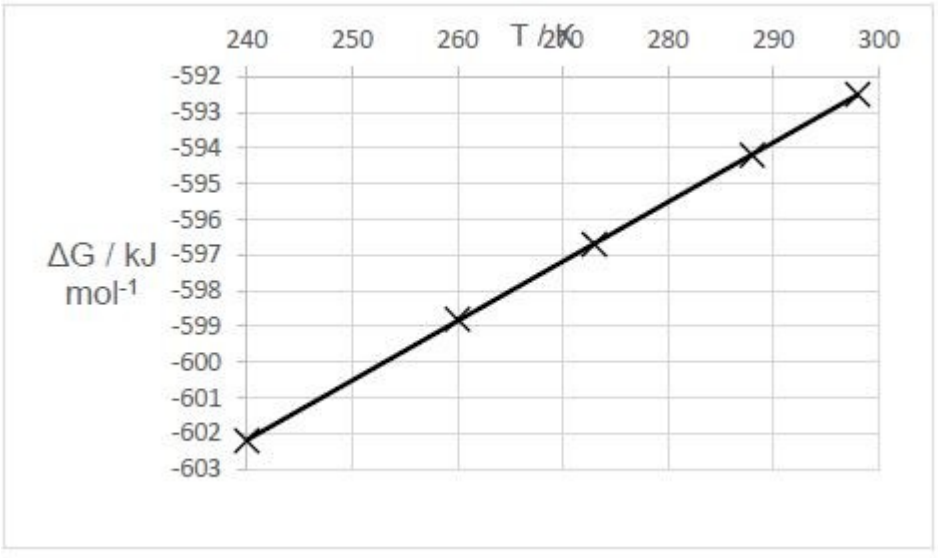
(3a) Extrapolate lines to when solid added (to find initial and final T)
(3b) $T_{final} - T_{initial} = \Delta T$ / idea of finding ΔT from graph at point of addition
(3c) $q = mc\Delta T$
(3d) amount = mass/Mr ($0.80/95.3 = 8.39 \times 10^{-3}$ mol)
(3e) $\Delta H_{soln} = -q/8.39 \times 10^{-3}$ or in words

This could all be described in words without showing actual calculations but describing stages

If method based on 'combustion' Max Level 1

6

(d)



***M1** = 5 points correctly plotted*
***M2** = line drawn correctly (NOT if curved, doubled or kinked)*
(Check line of best fit –
*if through 250, -600.5 and 280, -595.5 +/- one small square then award **M2**, if all crosses on line award **M1** as well)*

2

Gradient = $\Delta(\Delta G)/\Delta T$ = 0.167 ($kJ\ K^{-1}\ mol^{-1}$)

1

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($\Delta G = \Delta H - T\Delta S$ so gradient = $-\Delta S$)

ΔS = –167 (J K^{-1} mol^{-1})

M4 *= unit conversion i.e.* ***M3*** *× 1000; M5 = –sign (process marks)*

Correct answer with sign gets ***M3****,* ***M4*** *and M5*

ALLOW –163 to –171

1+1

[14]

Q5.

(a) $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

1 mark for correct formulae and balancing

1

1 mark for all correct state symbols

1

(b) (Standard) enthalpy of formation

1

Difficult to prevent C reacting with O_2 to form some CO_2

1

(c) $\Delta H = \Sigma\Delta H_c$ reactants − $\Sigma\Delta H_c$ products or a correct cycle

1

OR ΔH = −393−(−283)

ΔH = −110 (kJ $mol^{-1)}$

1

(d) Correctly drawn Hess's law cycle

1

4 (Xe–F) = 252 + (2 × 158) = 568

Xe–F = 568 / 4

1

Xe–F = 142 (kJ $mol^{-1)}$)

1

(e) Mean bond enthalpy found by taking an average for Xe–F in a range of compounds

1

[10]

Q6.

(a) Decrease

1

Increasing pressure moves equilibrium to the side of least moles i.e. backward reaction

1

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To oppose the increase in pressure or to decrease the pressure

1

(b) A catalyst speeds up the rate of the forward and backward reaction

1

By the same amount

1

(c) ΔH = −111 − (−75 − 242)

1

206 (kJ mol^{-1})

1

(d) $\Delta S = 3 \times 131 + 198 - (186 + 189) = 216$ J K^{-1} mol^{-1}

1

$\Delta G = \Delta H - T\Delta S$

1

$0 = 206 - T\frac{216}{1000}$

1

T = 953.7 or 954 K

1

T = 681 (°C)

If the value given in the question is used then the answer is 283 (°C)

1

[12]

Q7.

B

[1]

Q8.

(a) $C(s) + 2F_2(g) \longrightarrow CF_4(g)$

State symbols essential

1

(b) Around carbon there are 4 bonding pairs of electrons (and no lone pairs)

1

Therefore, these repel equally and spread as far apart as possible

1

(c) $\Delta H = \Sigma\ \Delta_f H$ products – $\Sigma\ \Delta_f H$ reactants or a correct cycle

1

Hence = (2 × –680) + (6 × –269) – (x) = –2889

1

x = 2889 – 1360 – 1614 = –85 (kJ mol^{-1})

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1

Score 1 mark only for +85 (kJ mol^{-1})

(d) Bonds broken = 4(C–H) + 4(F–F) = 4 × 412 + 4 × F–F

Bonds formed = 4(C–F) + 4(H–F) = 4 × 484 + 4 × 562

Both required

1

–1904 = [4 × 412 + 4(F–F)] – [4 × 484 + 4 × 562]

4(F–F) = –1904 – 4 × 412 + [4 × 484 + 4 × 562] = 632

1

F–F = 632 / 4 = 158 (kJ mol^{-1})

1

The student is correct because the F–F bond energy is much less than the C–H or other covalent bonds, therefore the F–F bond is weak / easily broken

Relevant comment comparing to other bonds

(Low activation energy needed to break the F–F bond)

1

[10]

Q9.

(a) The <u>enthalpy / heat energy change</u> when <u>1 mol</u> (of a substance)

If enthalpy of formation definition given CE=O

***NOT** just 'energy'*

***ALLOW** alternatives for substance e.g. molecule/compound/element*

1

Is <u>burned/reacts completely in oxygen</u>

***ALLOW** reacts in excess oxygen*

1

With all reactants and products in their <u>standard states</u>

OR

With all reactants and products in their normal states at 298K/given temp & 100kPa

***ALLOW** 'everything' for 'reactants and products'*

Penalise incorrect conditions if given

***ALLOW** 'normal states under standard conditions'*

1

(b) $\Delta H = \Sigma\Delta H_c$(reactants) - $\Sigma\Delta H_c$ (products)

OR

Correctly and fully balanced cycle

Correct answer scores 3

1

ΔH = [3(-394) + 4(-286)] – (-2010)

OR

ΔH = -2326 + 2010

M2 also scores M1

1

ΔH = -316 (kJ mol^{-1})

+316 scores 1 mark only

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IGNORE *units*

Check for AE in working – can award M3 as ecf (error carried forward) from M2 if M2 not given due to AE

1

(c) ΔH/-1893 = ΣB(reactants) - ΣB(products)
OR
ΔH/-1893 = ΣBonds broken - ΣBonds formed
OR
ΔH/-1893 = 2B(C-C) + 7B(C-H) + B(C-O) + B(O-H) + 4½ B(O=O) – 6B(C=O) – 8B(O-H)

Correct answer scores 3

1

-1893= 2B(C-C) + 7(412) + 360 + 463 + 4½(496) – 6(805) – 8(463)
OR
-1893= 2B(C-C) +5939 – 8534
OR
-1893= 2B(C-C) -2595
OR
2B(C-C) = 702

M2 also scores M1

May see no 463 in bonds broken and 7x463 in made (gives 5476 – 8071)

1

B(C-C) = (+)351(kJ mol^{-1})

*If **NOT** 351 check for AE. This would lose M2, but could gain M1 and M3*

(+)234 scores 1 (due to 3(C-C))

***NOT** M3 from incorrect M2 unless incorrect M2 is due to AE*

***IGNORE** units*

If no other mark awarded then

***ALLOW** 1 if 5939 or 5476 or 8534 or 8071 seen*

1

[9]

Q10.

(a) **M1 (could be scored by a correct mathematical expression)**

M1 $\underline{\Delta H = \sum \Delta H_f \textbf{ (products)} - \sum \Delta H_f \textbf{ (reactants)}}$
OR a <u>correct cycle of balanced equations</u>

M2 = 5(−635) − (−1560)

= − 3175 + 1560

(This also scores M1)

M3 = **<u>− 1615</u>** (kJ mol^{-1})
Award 1 mark ONLY for (+) 1615

*Correct answer to the calculation gains all of **M1**, **M2** and **M3***

Credit 1 mark for(+) 1615 (kJ mol^{-1})

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would*

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*score 2 marks (**M1** and **M2**)*

- *If no AE, check for a correct method; this requires either a correct cycle with V_2O_5 <u>and</u> 5CaO OR a clear statement of **M1** which could be in words and scores **<u>only M1</u>***

M4 Type of reaction is

- reduction
- redox
- (or accept) <u>V_2O_5 / it / V(V)</u> has been <u>reduced</u>

*In **M4** not "vanadium / V is reduced"*

M5 Major reason for expense of extraction − the answer must be about calcium

<u>Calcium is produced / extracted by electrolysis</u>
OR <u>calcium</u> is <u>expensive to extract</u>
OR <u>calcium extraction uses electricity</u>
OR <u>calcium extraction uses large amount of energy</u>
OR <u>calcium</u> is a (very) <u>reactive metal</u> / <u>reacts with water or air</u>
OR <u>calcium needs to be extracted / does not occur native</u>

QoL

Accept calcium is expensive "to produce" but not "to source, to get, to obtain, to buy" etc.

*In **M5** it is neither enough to say that calcium is "expensive" nor that calcium "must be purified"*

5

(b) **M1**

$2Al + Fe_2O_3 \longrightarrow 2Fe + Al_2O_3$

Ignore state symbols

Credit multiples of the equation

M2

(Change in oxidation state) <u>**0** to (+)**3**</u>
OR
(changed by) <u>**+3**</u>

*In **M2** if an explanation is given it must be correct and unambiguous*

2

(c) **M1**

$VCl_2 + H_2 \longrightarrow V + 2HCl$

*In **M1** credit multiples of the equation*

M2 and **M3**

Two hazards in either order

- <u>HCl / hydrogen chloride / hydrochloric acid is acidic / corrosive / toxic / poisonous</u>
- Explosion risk <u>with hydrogen</u> (gas) OR <u>H_2 is flammable</u>

*For **M2 / M3** there must be reference to hydrogen; it is not enough to refer simply to an explosion risk*

*For **M2 / M3** with HCl hazard, require reference to acid(ic) / corrosive / toxic <u>only</u>*

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M4
The only other product / the HCl is easily / readily <u>removed / lost / separated because it is a gas</u> *OR* <u>will escape</u> (or this idea strongly implied) <u>as a gas</u>
OR vanadium / it is the <u>only solid product</u> (and is easily separated)
OR vanadium / it is a <u>solid and the other product / HCl is a gas</u>

*In **M4** it is not enough to state simply that HCl is a gas, since this is in the question.*

4

[11]

Q11.

(a) (i) **3**Fe + Sb_2S_3 ⟶ **3**FeS + **2**Sb

Or multiples.
Ignore state symbols.

1

(ii) Fe ⟶ Fe^{2+} + $2e^-$

Ignore charge on the electron unless incorrect.
Or multiples.
Credit the electrons being subtracted on the LHS.
Ignore state symbols.

1

(b) (i) Sb_2S_3 + **4.5**O_2 ⟶ Sb_2O_3 + **3**SO_2

Or multiples.
Ignore state symbols.

1

(ii) SO_3 or sulfur trioxide / sulfur (VI) oxide

Credit also the following ONLY.
H_2SO_4 or sulfuric acid.
OR
Gypsum / $CaSO_4$ or plaster of Paris.

1

(c) (i) **M1 (could be scored by a correct mathematical expression)**

Correct answer gains full marks.

M1 <u>$\Delta H_r = \Sigma\Delta H_f$(**products**) − $\Sigma\Delta H_f$(**reactants**)</u>

OR a <u>correct cycle of balanced equations / correct numbers of moles</u>

Credit 1 mark for +104 (kJ mol^{-1}).

M2 = 2(+20) + 3(−394) − (−705) − 3(−111)

= 40 −1182 + 705 + 333

= −1142 − (−1038)

(This also scores M1)

M3 = **<u>−104</u>** (kJ mol^{-1})

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(Award 1 mark ONLY for + 104)

For other incorrect or incomplete answers, proceed as follows:

- *Check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks.*
- *If no AE, check for a correct method; this requires either a correct cycle with 3CO, 2Sb and $3CO_2$ OR a clear statement of **M1** which could be in words and scores **only M1**.*

3

(ii) It / Sb is <u>not in its standard state</u>

OR

<u>Standard state</u> (for Sb) <u>is solid / (s)</u>

OR

<u>(Sb) liquid is not its standard state</u>

Credit a correct definition of standard state as an alternative to the words 'standard state'.

QoL

1

(iii) Reduction **OR** reduced **OR** redox

1

(d) Low-grade ore extraction / it

- uses (cheap) <u>scrap / waste</u> <u>iron / steel</u>
- is a single-step process

uses / requires <u>less / low(er) energy</u>

Ignore references to temperature / heat or labour or technology.

1

[10]

Q12.

(a) ($Q = mc\Delta T$)

$= 50 \times 4.18 \times 27.3$

If incorrect (eg mass = 0.22 or 50.22 g) ***CE = 0 / 2***

1

= **5706 J** (accept 5700 and 5710)

Accept 5.7 kJ with correct unit. Ignore sign.

1

(b) M_r of 2-methylpropan-2-ol = 74(.0)

For incorrect M_r, lose M1 but mark on.

1

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Moles = mass / M_r

= 0.22 / 74(.0)

= **0.00297 moles**

1

ΔH = –5706 / (0.002970 × 1000)

= **–1921 (kJ mol^{-1})**

If 0.22 is used in part (a), answer = –8.45 kJ mol^{-1} scores 3

(Allow –1920, –1919)

If uses the value given (5580 J), answer = –1879 kJ mol^{-1} scores 3

Answer without working scores M3 only.

Do not penalise precision.

Lack of negative sign loses M3

1

(c) ΔH = ΣΔH products – ΣΔH reactants
OR a correct cycle

Correct answer with no working scores 1 mark only.

1

ΔH = −(−360) + (4 × −393) + (5 × −286)

M2 also implies M1 scored.

1

ΔH = **–2642** (kJ mol^{-1}) This answer only.

Allow 1 mark out of 3 for correct value with incorrect sign.

1

(d) (–2422 – part (b)) × 100 / –2422

Ignore negative sign.

Expect answers in region of 20.7

If error carried forward, 0.22 allow 99.7

If 5580 J used earlier, then allow 22.4

1

(e) Reduce the distance between the flame and the beaker / put a sleeve around the flame to protect from drafts / add a lid / use a copper calorimeter rather than a pyrex beaker / use a food calorimeter

Any reference to insulating material around the beaker must be on top.

Accept calibrate the equipment using an alcohol of known enthalpy of combustion.

1

(f) Incomplete combustion

1

[11]

Q13.

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(a) **M1 (could be scored by a correct mathematical expression**

*Correct answer to the calculation gains all of **M1**, **M2** and **M3***

M1 $\underline{\Delta H = \Sigma \Delta H_f \text{ (}\textbf{products}\text{)} - \Sigma \Delta H_f \text{ (}\textbf{reactants}\text{)}}$

Credit 1 mark for − 101 (kJ mol^{-1})

OR a correct cycle of balanced equations

M2 = − 1669 − 3(− 590)
= − 1669 + 1770
(This also scores M1)

M3 = **+ 101** (kJ mol^{-1})

Award 1 mark ONLY for − 101

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with 3Sr and 2Al OR a clear statement of **M1** which could be in words and scores **only M1***

M4 - Using powders
Any **one** from

- To increase collision frequency / collisions in a given time / rate of collisions
- To increase the surface contact / contact between the solids / contact between (exposed) particles

Ignore dividing final answer by 3

*Penalise **M4** for reference to molecules.*

5

M5 Major reason for expense of extraction
Any **one** from

- Aluminium is extracted by electrolysis ***OR*** aluminium extraction uses (large amounts of) electricity
- Reaction / process / It / the mixture requires heat
- It is endothermic

(b) Calcium has a higher melting point than strontium, because

Ignore general Group 2 statements.

Correct reference to size of cations / proximity of electrons
M1 (For Ca) delocalised electrons closer to cations / positive ions / atoms / nucleus
OR cations / positive ions / atoms are smaller
OR cation / positive ion / atom or it has fewer (electron) shells / levels

*Penalise **M1** if either of Ca or Sr is said to have more or less delocalised electrons OR the same nuclear charge.*

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Ignore reference to shielding.

Relative strength of metallic bonding
M2 (Ca) has stronger attraction between the cations / positive ions / atoms / nucleus and the delocalised electrons
OR
stronger metallic bonding

(assume argument refers to Ca but credit converse argument for Sr)

CE= 0 *for reference to molecules or Van der Waals forces or intermolecular forces or covalent bonds.*

2

(c) **M1** **2**Mg + O_2 ⟶ **2**MgO

M2 Mg + **2**H_2O ⟶ $Mg(OH)_2$ + H_2

Credit multiples of the equations.

M3 Magnesium hydroxide is used as an antacid / relieve indigestion (heartburn) / neutralise (stomach) acidity / laxative

Not simply "milk of magnesia" in ***M3***

3

[10]

Q14.

(a) (i) **M1 (could be scored by a correct mathematical expression which must have all Δ*H* symbols and the Σ or SUM)**

Correct answer gains full marks

Credit 1 mark ONLY if ***–122*** *(kJ mol^{-1})*

M1 $\Delta H = \Sigma\Delta H_f$ (**products**) - $\Sigma\Delta H_f$ (**reactants**)

OR a correct cycle of balanced equations

M2 $\Delta H = 3(-394) - 3(-111) - (-971)$
(This also scores M1)

M3 = **(+) 122**(kJ mol^{-1})

Award 1 mark ONLY for –122

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (****M1*** *and* ***M2****)*
- *If no AE, check for correct method; this requires either a correct cycle of balanced equations OR a clear statement of* ***M1*** *which could be in words and scores* ***M1 only***

3

(ii) By definition

Ignore reference to "standard state"

OR

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Because it is an element / elemental

1

(b) (i) $TiO_2 + \mathbf{2}Cl_2 + \mathbf{2}C \longrightarrow TiCl_4 + \mathbf{2}CO$

Allow multiples

OR

$TiO_2 + \mathbf{2}Cl_2 + C \longrightarrow TiCl_4CO_2$

Ignore state symbols

M1 use of Cl_2 and C

M2 a correct balanced equation

2

(ii) $TiCl_4 + \mathbf{4}Na \longrightarrow Ti + \mathbf{4}NaCl$

Allow multiples

OR

$TiCl_4 + \mathbf{2}Mg \longrightarrow Ti + \mathbf{2}MgCl_2$

Ignore state symbols

M1 use of Na ***OR*** Mg

M2 a correct balanced equation

2

(c) (i) $\mathbf{4}\,FeCr_2O_4 + \mathbf{8}\,Na_2CO_3 + \mathbf{7}O_2 \longrightarrow \mathbf{8}Na_2CrO_4 + 2Fe_2O_3 + 8CO_2$

Allow multiples

Ignore state symbols

1

(ii) $Cr_2O_3 + \mathbf{2}Al \longrightarrow Al_2O_3 + \mathbf{2}Cr$

Allow multiples

Ignore state symbols

1

[10]

Q15.

(a) The enthalpy change / heat (energy) change (at constant pressure) in a reaction is independent of the route / path taken (and depends only on the initial and final states)

Ignore the use of ΔH for enthalpy

1

(b) $\Delta H_{exp} + \Delta H_2 - \Delta H_1 = 0$

Any correct mathematical statement that uses all three terms

OR

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$\Delta H_{exp} + \Delta H_2 = \Delta H_1$ ***OR*** $\Delta H_1 = \Delta H_{exp} + \Delta H_2$

OR

$\Delta H_{exp} = \Delta H_1 - \Delta H_2$ ***OR*** $\Delta H_{exp} = \Delta H_1 + (- \Delta H_2)$

1

(c) $\Delta H_{exp} = \Delta H_1 - \Delta H_2$

$\Delta H_{exp} = -156 - 12 =$ ***−168*** *(kJ mol^{-1})*

Ignore units

Award the mark for the correct answer without any working

1

(d) (i) M1 q = m c ΔT OR calculation (25.0 x 4.18 x 14.0)

Award full marks for correct answer

M2 = **1463**J OR **1.46** kJ (This also scores **M1**)

*In **M1**, do not penalise incorrect cases in the formula*

M3 must have both the correct value within the range specified **<u>and</u>** the minus sign

*Penalise **M3** ONLY if correct numerical value but sign is incorrect; e.g. **+69.5 to +69.7 gains 2 marks** (ignore +70 after correct answer)*

For 0.0210 mol, therefore

$\Delta H_1 =$ **− 69.67** to **− 69.52** (kJ mol^{-1})

OR $\Delta H_1 =$ **− 69.7** to **− 69.5** (kJ mol^{-1})

*Penalise **M2** for arithmetic error but mark on*

Accept answers to 3sf or 4sf in the range − 69.7 to − 69.5

ΔT = 287, score q = m c ΔT only

Ignore -70 after correct answer

*If c = 4.81 (leads to 1684J) penalise **M2** ONLY and mark on for **M3** = <u>− 80.17</u> (range − 80.0 to − 80.2)*

Ignore incorrect units

3

(ii) The idea of <u>heat</u> loss

NOT impurity

OR

Incomplete reaction (of the copper sulfate)

NOT incompetence

OR

Not all the copper sulfate has dissolved

NOT incomplete combustion

1

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(e) Impossible to add / react the exact / precise amount of water

Not just "the reaction is incomplete"

OR

Very difficult to measure the temperature rise of a solid

OR

Difficult to prevent solid dissolving

OR

(Copper sulfate) solution will form

1

[8]

Q16.

(a) (Enthalpy change to) break the bond in 1 mol of chlorine (molecules)

Allow (enthalpy change to) convert 1 mol of chlorine molecules into atoms
Do not allow energy or heat instead of enthalpy, allow heat energy

1

To form (2 mol of) gaseous chlorine atoms / free radicals

Can score 2 marks for 'Enthalpy change for the reaction':
$Cl_2(g) \rightarrow 2Cl(g)$
Equation alone gains M2 only
Can only score M2 if 1 mol of chorine molecules used in M1 (otherwise it would be confused with atomisation enthalpy)
Any mention of ions, CE = 0

1

(b) (For atomisation) only 1 mol of chlorine atoms, not 2 mol (as in bond enthalpy) is formed / equation showing ½ mol chlorine giving 1 mol of atoms

Allow breaking of one bond gives two atoms
Allow the idea that atomisation involves formation of 1 mol of atoms not 2 mol
Allow the idea that atomisation of chlorine involves half the amount of molecules of chlorine as does dissociation
Any mention of ions, CE = 0

1

(c) (i) $\frac{1}{2}F_2(g) + \frac{1}{2}Cl_2(g) \rightarrow ClF(g)$

1

(ii) $\Delta H = \frac{1}{2}E(F–F) + \frac{1}{2}E(Cl–Cl) – E(Cl–F)$

Allow correct cycle

1

$E(Cl–F) = \frac{1}{2}E(F–F) + \frac{1}{2}E(Cl–Cl) - \Delta H$

$= 79 + 121 - (-56)$

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= 256 (kJ mol^{-1})

−256 scores zero

Ignore units even if wrong

1

(iii) ½Cl_2 + 3/2 F_2 → ClF_3

If equation is doubled CE=0 unless correcr answer gained by / 2 at end
This would score M1

1

ΔH = ½ E(Cl−Cl) + 3/2 E(F–F) − 3E(Cl−F)

= 121 + 237 − 768 / (or 3 × value from (c)(ii))

This also scores M1 (note = 358 − 768)

1

= −410 (kJ mol^{-1})

If given value of 223 used ans = −311
Allow 1 / 3 for +410 and +311

1

(iv) (Bond enthalpy of) Cl−F bond in ClF is different from that in ClF_3

Allow Cl-F bond (enthalpy) is different in different compounds (QoL)

1

(d) NaCl is ionic / not covalent

1

[11]

Q17.

(a) (i) **M1 (could be scored by a correct mathematical expression which must have**
all ΔH**symbols and the** $\sum$ or SUM)

M1 $\Delta H_r = \Sigma\Delta H_f$ **(products)** - $\Sigma\Delta H_f$ **(reactants)**

OR a correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$

M2 ΔH_r = – 201 + (– 242) – (– 394)
ΔH_r = – 201 – 242 + 394
ΔH_r = – 443 + 394
(This also scores M1)

M3 = – **49** (kJ mol^{-1})
(Award 1 mark ONLY for + 49)
Correct answer gains full marks
Credit 1 mark ONLY for + 49 (kJ mol^{-1})
For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires*

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either

correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$

*OR a clear statement of **M1** which could be in words*

and

*scores only **M1***

3

(ii) It is an element / elemental

Ignore reference to "standard state"

OR

By definition

1

(b) **M1** (The yield) increases / goes up / gets more

*If M1 is given as "decreases" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank M1*

M2 There are more moles / molecules (of gas) on the left / of reactants
OR fewer moles / molecules (of gas) on the right
/ products
OR there are 4 moles /molecules (of gas) on the left and 2 moles / molecules on the right.
OR (equilibrium) shifts / moves to the side with less moles / molecules

*Ignore "volumes", "particles" "atoms" and "species" for **M2***

M3: Can only score M3 if M2 is correct

The (position of) equilibrium shifts / moves (from left to right) to oppose the increase in pressure

*For **M3**, not simply "to oppose the change"*

*For **M3** credit the equilibrium shifts / moves (to right) to lower / decrease the pressure*

(There must be a specific reference to the change that is opposed)

3

(c) **M1** Yield increases goes up

M2 The (forward) reaction / to the right is endothermic OR takes in/ absorbs heat

OR

The reverse reaction / to the left is exothermic OR gives out / releases heat

*If M1 is given as "decrease" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank **M1***

Can only score M3 if M2 is correct

M3 The (position of) equilibrium shifts / moves (from left to right) to oppose the increase
in temperature **(QoL)**

*For **M3**, not simply "to oppose the change"*

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*For **M3**, credit the (position of) equilibrium shifts / moves **(QoL)***

*to absorb the heat **OR***

*to cool the reaction **OR***

to lower the temperature

(There must be a specific reference to the change that is opposed)

3

(d) (i) An activity which has no net / overall (annual) carbon emissions to the atmosphere

OR

An activity which has no net / overall (annual) greenhouse gas emissions to the atmosphere.

OR

There is no change in the total amount / level of carbon dioxide /CO_2 carbon /greenhouse gas present in the atmosphere.

The idea that the carbon /CO_2 given out equals the carbon /CO_2 that was taken in from the atmosphere

1

(ii) CH_3OH + **1**½ O_2 CO_2 + **2**H_2O

Ignore state symbols

Accept multiples

1

(iii) **3**H_2 + **1**½ O_2 **3**H_2O

Ignore state symbols

OR

Accept multiples

2H_2 + O_2 **2**H_2O

Extra species must be crossed through

1

(e) **M1** $q = m\ c\ \Delta T$

Award full marks for correct answer

Ignore the case for each letter

OR $q = 140 \times 4.18 \times 7.5$

M2 = 4389 (J) OR 4.389 (kJ) OR 4.39 (kJ) OR 4.4 (kJ)(also scores M1)

M3 Using 0.0110 mol
therefore ΔH = **– 399** ($kJmol^{-1}$)
OR **– 400**

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect; +399 **gains 2 marks***

*Penalise **M2** for arithmetic error and mark on*

*In **M1**, do not penalise incorrect cases in the formula*

If $\Delta T = 280.5$; score $q = m\ c\ \Delta T$ only

*If c = 4.81 (leads to 5050.5) penalise **M2** ONLY and mark on for **M3** = – 459*

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+399 or +400 gains 2 marks

Ignore incorrect units

3

[16]

Q18.

(a) (i) reduction **OR** reduced **OR** redox ***OR*** reduction–oxidation

Not "oxidation" alone

1

(ii) Fe^{3+} + **3**e^- ⟶ Fe

Ignore state symbols

Do not penalise absence of charge on electron

Credit Fe^{3+} ⟶ *Fe – **3**e^-*

Credit multiples

1

(b) (i) **Because (one of the following)**

CO is not the only product ***OR***

Reference to "incomplete combustion to form CO" does not answer the question

(Some) complete combustion (also)occurs ***OR***

CO_2 is (also) formed

Further oxidation occurs

1

(ii) The <u>enthalpy change</u> / <u>heat (energy) change at constant pressure</u> in a reaction is <u>independent of the route / path taken</u> (and depends only on the initial and final states)

1

(iii) **M1** The <u>enthalpy change</u> / <u>heat change at constant pressure</u> when <u>1 mol</u> of a compound / substance / element

For M1, credit correct reference to molecule/s or atom/s

M2 is <u>burned completely</u> / <u>undergoes complete combustion</u> in (excess) <u>oxygen</u>

M3 with <u>all reactants and products / all substances in standard states</u>

For M3

Ignore reference to 1 atmosphere

OR <u>all reactants and products / all substances in normal / specified states under standard conditions</u> / 100 kPa / 1 bar <u>and</u> specified T / 298 K

3

(c) **M1 (could be scored by a correct mathematical expression which <u>must</u> have <u>all</u> ΔH symbols and the $\sum$)**

Correct answer gains full marks

Credit 1 mark ONLY for –1 (kJ mol^{-1})

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M1 $\Delta H_r = \sum \Delta H_f$ (**products**) – $\sum \Delta H_f$ (**reactants**)

Credit 1 mark ONLY for – 27 (kJ mol^{-1}) i.e. assuming value for Fe(l) = 0

OR correct cycle of balanced equations with 2Fe, 3C and $3O_2$

M2 ΔH_r = 2(+14) + 3(– 394) – (– 822) – 3(–111)

= 28 –1182 + 822 + 333

(This also scores M1)

M3 = **(+) 1** (kJ mol^{-1})

(Award 1 mark ONLY for – 1)

(Award 1 mark ONLY for – 27)

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (M1 and M2)*
- *If no AE, check for a correct method; this requires either a correct cycle with 2Fe, 3C and $3O_2$ OR a clear statement of M1 which could be in words and scores only M1*

3

(d) (i) C(s) + O_2(g) CO_2(g)

State symbols essential

Possible to include C(s, graphite)

1

(ii) These two enthalpy changes are for the same reaction / same equation / same reactants and products

Penalise reference to CO_2 being produced by a different route

OR

They both make one mole of carbon dioxide only from carbon and oxygen (or this idea clearly implied)

"both form CO_2" is not sufficient (since other products might occur e.g.CO)

OR

The same number and same type of bonds are broken and formed

1

[12]

Q19.

(a) One from

- Ti is not produced

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- TiC / carbide is produced OR titanium reacts with carbon
- Product is brittle
- Product is a poor engineering material

Penalise ''titanium carbonate''

Ignore ''impure titanium''

Credit ''titanium is brittle''

1

(b) Heat (energy) change at constant pressure

QoL

1

(c) The enthalpy change in a reaction is independent of the route taken (and depends only on the initial and final states)

Credit ''heat change at constant pressure'' as an alternative to ''enthalpy change''

1

(d) **M1** The enthalpy change / heat change at constant pressure when 1 mol of a compound / substance / product

For M1, credit correct reference to molecule/s or atom/s

M2 is formed from its (constituent) elements

M3 with all reactants and products / all substances in standard states

OR all reactants and products / all substances in normal states under standard conditions / 100 kPa / 1 bar and any specified T (usually 298 K)

Ignore reference to 1 atmosphere

3

(e) (i) Na / it is not in its standard state / normal state under standard conditions

OR

Standard state / normal state under standard conditions for Na is solid / (s)

QoL

Ignore ''sodium is a liquid or sodium is not a solid''

1

(ii) **M1** $\Delta H_r = \sum \Delta H_f$ **(products)** $- \sum \Delta H_f$ **(reactants)**

M2 $\Delta H_r = 4(-411) - (-720) - 4(+3)$
$= -1644 + 720 - 12$
(This also scores M1)

M3 $= \mathbf{-936}$ (kJ mol^{-1})

Correct answer gains full marks

Credit 1 mark for + 936 *(kJ mol^{-1})*

Credit 1 mark for – 924 *(kJ mol^{-1})*

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i.e. assuming value for Na(l) = 0

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (M1 and M2)*
- *If no AE, check for a correct method; this requires* ***either*** *a correct cycle with $2Cl_2$ and 4Na OR a* ***clear complete statement*** *of M1 which could be in words and scores only M1*

3

(iii) Reducing agent

Ignore "reduces titanium"

OR reductant OR reduces $TiCl_4$

OR electron donor

1

[7]

Q20.

(a) Heat (energy) change at constant pressure

Ignore references to standard conditions, but credit specified pressure.

1

(b) The enthalpy change/heat (energy) change (at constant pressure) in a reaction is independent of the route/path taken (and depends only on the initial and final states)

1

(c) $\Delta H + 963 = -75 - 432$ OR $\Delta H + 963 = -507$ (**M1**)

$\Delta H = -75 - 432 - 963$ (**M1** and **M2**)

$\Delta H =$ **-1470** ($kJ\ mol^{-1}$)

Award 1 mark for + 1470

Award full marks for correct answer

Ignore units.

Ignore numbers on the cycle

M1 *and* ***M2*** *can score for an arithmetic error*

3

[5]

Q21.

(a) (i) **M1** The enthalpy change / heat change at constant pressure when 1 mol of a compound / substance / product

1

M2 Is formed from its (constituent) elements

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1

M3 With all reactants and products / all substances in standard states
OR
All reactants and products / all substances in normal states under standard conditions / 100 kPa / 1 bar and specified T / 298 K
Ignore reference to 1 atmosphere

1

(ii) By definition
OR
Because they are elements

1

(iii) **M1** $\Delta H_f = \Sigma \Delta H_f$ **(products)** – $\Sigma \Delta H_f$ **(reactants)**

1

M2 = –1669 – 3(–558)
(This also scores M1)

1

M3 = **(+) 5** (kJ mol^{-1})
Correct answer gains full marks.
Assume the value is positive unless specifically stated as negative.
Credit 1 mark if – 5 (kJ mol^{-1}).
For other incorrect or incomplete answers, proceed as follows:
- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (M1 and M2)*
- *If no AE, check for a correct method; this requires either a correct cycle with 3BaO OR a clear statement of M1 which could be in words and scores <u>only M1</u>*

1

(b) (i) *One from*

- <u>Aluminium is expensive</u> (to extract *OR* due to electrolysis)
- <u>High energy cost</u>
- The <u>cost of heating strongly</u>
  This requires a clear statement about <u>cost</u>

1

(ii) *One from*

- <u>increase collision frequency</u>
- OR <u>more collisions</u>
- OR <u>more chance of colliding</u>
  The answer MUST refer to <u>more collisions</u>.
  Ignore "more available to collide"

1

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(c) (i) $Ba + \mathbf{2}H_2O \rightarrow Ba(OH)_2 + H_2$

Ignore state symbols
Allow multiples and correct ionic equations

1

(ii) **M1** $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$
(or the ions together)

Allow crossed out Na^+ ions, but penalise if not crossed out

1

M2 White precipitate / white solid

Ignore state symbols
Ignore "milky"

1

(iii) **M1** Barium meal or (internal) X-ray or to block X-rays

1

M2 $BaSO_4$ / barium sulfate is insoluble (and therefore not toxic)

Accept a correct reference to M1 written in the explanation in M2, unless contradictory.

For M2 NOT barium ions
NOT barium
NOT barium meal and NOT "It".

Ignore radio-tracing.

1

[14]

Q22.

(a) The enthalpy change when 1 mol of a compound

1

is completely burnt in oxygen

1

under standard conditions, or 298K and 100kPA

1

(b) (i) $C_2H_6 + 3½O_2 \rightarrow 2CO_2 + 3H_2O$

1

(ii) $\Delta H = 2 \times \Delta H_f^{\ominus} (CO_2) + 3 \times \Delta H_f^{\ominus} (H_2O) - \Delta H_f^{\ominus} (C_2H_6)$

1

$= -788 - 858 - (-85)$

1

$= -1561$ kJ mol^{-1}

1

(c) moles methane = $\frac{0.10}{16} = 6.25 \times 10^{-3}$

1

kJ evolved = $6.25 \times 10^{-3} \times 890 = 5.56$

1

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5.56×10^3 joules = (mc)ΔT

1

$\Delta T = \frac{5.56 \times 10^3}{120}$ = 46.4 K

1

[11]

Q23.

(a) Enthalpy change when 1 mol of compound (1)

Is formed from it's elements (1)

All substances in their standard state (1)

3

(b) $\Delta H = \Sigma \Delta H^{\ominus}c$ (reactants) – $\Sigma \Delta H^{\ominus}c$ (products) (1)

= (7*x* – 394) + (4 *x* – 286) – (– 3909) (1)

= + 7 kJmol^{-1} (1)

3

(c) Heat change = m c Δ*T* (1)

= 250 × 4.18 × 60 = 62700J = 62.7kJ (1)

Moles C_7H_8 = 2.5 /92 = 0.0272 (1)

ΔH = 62.7 / 0.0272 = – 2307 kJ mol^{-1} (1)
(allow –2300 to –2323)

4

(d) Mass of water heated = 25 + 50 = 75g
Temp rise = 26.5 – 18 = 8.5 °C
*both for **(1)** mark*

Heat change = 75 × 4.18 × 8.5 = 2665 J = 2.665 kJ (1)

Moles HCl = 0.05 (1)

Δ*H* = – 2.665 / 0.05 = –53.3 kJmol^{-1} (1)
(allow –53 to –54)

4

(e) Less heat loss (1)

1

[15]

Q24.

(a) enthalpy change/ heat energy change when 1 mol of a substance

1

is completely burned in oxygen

1

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at 298K and 100 kPa or standard conditions

1

(not 1atm)

(b) $\Delta H = \sum$ bonds broken – $\sum$ bonds formed

1

= (6 × 412) + 612 +348 + (4.5 × 496) – ((6 × 743) + (6 × 463))

1

= – 1572 kJ mol^{-1}

1

(c) by definition ΔH_f is formation from an element

1

(d) $\Delta H_c = \sum \Delta H_f$ products -$\sum \Delta H_f$ reactants or cycle

1

= (3 × – 394) + (3 × –242) – (+20)

1

= − 1928 kJ mol^{-1}

1

(e) bond enthalpies are mean/average values

1

from a range of compounds

1

[12]

Q25.

(a) enthalpy (or energy) to break (or dissociate) a bond;

1

averaged over different molecules (environments);

1

enthalpy (or heat energy) change when one mole of a compound;

1

is formed from its elements;

1

in their standard states;

1

(b) enthalpy change = Σ(bonds broken) – Σ(bonds formed) or cycle;

1

= 4 × 388 +163 + 2 × 146 + 4 × 463 – (944 + 8 × 463);
(or similar)

1

= –789;

(+ 789 scores 1 only)

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1

(c) (i) zero;

1

(ii) $\Delta H = \Sigma$ (enthalpies of formation of products) $-\Sigma$ (enthalpies of formation of reactants)

1

= 4 × –242-(75 + 2 × –133);

1

= –777;

(+ 777 scores one only)

1

(d) mean bond enthalpies are not exact

(or indication that actual values are different from real values)

1

[13]

Q26.

(a) (i) <u>enthalpy change</u> when 1 mol of a substance (or compound) (QL mark)

1

is (completely) burned in oxygen (or reacted in <u>excess</u> oxygen)

1

at 298 K and 100 kPa (or under standard conditions)

1

(ii) heat produced = mass of water × Sp heat capacity $x\Delta T$ (or $mc\Delta T$)

1

= 150 × 4.18 × 64 (note if mass = 2.12 lose first 2 marks then conseq) = 40100 J or = 40.1 kJ (allow 39.9 - 40.2 must have correct units)

1

moles methanol = mass/M_r = 2.12/32 (1)
= 0.0663

1

ΔH = – 40.1/0.0663 = – 605 kJ (mol^{-1})

1

(allow –602 to –608 or answer in J)

(note allow conseq marking after all mistakes but note use of 2.12 g loses 2 marks

(b) (i) equilibrium shifts to left at high pressure

1

because position of equilibrium moves to favour fewer moles (of gas)

1

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(ii) at high <u>temperature</u> reaction yield is low (or at low *T* yield is high)

1

at low <u>temperature</u> reaction is slow (or at high *T* reaction is fast)

1

therefore use a balance (or compromise) between <u>rate</u> and <u>yield</u>

1

(c) $\Delta H = \Sigma \Delta H_c^{\ominus}$(reactants) – $\Sigma \Delta H_c^{\ominus}$(products) (or correct cycle)

1

$\Delta H_c^{\ominus}(CH_3OH) = \Delta H_c^{\ominus}(CO) + 2 \times \Delta H_c^{\ominus}(H_2) - \Delta H$

1

= (–283) + (2 × –286) – (–91) (mark for previous equation or this)
= –764 (kJ mol^{-1}) (*units not essential but lose mark if units wrong)*
(note + 764 scores 1/3)

1

[15]

Q27.

B

[1]

Q28.

A

[1]

Q29.

(a) $\Delta H = \Sigma$(bonds broken) – Σ(bonds formed) (or cycle)

1

= +146 – 496/2 (or 2 × 463 + 146 –(2 × 463 + 496/2)

1

= – 102 (kJ mol^{-1}) **(1)**
*(accept no units, wrong units loses a mark; +102 scores **(1)** only)*

1

(b) $C(s) + 2H_2(g) \rightarrow CH_4(g)$ equation **(1)** Correct state symbols **(1)**

2

(c) (i) Macromolecular
(accept giant molecule or carbon has many (4) bonds)

1

(ii) $\Delta H = \Sigma \Delta H_f$(products) – $\Sigma \Delta H_f$(reactants) (or cycle)

1

= 715 + 4 × 218 – (–74.9)

1

= 1662 (kJ mol^{-1})

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(accept no units, wrong units loses one mark, allow 1660 to 1663, –1662 scores one mark only)

1

(iii) 1662/4 = 415.5

(mark is for divide by four, allow if answer to (c)(ii) is wrong)

1

[10]

Q30.

(a) (i) Δ*H* atomisation/sublimation of magnesium

1

(ii) Bond/dissociation enthalpy of Cl-Cl

OR 2 × *H* atomisation of chlorine

1

(iii) Second ionisation enthalpy of magnesium

1

(iv) 2 × electron affinity of chlorine

1

(v) Lattice formation enthalpy of $MgCl_2$

1

(b) Equation $2MgCl(s) \rightarrow MgCl_2(s) + Mg(s)$

State symbols not required but penalise if incorrect

1

Calculation ΔH reaction = $\Sigma\Delta H_f$ products – $\Sigma\Delta H_f$ reactants

1

= – 653 – (2 × –133)

1

= – 427 ($kJmol^{-1}$)

Allow +427 to score (1) mark

Other answers; award (1) for a correct Δ H reaction expression

1

(c) ΔH soln $MgCl_2$ = – ΔH Lat.form. + ΔH hyd.Mg^{2+} + 2ΔH hyd.Cl^-

1

or cycle
= 2502 – 1920 – (2 × 364)

1

= – 146 ($kJmol^{-1}$)

Allow + 146 to score (1) mark

Other answers; award (1) for a correct ΔH soln $MgCl_2$ expression/cycle

1

[12]

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Q31.

(a) *M1* $K_p = (_PY)^3 . (_PZ)^2 / (_PW)^2 . (_PX)$ *NB [ ] wrong* **1**

M2 temperature **1**

M3 increase **1**

M4 particles have more energy or greater velocity/speed **1**

M5 more collisions with $E > E_a$ or more successful collisions **1**

M6 Reaction exothermic or converse **1**

M7 Equilibrium moves in the left **1**

Marks for other answers

Increase in pressure or concentration	*allow M1, M5, M6*	*Max 3*
Addition of a catalyst;	*allow M1, M5, M6*	*Max 3*
Decrease in temperature;	*allow M1, M2, M6*	*Max 3*
Two or more changes made;	*allow M1, M6*	*Max 2*

(b) (i) Advantage; reaction goes to completion, not reversible or faster **1**

Disadvantage; reaction vigorous/dangerous

(exothermic must be qualified)

or HCl(g) evolved/toxic
or CH_3COCl expensive

NB Allow converse answers
Do not allow reactions with other reagents e.g. water or ease of separation **1**

(ii) $\Delta S = \Sigma S$ products $- \Sigma S$ reactants **1**

$\Delta S = (259 + 187) - (201 + 161)$ **1**

$\Delta S = 84$ (JK^{-1} mol^{-1}) *(Ignore units)*
*Allow – 84 to score **(1)** mark* **1**

$\Delta G = \Delta H - T\Delta S$ **1**

$= -21.6 - 298 \times 84/1000$
$= -46.6$ kJ mol^{-1} or $-46\,600$ J mol^{-1} **1**

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*Allow **(2)** for – 46.6 without units*
(Mark ΔG consequentially to incorrect ΔS)
(e.g. ΔS = –84 gives ΔG = +3.4 kJ mol^{-1})

1

[15]

Q32.

D

[1]

Q33.

C

[1]

Q34.

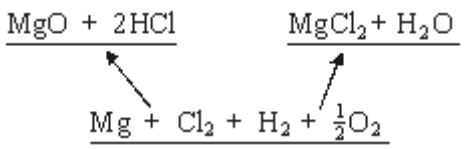
(a) (i) enthalpy (or heat or heat energy) change when
1 mol of a substance **(1)** (QL mark) is formed from its elements **(1)**
all substances in their standard states **(1) (**or normal states at 298K, 100 kPa or std condits)

***not** STP, NTP*

3

(b) enthalpy change (or enthalpy of reaction) is independent of route **(1)**

$\Delta H = \Sigma\Delta H_f^{\ominus}$ prods - $\Sigma\Delta H_f^{\ominus}$ reactants (or cycle) **(1)**
minimum correct cycle is:



ΔH = -642 – 286 – (–602 + 2 × –92) **(1)**
= –142 (kJ mol^{-1}) **(1)**

penalise this mark for wrong units
+142 scores 1 mark out of the last three

4

(c) $\Delta H = mcT$ **(1)** (or $mc\Delta T$)
= 50 × 4.2 × 32 = 6720 J = 6.72J **(1)**

mark is for 6720 J or 6.72 kJ

$$\text{moles HCl} = \frac{\text{vol}}{1000} \times \text{conc} = \frac{50}{1000} \times 3$$ **(1)**

= 0.15 **(1)**

if error here mark on conseq.

Therefore moles of MgO reacted = moles HCl/2 **(1)**

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(mark is for/2, CE if not/2)
= 0.15/2 = 0.075

Therefore ΔH = 6.72/0.075 **(1)**
= –90 kJ (mol^{-1})
kJ must be given, allow 89 to 91
*value **(1)***
*sign **(1)**; this mark can be given despite CE for /2*

8

Note various combinations of answers to part (c) score as follows:

–89 to –91 kJ **(8)** (or –89000 to 91000J)
*no units **(7)***

+89 to +91 kJ **(7)** (or + 89000 to +91000J)
*no units **(6)***

–44 to –46 kJ **(5)** (or -44000 to -46000J)
*no units **(4)** if units after 6.72 or 6720 (5)*

+44 to +46 kJ **(4)** (or +44000 to + 46000)
if no units and
*if no units after 6.72 or 6720 **(3)***
*otherwise check, could be **(4)***

[15]

Q35.

(a) *Standard enthalpy change, $\Delta H^{\ominus}$*: $\Delta H_R = \Sigma\Delta H_{f\text{products}} - \Sigma\Delta H_{f\text{reactants}}$ **(1)**
or cycle

ΔH_R = (0 + [2 × –242]) – (4 × –92) **(1)**
= -484 + 368
= –116 (kJ mol^{-1})
Allow max 1 for +116

Standard entropy change, $\Delta S^{\ominus}$: $\Delta S = \Sigma\Delta H_{f\ products} - \Sigma\Delta H_{f\ reactants}$

ΔS = ([2 × 223] + [2 × 189]) - (205 + [4 × 187]) **(1)**

= 824 – 953

= –129 (J K^{-1} mol^{-1})
allow max one for +129

6

(b) (i) *Effect*: Equilibrium displaced to right / to products **(1)**
Explanation: Reaction is endothermic **(1)**
Constraint reduced **(1)**
mark separately

(ii) Feasible when $\Delta G \leq 0$ **(1)**

$\Delta G = \Delta H - T\Delta S$ **(1)**

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T = $\Delta H/\Delta S$ = 208 × 1000 **(1)** / 253

= 822 K **(1)**

7

[13]

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Q1.

(a) This was answered well – nearly all students (83.8%) were able to state two correct oxidation states.

(b) Very few students were able give the first half-equation for the oxidation of chlorine whereas the second half-equation was more regularly correct.

(c) Only some students (23.1%) were able to recall this equation from the specification.

(d) Some students successfully calculated the mass of potassium iodide. However, many did not appreciate that this reaction was not 1:1 and so used the incorrect reacting ratio in their calculations. Many students stated incorrectly that the iodine formed would be observed as purple fumes or as a purple solution. This question discriminated particularly well.

(e) Most students were able both to write the correct equation and calculate the enthalpy change. Only 8.4% of students were unable to score at least one mark.

Q2.

Just over a third of students calculated the correct answer of +112 kJ mol^{-1}, but almost as many students gave –112 kJ mol^{-1}. A possible reason for this wrong answer is that students may use summary equations in calculations such as these and may be uncertain whether these involve (products – reactants) or (reactants – products).

Q3.

(a) This was poorly answered, with many students missing state symbols and balancing the equation incorrectly. Only the best students (24.6%) gained the mark here.

(b) This proved challenging compared to questions set in the previous specification from this topic area. 34.3% of students failed to pick up even one mark.

(c) Again challenging for all but the best students, only 26.3% scored more than one mark.

(d) This was not as well answered as might have been expected. The fact that mean bond enthalpies are calculated using a range of compounds was not well understood.

Q4.

(a) This proved to be a much tougher starter question than had been anticipated, with only 12% of students earning the mark. Students did not recognise that enthalpy change could not be measured directly. In this case, the enthalpy change was for the formation of a hydrated salt from an anhydrous one, with the expected answer being that it would be impossible to prevent some salt dissolving during the addition of water to the anhydrous salt. An alternative answer, related to the difficulty in measuring the temperature of a solid, was also allowed.

Some students' answers revealed confusion between calorimetry and colorimetry, with suggested answers including the lack of colour change during the reaction. Some students also seemed to believe that calorimetry is only possible if something

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is being burned.

(b) This calculation was answered reasonably well, with less than 20% of students failing to score. There was confusion about the 'direction' around the Hess Cycle, and evidence of many students thinking that an equation of the form $\Delta H = \Sigma \Delta H_f$(products) - $\Sigma \Delta H_f$(reactants) can be used universally, when it only applies to the specific use of enthalpies of formation.

(c) Most students' encounter with this 'extended response' style of question produced a good spread of marks, although 37% of students failed to score. This was usually due to a completely inappropriate method being described, with incorrect answers such as: "making a solution of magnesium chloride", "using it to fill a spirit burner and lighting it under a beaker of water" and "putting a solution of magnesium chloride in a polystyrene cup and heating it over a Bunsen burner". Other incorrect answers included descriptions of the preparation of a standard solution followed by a titration and the addition of magnesium chloride to acid instead of to water.

This question was marked using a 'levels of response' mark scheme. The key to success was for students to concentrate first on the inclusion of as much correct chemistry as possible to ensure access to Level 3 (worth 5 or 6 marks). Within a level, the mark awarded depended on the clarity and coherence of an answer, together with a clear, logical progression through the description. Appropriate apparatus and quantities should have been mentioned as necessary. For example, rather than writing 'add water to a container', a good start to the answer would be to write 'A measuring cylinder was used to measure 50 cm^3 of water into a polystyrene cup'.

Despite the fact that many students suggested in part (a), that it is difficult to measure the temperature of a solid, many then suggested putting the magnesium chloride into the polystyrene cup first and then recording its initial temperature, before adding the water.

(d) This was a challenging question, but one for which it proved relatively easy to score two marks; nearly 20% of students scored full marks here. Most students could successfully plot the points and draw a best fit line, although the negative scale on the y-axis confused some. Most students were also able to calculate the gradient of their line, although, as mentioned previously, it was not always clear what their suggested answer was. The calculation of ΔS proved trickier, with many trying to use the relationship $\Delta G = \Delta H - T\Delta S$, and either ignoring their calculated gradient or substituting it in for ΔH. Relatively few students recognised that this equation can be taken as $y = mx + c$ ($y = c - xm$ in this case) so that this graph of ΔG (y) vs T (x) gives a straight line with a gradient of $-\Delta S$.

Q9.

Two-thirds of the marks in this enthalpy-based question involved students being able to carry out calculations based on Hess' Law and, as always, there was a divide between those who could cope with such questions and those who couldn't.

In part (a) the importance of learning definitions was illustrated. Many students failed to make clear that <u>all</u> reactants and products need to be in their standard states.

In questions such as part (b) students are strongly advised to start with a clear and complete indication of the expression relating the enthalpy change of the reaction to the data given or to draw out a clearly labelled cycle. Students who relied on the use of a learned expression often got this wrong way round, possibly due to confusion with the use of enthalpies of formation whereas, in this case, the data provided were enthalpies of

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combustion.

In a question like part (c) students are strongly advised to sketch out the displayed formulae of all reactants and products when working with bond energies. Failing to do so in many cases meant that bonds were omitted or miscounted (3 × C-C in propan-1-ol was often seen) by students.

Q10.

This question provided a range of challenges. The calculation in part (a) was answered well and the necessity to focus on either the extraction or the reactivity of calcium was understood by many. In part (b), many students were unable to write a correct formula either for iron(III) oxide or for aluminium oxide and there was often a lack of clarity when stating the change in oxidation state of aluminium in this reaction. The equation in part (c) was generally done well and many students correctly linked an appropriate hazard to each of hydrogen and hydrogen chloride. The idea that the HCl could escape as a gas and the only other product was vanadium, was necessary to gain the final mark.

Q11.

Too many students had problems writing and balancing the equations in each of parts (a)(i), (a)(ii) and (b)(i). The calculation in part (c)(i) was straightforward and most students scored all 3 marks although errors were seen in simple mathematical operations. The remainder of the question was also relatively high scoring.

Q12.

(a) This part was mostly well answered, with the exception of those who chose to use the wrong mass.

(b) In this part, failure to give the negative sign was the most common error where students did not score full marks.

(c) This part was usually done very well.

(d) In contrast, this part was very poorly answered, almost always because –2642 was used from (c) rather than their answer to (b).

(e) Many vague answers were seen in response to this part. Simply adding insulation was insufficient and use of a polystyrene cup was wrong in this situation.

(f) The idea of incomplete combustion seemed to be poorly understood in this part, with quite a few students stating that 'not all the alcohol had burned'. Comments about heat loss etc were disqualified by the question.

Q13.

The whole of this question was relatively straightforward and it was pleasing to see the majority of students gain at least 3 marks in part (a) and over 40% gain both marks in part (b).

In part (c), too many students failed to balance their equations or could not write the correct formula for magnesium hydroxide. Fewer than half of all students gained all three marks.

Q14.

The calculation in part (a)(i) was high scoring with 72% gaining full marks and incorrect answers from the remainder due either to simple arithmetic errors or to chemical errors. In parts (b) and (c), incorrect chemical formulae were relatively common.

Q15.

Almost 85% of students were able to give a correct statement for Hess's Law and then attempted to apply it in parts (b) and (c), with over 70% success. No credit was given for a value calculated in part (c), consequent on an incorrect expression in part (b), since that is a chemical error.

Part (d) was generally well-answered although the negative sign was often missed in the answer leading to only 35% gaining all three marks. Only 7% were able to deduce a correct answer to part (e).

Q16.

Answers to this question were disappointingly poor. In part (a), there was not much evidence that the precise meaning of the term **bond dissociation enthalpy** was understood or had been learned. Only 20% of students scored both marks and over 50% scored zero. This enthalpy change refers to the conversion of one mole of chlorine gas into two moles of chlorine atoms but this was not usually stated. Answers to part (b) did not usually convey the understanding that this process is exactly the same as bond dissociation but that it involves only half a mole of chlorine gas. There was also confusion between chlorine molecules, chlorine atoms and chloride ions. Part (c)(i) was answered better but many answers were incorrect because they did not show chlorine and fluorine molecules. In part (c)(iii), many students used incorrect cycles or formulae and obtained an exothermic rather than an endothermic answer. In part (c)(iv), most students did not read or did not understand the question. A statement that bond enthalpies are obtained by averaging values from different compounds may be a correct statement but it is not an answer to the question.

Q17.

The standard enthalpy change calculation in part (a) was straightforward and high scoring. In parts (b) and (c), good discrimination occurred and a great many well–articulated responses were seen. It is worth noting that no marks were scored in either of parts (b) or (c), if the effect on the yield was assigned incorrectly. The meaning of *carbon–neutral* in part (d) is spelled out in the specification and needs to refer to <u>net</u> emissions of carbon dioxide to the atmosphere. Parts (d)(ii) and (d)(iii) were challenging and only the best students were able to arrive at the equation for the overall reaction between hydrogen and oxygen to make water. Most students scored at least one mark in part (e); the commonest error was a failure to give the final answer a negative sign for this exothermic process.

Q18.

The thinking required in part (b)(i) proved too much for many and only a few were able to state that, in practice, CO is not the only product and that some complete combustion to form CO_2 would occur. The answer of +1 kJ mol^{-1} was seen frequently in part (c), but some were disconcerted by this value and sought to find an alternative. State symbols were often missed in part (d)(i) and a clear statement in part (d)(ii) that the same reaction occurs for the two specified standard enthalpies was not well understood.

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Q19.

Overall, this was a relatively high-scoring question although only 26% of the candidates stated that enthalpy change is the heat change at constant pressure in part (b). Definitions continue to be learned poorly by a proportion of candidates and 15% of candidates failed to score any marks in part (d).

Q20.

Only 20% of the candidates stated that enthalpy change is the heat change at constant pressure, even though this is stated clearly in the specification. It was pleasing to see that more than half the candidates could correctly apply Hess's Law to an unfamiliar cycle and arrive at the right answer for the specified enthalpy change.

Q21.

The range of answers given to the meaning of the term *standard enthalpy of formation* in part (a)(i) indicated the variation in the ability of the candidates to learn basic information. Application of that information in the remainder of part (a) was generally well done, although too many candidates had their data the wrong way around in part (a)(iii).

Part (b) was answered correctly by approximately half of the candidates and there were some good answers in each section of part (c). The ability to construct and balance equations, including the simplest ionic equation in part (c)(ii), was made impossible for those candidates who did not know that Ba^{2+} is the formula of the barium ion.

Q23.

Part (a) was generally well done by most candidates. The most common error was not referring to standard states. The calculation in part (b) proved more demanding for students than some previous enthalpy calculations with many candidates giving the incorrect answer of –7kJmor\ A large number of candidates did not give the correct mass or correct temperature rise in part (c) and therefore only scored the mark for the $Q = mc\Delta t$ equation. Many of the candidates who did calculate the heat evolved then failed to calculate molar quantities. The calculation in part (d) proved very difficult for candidates with very few scoring full marks. Common errors were incorrect mass, incorrect temperature rise and lack of conversion to molar quantities. Candidates should know that exothermic reactions are shown by a negative sign e.g. $–53.3kJmol^{-1}$. In part (e) many candidates failed to make the comparison regarding heat loss between the two experiments.

Q24.

More able candidates were able to obtain high marks in this question but the weaker candidates found the calculations difficult. The definition in (a) was usually attempted well with the majority of candidates scoring 3 marks. Answers to (b) discriminated between candidates. There were several arithmetic errors in the calculation, and a few candidates who did not know to subtract the sum of the bonds made from the sum of the bonds broken leading to an incorrect sign in the final answer. Most candidates realised that oxygen was an element in (c). Again the calculation in (d) discriminated well. A common incorrect answer was 1888 $kJmol^{-1}$ which was usually due to doing the calculation the wrong way round. Weaker candidates also failed to take account of the 3 moles of water and carbon dioxide in their calculation. The explanation of why answers to (b) were less accurate than (a) was not done as well as expected with many candidates scoring one out of the 2 marks. Candidates should know that mean bond enthalpies are averaged over a range of compounds which contain the same bond, or from the same compound which contains several of the same type of bond. A common incorrect answer here was 'heat

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loss'.

Q25.

More able candidates were able to obtain high marks for this question but less able candidates found the calculations hard. In part (a) candidates lost a mark if they referred to bond-formation instead of bond-breaking. Less able candidates were unable to explain that mean bond enthalpy refers to an average of bonds where the environment is different, usually due to existence in different molecules. In part (b) many candidates provided incorrect answers because they did not work out the correct number of bonds being broken or formed. For example, only the best candidates recognised that two O—O bonds were broken. It was disappointing in part (c) (i) that many candidates did not understand the question. It was quite common to find candidates attempting a calculation using the equation, the enthalpy of formation values given in the table and an assumption that the enthalpy change for the equation was zero. Answers to part (c) (ii) were more usually correct though weaker candidates failed to take account of the two moles of hydrogen peroxide and the four moles of water. Answers to part (d) were usually incorrect. A common wrong answer was the statement 'Heat loss'.

Q26.

In this question, good candidates were able to score full marks. Weaker candidates were less successful though they were usually able to pick up at least five or six marks.

Answers to part (a) usually gained all three marks. Answers to part (b) by weaker candidates were less successful. One common error in the expression $mc\Delta T$ was to use the mass of methanol (2.12 g) instead of the mass of water (100 g). Another common error was to give an incorrect sign for the final value of the enthalpy of combustion. Candidates were expected to recognise that this exothermic process should lead to a negative value for the enthalpy of combustion of methanol. Weaker candidates also lost marks for incorrect units or for giving no units. It is important for candidates to give correct units for intermediate values in the calculation as well as for the answer. In this case, if a candidate gave a wrong final answer, it was still possible to gain an intermediate mark for the heat released to the 100 g of water. However, if the candidate did not make it clear whether the intermediate value was expressed in Joules or in kJ, it was not possible to give any credit.

Answers to part (b) were of a good standard and in part (b) (i) almost all candidates were awarded the two marks. Answers to part (b) (ii) were not quite so accurate and, in particular, only the best candidates stated that 500 K achieves the best balance between rate of reaction and yield.

Good candidates found part (c) straightforward but weaker candidates often omitted to allow for two moles of hydrogen and also used the wrong sign for the enthalpy of reaction (-91 kJ mol^{-1}) relative to the enthalpies of combustion of carbon monoxide and hydrogen.

Q29.

Good candidates were able to obtain high marks for this question but weak candidates found it very difficult and marks of zero out of ten were not unusual. In part (a), a common mistake was to use the O—O single bond enthalpy rather than the correct value for the O=O double bond and also to use one mole of oxygen rather than half a mole. In part (b) the balanced equation was usually correct but the state symbol for carbon was frequently shown as gaseous rather than solid (or graphite). In Part (c) (i) only the best candidates appeared to notice the wording in the question which required a reference to the structure of solid carbon. Part (c) (ii) also proved to be a difficult question for weaker candidates who rarely multiplied the enthalpy of formation of hydrogen atoms by the factor four. Also,

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the enthalpy of formation of methane (–74.9 kJ mol^{-1}) was usually added rather than subtracted. Incorrect cycles and equations involving combustion of methane were also common errors. Part (c) (iii) was answered well; the mark was awarded for dividing the answer to part (c) (ii) by four.

Q30.

Although candidates were specifically told in part (a) to note the direction of the indicated enthalpy change and the number of moles of species involved in the Born-Haber cycle, a significant number of candidates lost marks by failing to take this advice. Almost all candidates gave a correct equation for the disproportionation of MgCl in part (b) and many candidates scored full marks for the calculations required in parts (b) and (c). Sadly it was often impossible to award part scores to candidates who did not complete these calculations correctly as they did not give the necessary steps. Candidates must be encouraged to always show their working.

Q31.

Many candidates gave a correct expression for the equilibrium constant, K_p, for the reaction given in part (a). Some, who gave correct indices, lost a mark as they included square brackets, which are specific used to indicate concentration, in their expression. Identifying the one change which would increase the rate of reaction and decrease the value of K_p proved challenging but part marks were awarded for answers which addressed either of the two required changes. Candidates who gave more than one change of condition were able to score one mark for a correct K_p expression. There were many vague answers to part (b)(i), some of which assumed there were other reactants present with the most common example being water in Reaction 2. By contrast, (b)(ii) was very well answered with many candidates scoring full marks. Most candidates now remember to use either kJ mol^{-1} or J mol^{-1} throughout these calculations but a small number still failed to do this. Consequential marks were awarded in each part of the calculation.

Q34.

Most candidates answered this question well though it proved to be difficult to score maximum marks. The definition of standard enthalpy of formation in part (a) was usually correct though some candidates lost one mark because they did not make it clear that reactants and products should be in their standard states. In part (b) good candidates were able to score maximum marks but weaker candidates sometimes referred to energy rather than enthalpy when stating Hess's Law and such candidates often predicted an endothermic enthalpy change (+142 kJ mol^{-1}) rather than an exothermic one. Part (c) proved to be the most difficult part of this question. The major error was in the number of moles of magnesium oxide. Most candidates assumed that the number of moles of MgO would be the same as that of hydrochloric acid whereas it should have been half of that. This error led to a value for the enthalpy change that was too small by a factor of two. Such an answer resulted in the loss of three marks.

Q35.

This question was very well answered with many candidates scoring full, or nearly full marks. Just a few of the weaker candidates made errors when calculating the standard enthalpy change, $\Delta H^{\ominus}$, and the standard entropy change, $\Delta S^{\ominus}$, and marks were awarded consequentially to an arithmetic error. In part (b), most deduced correctly the effect of an increase in temperature on the equilibrium reaction but not all gave a full explanation of their answer. The calculation of the minimum temperature for the reaction to be feasible was also well done with few failing to use the same units for the enthalpy and the entropy changes.

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