**1** (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.

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

**(1)**

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

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**(1)**

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

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

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**(1)**

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

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**(1)**

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

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

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**(3)**

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

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**(3)**

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

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

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

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**(3)**

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

Reason 1 .......................................................................................................

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Reason 2 .......................................................................................................

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**(2)**
**(Total 15 marks)**

**2** 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.

| | $V_2O_5(s)$ | $CaO(s)$ |
|---|---|---|
| $\Delta H_f^\theta$ / kJ mol$^{-1}$ | −1560 | −635 |

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

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

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

State the type of reaction that $V_2O_5$ has undergone.

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

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**(5)**

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

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

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

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**(2)**

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

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

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

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

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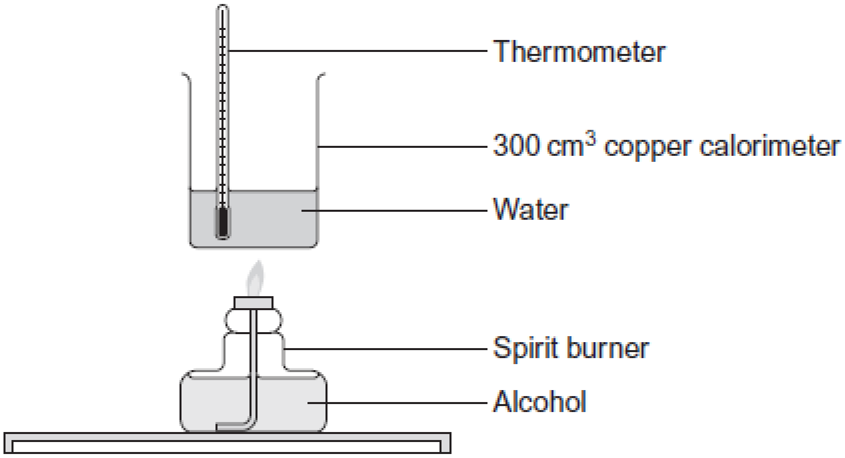
**(4)**
**(Total 11 marks)**

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



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

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

Change in volume: ........................................................................................

Explanation: ................................................................................................

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**(Total 2 marks)**

**4** 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)**

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

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**(1)**

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

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**(2)**

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

**Table 1**

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

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

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

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

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

**(3)**

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

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

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

**Table 2**

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

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

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

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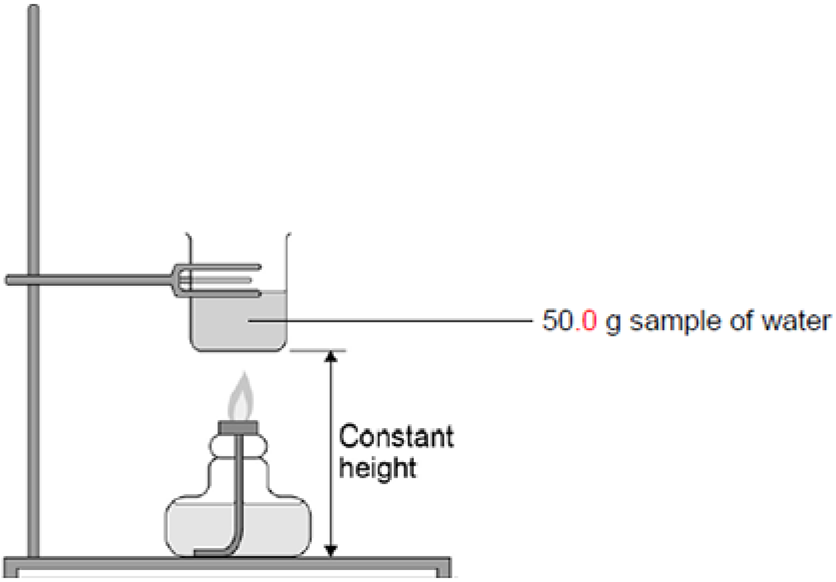
**(4)**
**(Total 10 marks)**

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



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

The following table shows the results obtained.

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

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

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**(1)**

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

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

**(4)**

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

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**(2)**

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

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

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**(2)**
**(Total 9 marks)**

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

An equation for this formation of methanol is given below.

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

Some mean bond enthalpies are shown in the following table.

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

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

H–H bond enthalpy = .............................. kJ mol$^{-1}$

**(3)**

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

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

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**(1)**

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

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**(1)**

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

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**(3)**

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

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**(1)**

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

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

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

$K_p$ = .............................. Units = ..............................

**(7)**
**(Total 16 marks)**

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

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

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**(4)**

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

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

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

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

**(4)**

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

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

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

**(2)**

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

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**(2)**
**(Total 12 marks)**

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

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

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

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**(1)**

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

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**(1)**

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

(i) Write an equation for this reaction.

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**(1)**

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

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**(1)**

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

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

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

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

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**(3)**

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

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**(1)**

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

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**(1)**

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

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**(1)**
**(Total 10 marks)**

**10** 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 $2.40 \times 10^{-3}$ mol of pure ethanol was burned in air.

Use the student's results to calculate a value, in kJ mol $^{-1}$, for the enthalpy change when one mole of ethanol is burned.

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

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

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**(5)**

(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)**

**11** 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.

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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)**

**12** 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

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

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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**(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.

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**(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.

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**(1)**

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

**(1)**

**(Total 17 marks)**

**13** 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)**

**14** 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.

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**(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.

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*(Extra space)* ..........................................................................................

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**(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.

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$^{-1}$.

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**(5)**
**(Total 13 marks)**

**15** 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.

(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 |

$$Mn_2O_3(s) + 3CO(g) \longrightarrow 2Mn(s) + 3CO_2(g)$$

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**(3)**

(ii) State why the value for the standard enthalpy of formation of Mn(s) is zero.

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**(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.

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**(2)**

(ii) Write an equation for the second stage of this extraction in which titanium(IV) chloride is converted into titanium.

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**(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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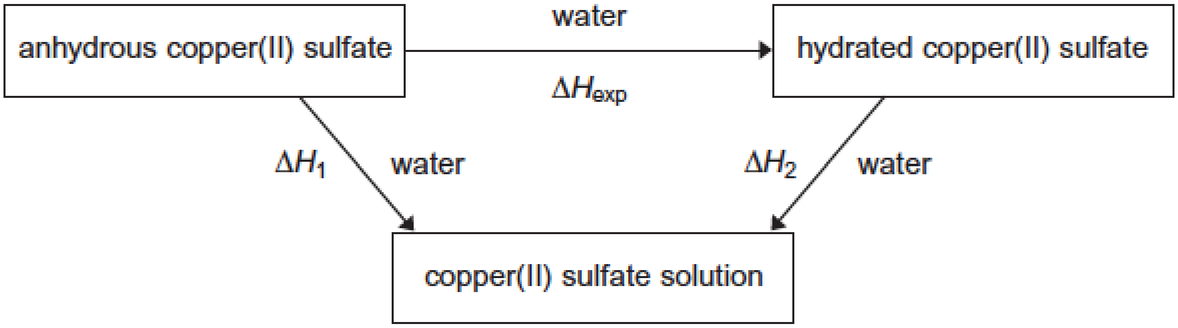
**(1)**
**(Total 10 marks)**

**16** 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 $\Delta H_{exp}$ by the student in a scheme of reactions.



(a) State Hess's Law.

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**(1)**

(b) Write a mathematical expression to show how $\Delta H_{exp}$, $\Delta H_1$ and $\Delta H_2$ are related to each other by Hess's Law.

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**(1)**

(c) Use the mathematical expression that you have written in part (b), and the data book values for the two enthalpy changes $\Delta H_1$ and $\Delta H_2$ shown, to calculate a value for $\Delta H_{\text{exp}}$

$\Delta H_1 = -156$ 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 $\Delta H_1$

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 $\Delta H_1$ calculated in part (d)(i) is less accurate than the data book value given in part (c).

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**(1)**

(e) Suggest **one** reason why the value for $\Delta H_{exp}$ **cannot** be measured directly.

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*(Extra space)* ..........................................................................................

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**(1)**
**(Total 8 marks)**

**17** 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*.

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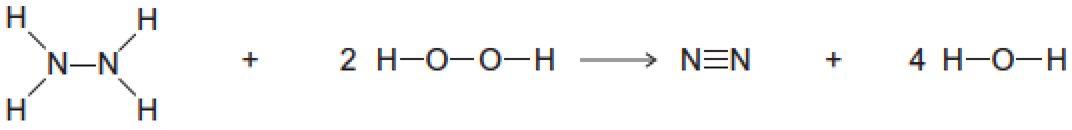
**(2)**

(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.



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**(3)**
**(Total 6 marks)**

**18** 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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**(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

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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.

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**(1)**
**(Total 11 marks)**

**19** 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.

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**(1)**

(b) State and explain what happens to the yield of methanol when the total pressure is increased in this synthesis.

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

Effect on yield ..........................................................................................

Explanation ..............................................................................................

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*(Extra space)* ..........................................................................................

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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 ..............................................................................................

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*(Extra space)* ..........................................................................................

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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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*(Extra space)* ..........................................................................................

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**(1)**

(ii) Write an equation for the complete combustion of methanol.

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**(1)**

(iii) The equation for the synthesis of methanol is shown below.

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

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)**

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

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

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

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

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

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

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

**(5)**

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

Temperature before mixing ..........................................................................

**(1)**

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

Temperature after mixing ..........................................................................

**(1)**

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

Temperature rise ..........................................................................................

**(1)**

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

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**(2)**

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

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**(1)**

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

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

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**(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.

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**(1)**

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

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**(1)**
**(Total 16 marks)**

**21** 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.

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**(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 ..........................................................................................

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Mass of NaOH ...........................................................................................

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**(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.

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**(1)**

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

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**(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(lll) oxide. The heat released warms the container.

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

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**(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 ..............................................................................

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Explanation .........................................................................................

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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.

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**(1)**

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

Step 1 ........................................................................................................

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Step 2 ........................................................................................................

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**(2)**
**(Total 14 marks)**

**22** (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.

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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.

$$\text{C(s,graphite)} + \frac{1}{2}\text{O}_2\text{(g)} \longrightarrow \text{CO(g)}$$

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**(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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*(Extra space)* ..........................................................................................

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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) | $CO_2(g)$ |
|---|---|---|---|---|
| $\Delta H_f^\ominus$/ kJ mol$^{-1}$ | - 822 | - 111 | +14 | - 394 |

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

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*(Extra space)* ..........................................................................................

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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.

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**(1)**

**(Total 12 marks)**

**23** 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) |
|---|---|---|---|---|
| $\Delta H_f^\circ$ / 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)**

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

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**(1)**
**(Total 11 marks)**

**24** 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.

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**(1)**

(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 Δ*H* value of –46 kJ $mol^{-1}$ and your answer from part (b) to calculate a value for Δ*G*, 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 Δ*G* that you have obtained to comment on the feasibility of the reaction at 800 K.

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**(1)**
**(Total 11 marks)**

**25** 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 ..........................................................................

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Lattice dissociation enthalpy ....................................................................

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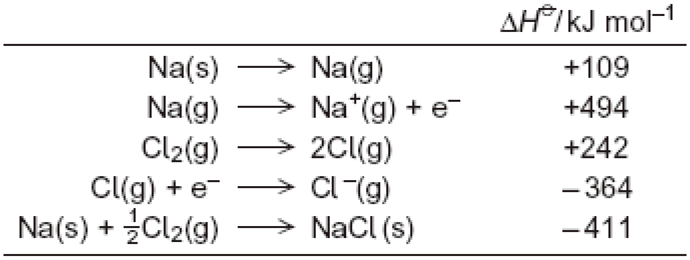
**(4)**

(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 ($\Delta H_L^\ominus$) data.

| | NaBr | AgBr |
|---|---|---|
| $\Delta H_L^\ominus$(experimental)/kJ mol$^{-1}$ | +733 | +890 |
| $\Delta H_L^\ominus$(theoretical)/kJ mol$^{-1}$ | +732 | +758 |

The values of $\Delta H_L^\ominus$ (experimental) have been determined from Born–Haber cycles.

The values of $\Delta H_L^\ominus$ (theoretical) have been determined by calculation using a perfect ionic model.

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

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**(2)**

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

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**(1)**

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

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**(1)**
**(Total 11 marks)**

**26** 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*.

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**(1)**

(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 |

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**(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.

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**(1)**

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

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**(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.

| | $NH_3(g)$ | $O_2(g)$ | $N_2O(g)$ | $H_2O(l)$ |
|---|---|---|---|---|
| $\Delta H_f^{\ominus}$/ 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.

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**(1)**
**(Total 8 marks)**

**27** 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<br>$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$ |
| Process **2** | Fermentation of glucose to form ethanol |
| Process **3** | Complete combustion of ethanol<br>$CH_3CH_2OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$ |

(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.

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**(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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**(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)**

**28** 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.

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**(1)**

(iii) State **one** risk of using hydrogen gas in metal extractions.

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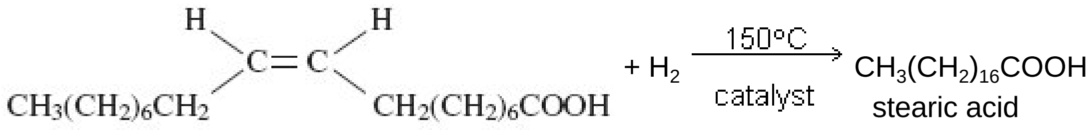
**(1)**

(b) Hydrogen is used to convert oleic acid into stearic acid as shown by the following equation.



$+ H_2 \xrightarrow[\text{catalyst}]{150^\circ C} CH_3(CH_2)_{16}COOH$

stearic acid

(i) Use your knowledge of the chemistry of alkenes to deduce the type of reaction that has occurred in this conversion.

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**(1)**

(ii) State the type of stereoisomerism shown by oleic acid.

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**(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.

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**(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 |

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**(3)**
**(Total 11 marks)**

**29** 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*.

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**(1)**

(b) State Hess's Law.

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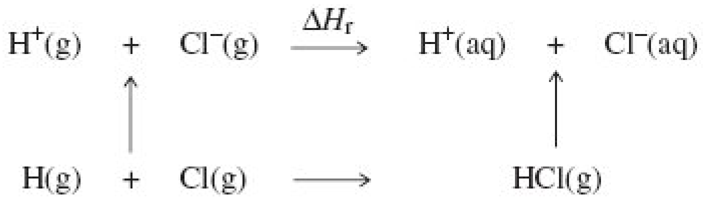
**(1)**

(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 $\Delta H_r$

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**(3)**
**(Total 5 marks)**

**30** 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) | $Al_2O_3(s)$ |
|---|---|---|
| $\Delta H_f^\ominus$ / 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.

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**(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.

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**(1)**

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

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**(1)**

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

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**(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

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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 ..........................................................................................

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**(2)**
**(Total 14 marks)**

**31** 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 ($\Delta T$) 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 ($\Delta T$).

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**(1)**

(ii) Calculate the amount of heat required to increase the temperature of 8.80 g of ethyl ethanoate by 9.5 K during the mixing process. (You should assume that $c$ for ethyl ethanoate = 1.92 J $g^{-1}$ $K^{-1}$)

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**(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 $g^{-1}$ $K^{-1}$)

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**(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.

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**(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.

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**(1)**
**(Total 6 marks)**

**32** The combustion of hydrocarbons is an important source of energy.

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

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**(3)**

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

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

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**(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 $mol^{-1}$.

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**(4)**
**(Total 11 marks)**

**33** 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 |

**(3)**

(b) A manager in charge of ammonia production wished to increase the daily production 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)**

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

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**(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, $\Delta H_c^\circ$ /kJ mol$^{-1}$ | –394 | –286 | –3909 |

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

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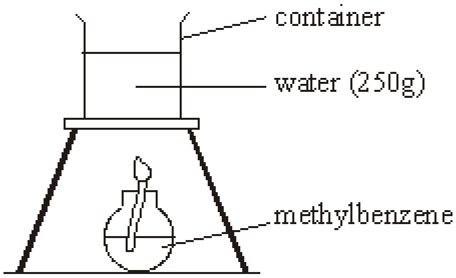
**(3)**

(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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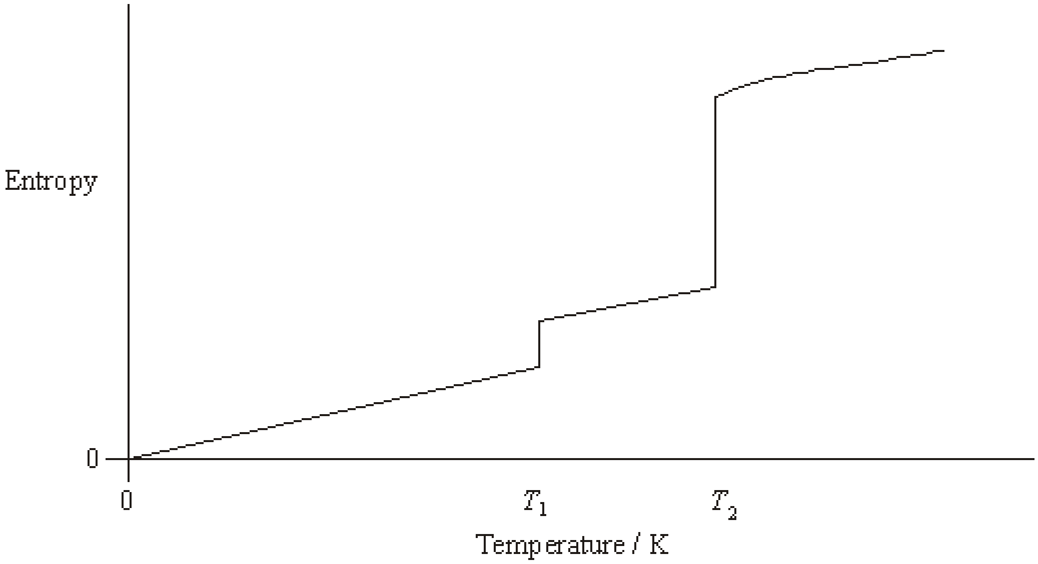
**(1)**
**(Total 15 marks)**

**35** 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.

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**(1)**

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

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**(1)**

(c) Explain why the entropy change, $\Delta S$, at temperature $T_2$ is much larger than that at temperature $T_1$.

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**(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, $\Delta H$, 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, $\Delta G$, enthalpy change, $\Delta H$, and entropy change, $\Delta S$.

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(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 $\Delta S$ 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* ........................................................................................

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*Units* ..................................................................................................

**(6)**
**(Total 10 marks)**

**36** The table below shows data for the four hydrocarbons ethyne, propyne, propene and propane. $\Delta Hc$ is the standard enthalpy of combustion of these hydrocarbons.

| **Compound** | **Name** | $M_r$ | $-\Delta Hc^\ominus$ / kJ mol$^{-1}$ |
|---|---|---|---|
| HC≡CH | ethyne | 26 | 1300 |
| HC≡CCH$_3$ | propyne | 40 | 1940 |
| H$_2$C=CHCH$_3$ | propene | 42 | 2060 |
| CH$_3$CH$_2$CH$_3$ | propane | 44 | 2220 |

The complete combustion of 2.0 g of one of the above hydrocarbons releases exactly 100 kJ of heat energy.

This hydrocarbon is

**A** ethyne

**B** propyne

**C** propene

**D** propane

**(Total 1 mark)**

**37** (a) Define the term *standard enthalpy of combustion*, $\Delta H_c^\ominus$

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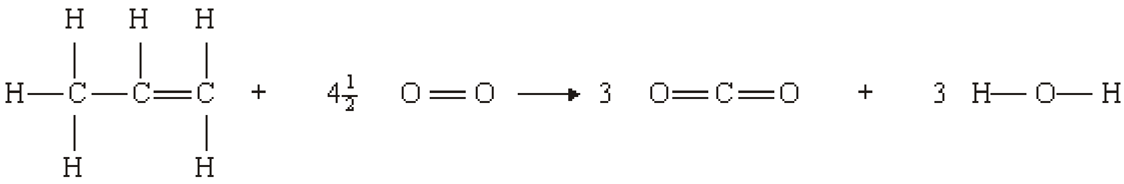
**(3)**

(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 |



$$H_3C{-}CH{=}CH_2 + 4\tfrac{1}{2}\ O{=}O \longrightarrow 3\ O{=}C{=}O + 3\ H{-}O{-}H$$

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**(3)**

(c) State why the standard enthalpy of formation, $\Delta H_f^\ominus$, of oxygen is zero.

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**(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, $\Delta H_f^\circ$/ 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)**

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

*Mean bond enthalpy* ......................................................................................

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Standard enthalpy of formation ...................................................................

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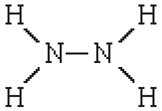
**(5)**

(b) Some mean bond enthalpies are given below.

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

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



+ 2 H—O—O—H ⟶ N ≡ N + 4 H—O—H

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**(3)**

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

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

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

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

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

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

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**(4)**

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

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**(1)**
**(Total 13 marks)**

**39** 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)**

**40** Methanol, $CH_3OH$, is a convenient liquid fuel.

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

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

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

**(7)**

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

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

*Stage 2* $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H^{\circ} = -91$ 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.

(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*.

**(5)**

(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)**

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**(Total 15 marks)**

**41** 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 | $CO(g)$ | $H_2O(g)$ | $CO_2(g)$ | $H_2(g)$ |
|---|---|---|---|---|
| $\Delta H_r^{\ominus}$ / 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$^{-1}$

**C** +262 kJ mol$^{-1}$

**D** −262 kJ mol$^{-1}$

**(Total 1 mark)**

**42** 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)**

**43** (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.

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

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**(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.

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

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

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

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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.

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

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(iii) Use your answer from part (c)(ii) to calculate a value for the mean bond enthalpy of a C–H bond in methane.

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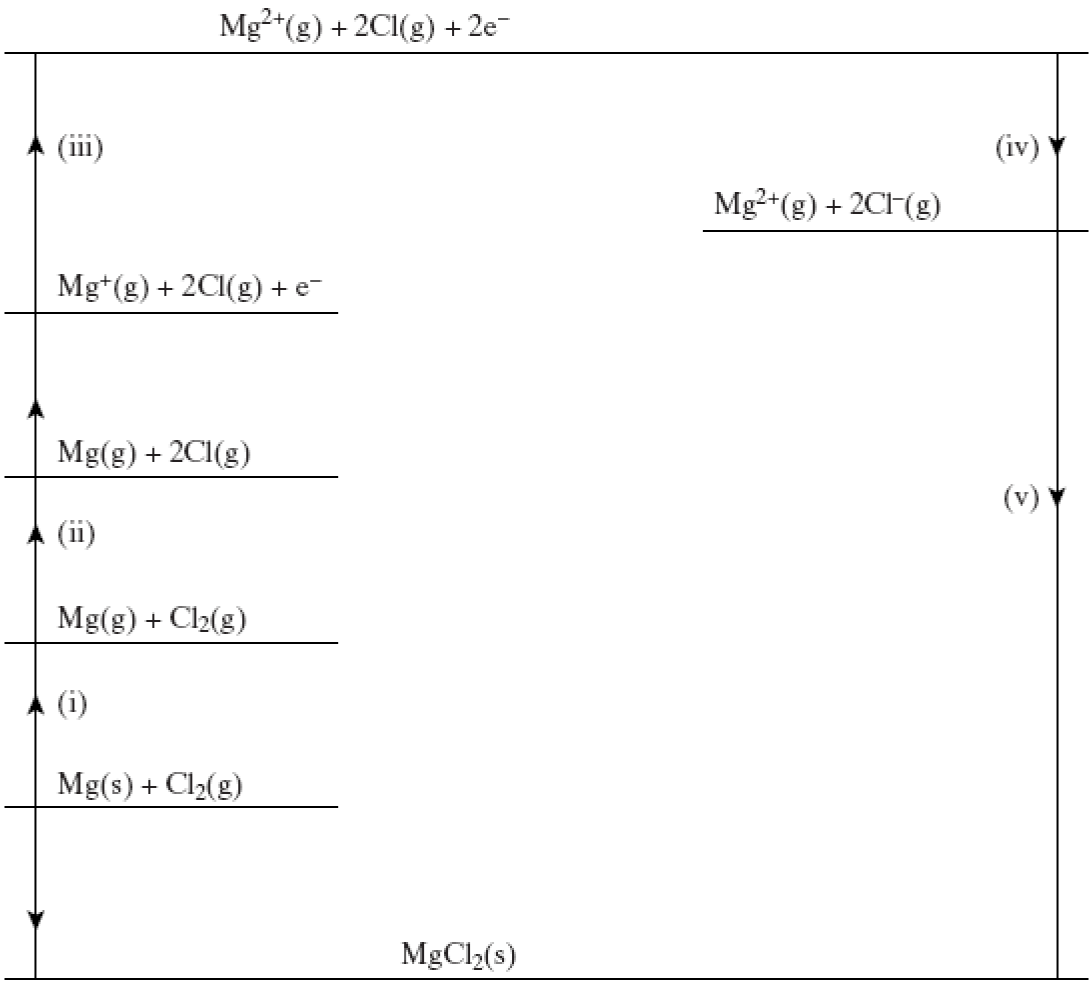
**(5)**
**(Total 10 marks)**

**44** (a) A Born–Haber cycle for the formation of magnesium(II) chloride is shown below.



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 $mol^{-1}$ |
| $\Delta H^\ominus_{\text{hydration}}$ of $Mg^{2+}$(g) | = –1920 kJ $mol^{-1}$ |
| $\Delta H^\ominus_{\text{hydration}}$ of $Cl^-$(g) | = –364 kJ $mol^{-1}$ |

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**(3)**
**(Total 12 marks)**

**45** (a) The gaseous reactants **W** and **X** were sealed in a flask and the mixture left until the following equilibrium had been established.

$$2W(g) + X(g) \rightleftharpoons 3Y(g) + 2Z(g) \qquad \Delta H = -200 \text{ kJ mol}^{-1}$$

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.

**(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**.

(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 |

**(8)**
**(Total 15 marks)**

**46** 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)**

**47** Nitric acid is produced industrially from ammonia, air and water using the following sequence of reactions:

(1) $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$ $\Delta H = –909 \text{ kJ mol}^{-1}$

(2) $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$ $\Delta H = –115 \text{ kJ mol}^{-1}$

(3) $3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(aq) + NO(g)$ $\Delta H = –117 \text{ kJ mol}^{-1}$

Which is the enthalpy change (in $\text{kJ mol}^{-1}$) for the following reaction?

$$4NH_3(g) + 7O_2(g) \rightarrow 4NO_2(g) + 6H_2O(g)$$

**A** −679

**B** −794

**C** −1024

**D** −1139

**(Total 1 mark)**

**48** Use the information below to answer this question.

$C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H^\ominus = -393.5 \text{ kJ mol}^{-1}$

$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ $\Delta H^\ominus = -285.8 \text{ kJ mol}^{-1}$

$3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$ $\Delta H^\ominus = -104.0 \text{ kJ mol}^{-1}$

$4C(s) + 5H_2(g) \rightarrow C_4H_{10}(g)$ $\Delta H^\ominus = -125.2 \text{ kJ mol}^{-1}$

The value in $\text{kJ mol}^{-1}$ for the enthalpy of combustion of propane is

**A** −211.7

**B** −419.7

**C** −2220

**C** −2878

**(Total 1 mark)**

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

**(3)**

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

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

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

**(4)**

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

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

**(8)**
**(Total 15 marks)**

**50** 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*, $\Delta H^\ominus$ ...............................................................

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*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.

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**(7)**
**(Total 13 marks)**

**51** The data below refer to the industrial production of nitric acid from ammonia.

*Reaction 1* $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $\Delta H^\ominus = -909 \text{ kJ mol}^{-1}$

*Reaction 2* $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H^\ominus = -115 \text{ kJ mol}^{-1}$

*Reaction 3* $3NO_2(g) + H_2O(l) \rightleftharpoons 2HNO_3(aq) + NO(g)$ $\Delta H^\ominus = -117 \text{ kJ mol}^{-1}$

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)**

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

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**(1)**

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

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

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(ii) Calculate the heat energy required to raise the temperature of 100 g of water from 293.1 K to 351.2 K.

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

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

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**(5)**

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

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

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

*Difference* ..........................................................................................

*Explanation* ........................................................................................

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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 |

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

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**(3)**
**(Total 12 marks)**

**53** 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$^{-1}$

| | **$Fe_2O_3(s)$** | **$H_2(g)$** | **Fe(s)** |
|---|---|---|---|
| $\Delta H_r^\ominus$ / 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)**

**54** 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?

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**(1)**

(b) State Hess's Law.

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**(2)**

(c) Use $DH_f^{\ominus}$ 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)**

**55** The table below contains some mean bond enthalpy data.

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

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

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**(2)**

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

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

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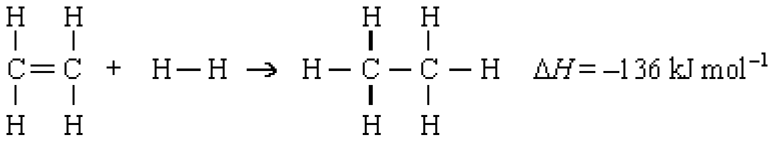
**(4)**

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



$$H_2C{=}CH_2 + H{-}H \rightarrow H_3C{-}CH_3 \quad \Delta H = -136\ \text{kJ mol}^{-1}$$

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**(3)**

**(Total 9 marks)**

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

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**(2)**

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

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

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**(5)**

(c) State Hess's Law.

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**(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)**

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

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

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**(1)**

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

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**(2)**

(c) Calculate the heat energy evolved by the reaction in this experiment assuming that all the energy evolved is used to heat only the 50.0 g of water in the mixture.

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

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**(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.

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**(1)**
**(Total 8 marks)**

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

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**(3)**

(b) State Hess's law.

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**(1)**

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

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

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

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

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**(3)**
**(Total 7 marks)**

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

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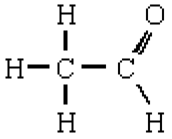
**(2)**

(b) Ethanal has the structure 

Gaseous ethanal burns as shown by the equation

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

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

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

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

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

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

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**(5)**
**(Total 7 marks)**

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

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

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

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

**A** $-1538\ kJ\ mol^{-1}$

**B** $-1094\ kJ\ mol^{-1}$

**C** $-750\ kJ\ mol^{-1}$

**D** $+286\ kJ\ mol^{-1}$

**(Total 1 mark)**

# Mark schemes

**1** (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 ΔT

***OR*** q =150 × 4.18 × 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 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)** = $\Delta H$

***OR***

Sum of bonds broken − 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) = $\Delta H$

**M2** (also scores **M1**)

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

(696) (2472) (1984)

− 6(805) − 6(463) [RHS = (−) **7608**] = $\Delta H$

(4830) (2778)

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

**M3**

$\Delta H$= **− 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 4$O_2$, 3$CO_2$ and 3$H_2O$ 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]**

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

**M1** $\Delta H = \Sigma\Delta H_f$ **(products)** $- \Sigma\Delta H_f$ **(reactants)**

***OR*** a correct cycle of balanced equations

**M2** $= 5(-635) - (-1560)$

$= -3175 + 1560$

(This also scores M1)

**M3** = **− 1615** (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 score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with $V_2O_5$ and 5CaO OR a clear statement of **M1** which could be in words and scores **only M1***

**M4 Type of reaction is**

- reduction
- redox
- (or accept) $V_2O_5$ / it / V(V) has been reduced

*In **M4** not "vanadium / V is reduced"*

**M5 Major reason for expense of extraction − the answer must be about calcium**

Calcium is produced / extracted by electrolysis

***OR*** calcium is expensive to extract

***OR*** calcium extraction uses electricity

***OR*** calcium extraction uses large amount of energy

***OR*** calcium is a (very) reactive metal / reacts with water or air

***OR*** calcium needs to be extracted / does not occur native

***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>*

**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]**

**3** 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]**

**4** (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) $H_2 + \frac{1}{2}O_2 \longrightarrow H_2O$

$\Delta H$ = (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 $\text{mol}^{-1}$)

*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]**

**5** (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

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]**

**6**

(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 × 4.18 × 20.1 = 4201 (J)

1

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

∴ mol of alcohol = *n* = 0.54 / 100 = 0.0054

1

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

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

1

$\Delta H$ = –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]**

**7** (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

(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)<br>= 0.14 | (3–3×0.86)<br>= 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 =*

$pp_{CO2} = 0.0614 \times 500$

$pp_{H2} = 0.1842 \times 500$

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 =*

$pp_{CH3OH} = 0.3772 \times 500$

$pp_{H2O} = 0.3772 \times 500$

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 = <u>kPa</u>$^{-2}$

1

**[16]**

**8** (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*

1

Moles of KCl = 5.00 / 74.6 = 0.0670

1

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

1

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

*Answer must be given to this precision*

1

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

$\Delta H_{\text{lattice}} = \Delta H_{\text{solution}} - \Delta H\text{(hydration of calcium ions)} - 2 \times \Delta\text{H(hydration of chloride ions)}$

1

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

1

(d) Magnesium ion is smaller than the calcium ion

1

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

1

**[12]**

**9** (a) (i) $\mathbf{3}\text{Fe} + \text{Sb}_2\text{S}_3 \longrightarrow \mathbf{3}\text{FeS} + \mathbf{2}\text{Sb}$

*Or multiples.*

*Ignore state symbols.*

1

(ii) $\text{Fe} \longrightarrow \text{Fe}^{2+} + 2\text{e}^-$

*Ignore charge on the electron unless incorrect.*

*Or multiples.*

*Credit the electrons being subtracted on the LHS.*

*Ignore state symbols.*

1

(b) (i) $Sb_2S_3 + \mathbf{4.5}O_2 \longrightarrow Sb_2O_3 + \mathbf{3}SO_2$

*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** $\underline{\Delta H_r = \Sigma\Delta H_f(\textbf{products}) - \Sigma\Delta H_f(\textbf{reactants})}$

**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** $= \underline{\mathbf{-104}}$ (kJ mol$^{-1}$)

**(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 not in its standard state

**OR**

Standard state (for Sb) is solid / (s)

**OR**

(Sb) liquid is not its standard state

*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) scrap / waste iron / steel
- is a single-step process

uses / requires less / low(er) energy

*Ignore references to temperature / heat or labour or technology.*

1

**[10]**

**10** (a)

**M1** $C_6H_{12}O_6 \longrightarrow \mathbf{2}CH_3CH_2OH + \mathbf{2}CO_2$

$(2C_2H_5OH)$

*Penalise $C_2H_6O$ for ethanol in **M1**.*

**M2** and **M3**

*Mark **M2** and **M3** independently.*

Any **two** conditions <u>**in any order**</u> for **M2** and **M3** from

- (enzymes from) yeast or zymase
- 25 °C ≤ T ≤ 42 °C OR 298 K ≤ T ≤ 315 K
- <u>anaerobic / no oxygen / no air</u> OR neutral pH

*A lack of oxygen can mean either without oxygen or not having enough oxygen and does not ensure <u>no oxygen</u>, 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 <u>net / overall</u> (annual) <u>carbon dioxide / $CO_2$ emission</u> <u>to the atmosphere</u>

**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 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 ($2.40 \times 10^{-3}$ 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)

*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**) = $\Delta H$

**OR**

Sum of bonds broken − Sum of bonds formed = $\Delta H$

**OR**

B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O)
– 4B(C=O) – 6B(O–H) = $\Delta H$ = −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) = $\Delta H$ = − 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]**

**11** (a) (Q = mc$\Delta$T)

= 50 × 4.18 × 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**

Moles = mass / $M_r$

= 0.22 / 74(.0)

= **0.00297 moles**

**1**

$\Delta H$ = –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) $\Delta H = \Sigma\Delta H$ products – $\Sigma\Delta H$ reactants
OR a correct cycle

*Correct answer with no working scores 1 mark only.*

**1**

$\Delta H = -(-360) + (4 \times -393) + (5 \times -286)$

*M2 also implies M1 scored.*

**1**

$\Delta H$ = **–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]**

**12** (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 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

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*

<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**

3

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

*Not “reduction”.*

*Not “oxidation”.*

*Not “electron pair donor”.*

1

(ii) $CH_3COOH$

1

**[17]**

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

*Correct answer to the calculation gains all of **M1**, **M2** and **M3***

M1 $\Delta H = \Sigma\Delta H_f$ (**products**) − $\Sigma\Delta H_f$ (**reactants**)

*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.*

*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** $\mathbf{2}Mg + O_2 \longrightarrow \mathbf{2}MgO$

**M2** $Mg + \mathbf{2}H_2O \longrightarrow Mg(OH)_2 + H_2$

*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]**

**14** (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 + $\Delta H_{hyd}$ $Br^-$ 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 = $\underline{0.067(0)\text{ mol}}$

*If moles of KCl not worked out can score M3, M4 only (answer to M4 likely to be 205.7 K)*

**1**

Heat absorbed = 17.2 × 0.0670 = 1.153 kJ

*Process mark for M1 × 17.2*

**1**

Heat absorbed = mass × sp ht × $\Delta T$

(1.153 × 1000) = 20 × 4.18 × $\Delta T$

*If calculation uses 25 g not 20, lose M3 only (M4 = 11.04, M5 = 287)*

**1**

$\Delta T$ = 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]**

**15** (a) (i) **M1 (could be scored by a correct mathematical expression which <u>must</u> have <u>all</u> Δ*H* symbols and the ∑ or SUM)**

*Correct answer gains full marks*

*Credit 1 mark ONLY if* ***–122*** *(kJ mol$^{-1}$)*

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 $\underline{\Delta H} = 3(-394) - 3(-111) - (-971)$
(This also scores M1)

M3 = <u>**(+) 122**</u>(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 **<u>M1 only</u>***

**3**

(ii) By definition

*Ignore reference to "standard state"*

***OR***

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 $Cl_2$ <u>and</u> 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]**

**16** (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***

$\Delta H_{exp} + \Delta H_2 = \Delta H_1$ ***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) $\Delta H_{exp} = \Delta H_1 - \Delta H_2$

$\Delta H_{exp} = -156 - 12 = \mathbf{-168}\ (kJ\ mol^{-1})$

*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

$\Delta H_1 = \mathbf{-\ 69.67}$ to $\mathbf{-\ 69.52}$ (kJ $mol^{-1}$)

**OR** $\Delta H_1 = \mathbf{-\ 69.7}$ to $\mathbf{-\ 69.5}$ (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**

(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]**

**17** (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

$\sum$ (bonds broken) − $\sum$ (bonds formed) = $\Delta H$

*__M1__ could stand alone*

***OR***

Sum of bonds broken − Sum of bonds formed = $\Delta H$

*Award full marks for correct answer*

M2 (also scores **M1**)

*Ignore units*

4(+388) + 163 + 2(146) + 4(463) − 944 − 8(463) = $\Delta$H
OR broken +3859 (2007) formed − 4648 (2796)

M3

$\Delta$H = **− 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]**

**18** (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**

$E(Cl–F) = \frac{1}{2}E(F–F) + \frac{1}{2}E(Cl–Cl) - \Delta H$

$= 79 + 121 - (-56)$

$= 256$ ($kJ\ mol^{-1}$)

*−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**

(d) NaCl is ionic / not covalent

**1**

**[11]**

**19** (a) (i) **M1 (could be scored by a correct mathematical expression which <u>must</u> have <u>all</u>** $\Delta H$**symbols and the** ∑ or SUM)

**M1** $\underline{\Delta H_r} = \Sigma\Delta H_f$ **(products) -** $\Sigma\Delta H_f$ **(reactants)**

***OR*** a <u>correct cycle of balanced equations with 1C, 3$H_2$ and 1$O_2$</u>

**M2** $\underline{\Delta H_r} = – 201 + (– 242) – (– 394)$
$\underline{\Delta H_r} = – 201 – 242 + 394$
$\underline{\Delta H_r} = – 443 + 394$
(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, 3$H_2$ and 1$O_2$*

  *OR a clear statement of **M1** which could be in words and scores <u>only **M1**</u>*

**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 <u>more moles / molecules</u> (of gas) on the left / of reactants
***OR*** <u>fewer moles / molecules</u> (of gas) on the right / products
***OR*** there are <u>4 moles /molecules</u> (of gas) on the left <u>and 2 moles / molecules</u> on the right.
***OR*** (equilibrium) shifts / moves <u>to the side with less moles / molecules</u>

*Ignore "volumes", "particles" "atoms" and "species" for **M2***

**M3: Can only score M3 if <u>M2 is correct</u>**

The (position of) <u>equilibrium shifts / moves</u> (from left to right) to <u>oppose the increase in pressure</u>

*For **M3**, <u>not</u> simply "to oppose the change"*

*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) $CH_3OH + \mathbf{1\tfrac{1}{2}}\ O_2 \longrightarrow CO_2 + \mathbf{2}H_2O$

*Ignore state symbols*

*Accept multiples*

**1**

(iii) $\mathbf{3}H_2 + \mathbf{1\tfrac{1}{2}}\ O_2 \longrightarrow \mathbf{3}H_2O$

*Ignore state symbols*

***OR***

*Accept multiples*

$\mathbf{2}H_2 + O_2 \longrightarrow \mathbf{2}H_2O$

*Extra species must be crossed through*

**1**

(e) **M1** q = m c ΔT

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

*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 ΔH = **<u>– 399</u>** (kJmol$^{-1}$ )
OR **<u>– 400</u>**

*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 ΔT = 280.5; score q = m c ΔT 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]**

**20** (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.*

**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* $9 \times 10^{-3}$ *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* $9.01 \times 10^{-3}$ *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 toxic / poisonous / corrosive

*Do not allow 'harmful'.*

1

(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]**

**21** (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**

(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]**

**22** (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* $Fe^{3+} \longrightarrow Fe - \mathbf{3}e^{-}$

*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 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**

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

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

**M2** is burned completely / undergoes complete combustion in (excess) oxygen

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

*For M3*

*Ignore reference to 1 atmosphere*

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

**3**

(c) **M1 (could be scored by a correct mathematical expression which <u>must</u> have <u>all</u> <u>$\Delta$H</u> symbols and the $\sum$)**

*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 3$O_2$</u>

**M2** $\Delta H_r$ = 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 3$O_2$ 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) $CO_2$(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]**

**23** (a) One from

- Ti is not produced
- 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** $=$ **−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

*Ignore "reduces titanium"*

OR reductant OR reduces $TiCl_4$

OR electron donor

**1**

**[7]**

**24** (a) (i) $\Delta H = \Sigma$ bonds broken $- \Sigma$ bonds formed

**1**

$= 944/2 + 3/2 \times 436 - 3 \times 388$

**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**

$= 193 - (192/2 + 131 \times 3/2)$

**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) $\Delta G = \Delta H - T\Delta S = -46 + 800 \times 99.5/1000$

*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)*

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]**

**25** (a) <u>Enthalpy change</u> for the formation of <u>1 mol</u> of <u>gaseous atoms</u>

*allow <u>heat energy change</u> for <u>enthalpy change</u>*

1

From the <u>element</u> (in its standard state)

*ignore reference to conditions*

1

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

*enthalpy change not required but penalise energy*

1

Into (its component) <u>gaseous ions</u>

*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

*Or has covalent character/partially covalent*

*Allow mention of polarisation of ions or description of polarisation*

**1**

**[11]**

**26** (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)**

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

OR a correct cycle of balanced equations

**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**
$\Delta H = \underline{-684}$ (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 100 kPa OR 1 bar or $10^5$ Pa

***OR***

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

*Ignore 1 atmosphere/101 kPa*

*Ignore "constant pressure"*

1

**[8]**

**27** (a) **Three conditions in any order 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** 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***

$(\Sigma)\ B_{reactants} - (\Sigma)\ B_{products} = \Delta H$

(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 = **<u>–1031</u>** (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 <u>not specific</u> for this reaction *OR* they are <u>average</u> values from many <u>different compounds/molecules</u>

***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 = **<u>– 669</u>** kJ mol$^{-1}$ OR – **<u>670</u>** kJmol$^{-1}$

OR **<u>–668.8</u>** kJ mol$^{-1}$

*Award M1, M2 and M3 for <u>correct answer</u> 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]**

**28** (a) (i) Reducing agent

***OR***

Reduce(s) ($WO_3$/tungsten oxide)

OR

electron donor

OR

to remove oxygen (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 equilibrium will shift/move/change/respond/act so as to oppose the change.

***OR***

(When a system/reaction in equilibrium is disturbed), the equilibrium shifts/moves in a direction which tends to reduce the disturbance

*A variety of wording will be seen here and the key part is the last phrase and must refer to movement of the equilibrium.*

***QoL***

**1**

(ii) **M1 – Statement of number of moles/molecules**

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.

*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) $\Sigma$B(reactants) – $\Sigma$B(products) = $\Delta H$ (**M1**)

***OR***

<u>Sum</u> of bonds broken – <u>Sum</u> of bonds formed = $\Delta$H (**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) = (+)<u>436</u> (kJ mol$^{-1}$) (**M3**)

Award 1 mark for – 436

Candidates may use a cycle and gain full marks.

*M1 could stand alone*

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

*Ignore units.*

*Two marks can score with an arithmetic error in the working.*

3

**[11]**

**29** (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]**

**30** (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

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
- OR more chance of colliding

*The answer MUST refer to more collisions.*

*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** 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]**

**31** (a) (i) $q = mc\,\Delta T$

*Ignore case except T*

1

(ii) $8.80 \times 1.92 \times 9.5 =$ **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.*
*Ignore heat loss and ignore poor mixing.*

1

**[6]**

**32** (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) $\Delta H = 2 \times \Delta H_f^o (CO_2) + 3 \times \Delta H_f^o (H_2O) - \Delta H_f^o (C_2H_6)$

**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**

$5.56 \times 10^3$ joules = $(mc)\Delta T$

**1**

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

**1**

**[11]**

**33** (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 (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<br>**Descriptor**<br>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<br>– good use of information or ideas about chemistry, going beyond those given in the question<br>– argument well structured with minimal repetition or irrelevant points<br>– accurate and clear expression of ideas with only minor errors of grammar, punctuation and spelling |
| 2-3 | – claims partially supported by evidence<br>– good use of information or ideas about chemistry given in the question but limited beyond this<br>– the argument shows some attempt at structure<br>– 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<br>– limited use of information or ideas about chemistry<br>– unstructured<br>– 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

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]**

**34** (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) $\Delta H = \Sigma \Delta H^{o}_{c}$ (reactants) – $\Sigma \Delta H^{o}_{c}$ (products) (1)

$= (7x - 394) + (4\ x - 286) - (-\ 3909)$ (1)

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

3

(c) Heat change = m c $\Delta T$ (1)

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

Moles $C_7H_8$ = 2.5 /92 = 0.0272 (1)

$\Delta H = 62.7 / 0.0272 = -\ 2307\ \text{kJ mol}^{-1}$ (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)

$\Delta H$ = – 2.665 / 0.05 = –53.3 kJmol$^{-1}$ (1)

*(allow –53 to –54)*

**4**

(e) Less heat loss (1)

**1**

**[15]**

**35** (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)*

**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

$\Delta S$ = 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]**

**36** A

**[1]**

**37** (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) ΔH = ∑ bonds broken – ∑ bonds formed

1

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

1

= – 1572 kJ $mol^{-1}$

1

(c) by definition $\Delta H_f$ is formation from an element

1

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

1

$= (3 \times -394) + (3 \times -242) - (+20)$

1

$= -1928$ kJ mol$^{-1}$

1

(e) bond enthalpies are mean/average values

1

from a range of compounds

1

**[12]**

**38** (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 = $\Sigma$(bonds broken) – $\Sigma$(bonds formed) or cycle;

1

$= 4 \times 388 + 163 + 2 \times 146 + 4 \times 463 - (944 + 8 \times 463)$;
*(or similar)*

1

$= -789$;

*(+ 789 scores 1 only)*

1

(c) (i) zero;

1

(ii) $AH = \Sigma$ (enthalpies of formation of products)
$-\Sigma$ (enthalpies of formation of reactants)

1

$= 4 \times -242-(75 + 2 \times -133)$;

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]**

**39** C

**[1]**

**40** (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

$\Delta H = -40.1/0.0663 = -605$ 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]**

**41** B

**[1]**

**42** A

**[1]**

**43** (a) $\Delta H = \Sigma$(bonds broken) – $\Sigma$(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 $mol^{-1}$)

*(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]**

**44** (a) (i) $\Delta H$ 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 $\Delta H$ reaction = $\Sigma\Delta H_f$ products – $\Sigma\Delta H_f$ reactants

1

= – 653 – (2 × –133)

1

= – 427 (kJ$mol^{-1}$)

*Allow +427 to score (1) mark*

*Other answers; award (1) for a correct D H reaction expression*

1

(c) $\Delta H$ soln $MgCl_2$ = – $\Delta H$ Lat.form. + $\Delta H$ hyd.$Mg^{2+}$ + 2$\Delta H$ 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]**

**45** (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

*Allow* ***(2)*** *for – 46.6 without units*

*(Mark ΔG consequentially to incorrect ΔS)*

*(e.g. $\Delta S = -84$ gives $\Delta G = +3.4$ kJ $mol^{-1}$)*

1

**[15]**

**46** D

**[1]**

**47** D

**[1]**

**48** C

**[1]**

**49**

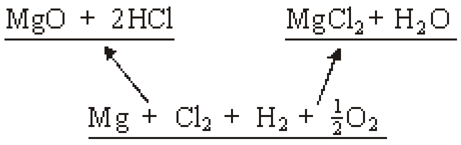
(a) (i) enthalpy (or heat or heat energy) change when
1 mol of a substance **(1)** (QL mark) is formed from its elements **(1)**
all substances in their standard states **(1) (**or normal states at 298K, 100 kPa or std condits)

*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:



$\Delta H = -642 – 286 – (–602 + 2 \times –92)$ **(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 $\Delta H$ = 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]**

**50** (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

$\Delta H_R = (0 + [2 \times -242]) - (4 \times -92)$ **(1)**
$= -484 + 368$
$= -116$ (kJ mol$^{-1}$)
*Allow max 1 for +116*

*Standard entropy change,* $\Delta S^{\ominus}$: $\Delta S = \Sigma\Delta H_{f\text{ products}} - \Sigma\Delta H_{f\text{ reactants}}$

$\Delta S = ([2 \times 223] + [2 \times 189]) - (205 + [4 \times 187])$ **(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)**

$T = \Delta H/\Delta S = 208 \times 1000$ **(1)** / 253

= 822 K **(1)**

7

**[13]**

**51** A

**[1]**

**52** (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)

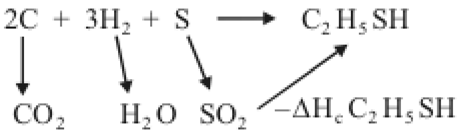
*QoL mark*

*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)**

(or cycle



)

= (2 × –394) + (3 × –286) + (–297) – (–1170)**(1)**
= –773 **(1)**

*ignore units even if wrong*

*Allow* 1/3 *for +773*

3

**[12]**

**53** C

**[1]**

**54** (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) $\Delta H = \Sigma\Delta H_f^\ominus(\text{products}) - \Sigma\Delta H_f^\ominus(\text{reactants})$ **(1) (Or a cycle)**

$= 2 \times -242 + ½ \times -394 - (-365)$ **(1) (also implies first mark)**

$= -316\ \text{kJ mol}^{-1}$ **(1)**

3

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

**[6]**

**55** (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) $1/2\ N_2 + 3/2\ H_2 \rightarrow NH_3$ **(1)**

*Ignore s s*

(ii) $\Delta H = (\Sigma)\text{bonds broken} - (\Sigma)\text{bonds formed}$ **(1)**

$= 1/2 \times 944 + 3/2 \times 436 - 3 \times 388$ **(1)**

$= -38\ \text{kJ mol}^{-1}$ **(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 $\text{mol}^{-1}$) **(1)**

*Note: allow (1) for –836*
*another (1) for –418*

3

**[9]**

**56** (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*

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

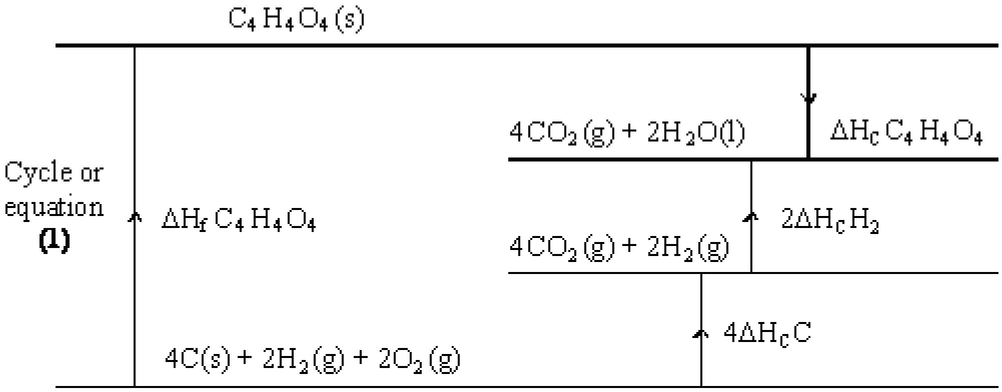
5

(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]**

**57** (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 = $1.00 \times 10^{-2}$

2

(c) Heat energy change = mC$\Delta$T **(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]**

**58** (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]**

**59** (a) (Energy required) to break a given covalent 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)**

= 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) $\Delta H_R$ = ΣBonds broken − ΣBonds made

= +3980 − 4800 = −820 **(1)**

*Conseq Mark for incorrect answers in (i) and (ii) as*
*(i) Answer + (ii) Answer =*

5

**[7]**

**60** C

**[1]**