8 A 20 g sample of iron(III) sulfate, $Fe_2(SO_4)_3$, was dissolved in water. How many sulfate ions are in the solution formed?

[Assume M_r $Fe_2(SO_4)_3 = 400$
Avogadro constant, $L = 6.0 \times 10^{23}$ mol^{-1}]

☒ **A** 3×10^{22}

☒ **B** 9×10^{22}

☒ **C** 1.2×10^{23}

☒ **D** 1.5×10^{23}

3 The standard enthalpy changes of combustion for a series of alkanes are shown.

Alkane formula	$\Delta_c H^\ominus$ / kJ mol^{-1}
$C_2H_6(g)$	−1560
$C_3H_8(g)$	−2219
$C_4H_{10}(l)$	−2877
$C_5H_{12}(l)$	−3509

Another alkane has an enthalpy change of combustion of −6125 kJ mol^{-1}.

Which is the most likely formula for this alkane?

☒ **A** C_6H_{14}

☒ **B** C_7H_{16}

☒ **C** C_8H_{18}

☒ **D** C_9H_{20}

(Total for Question 3 = 1 mark)

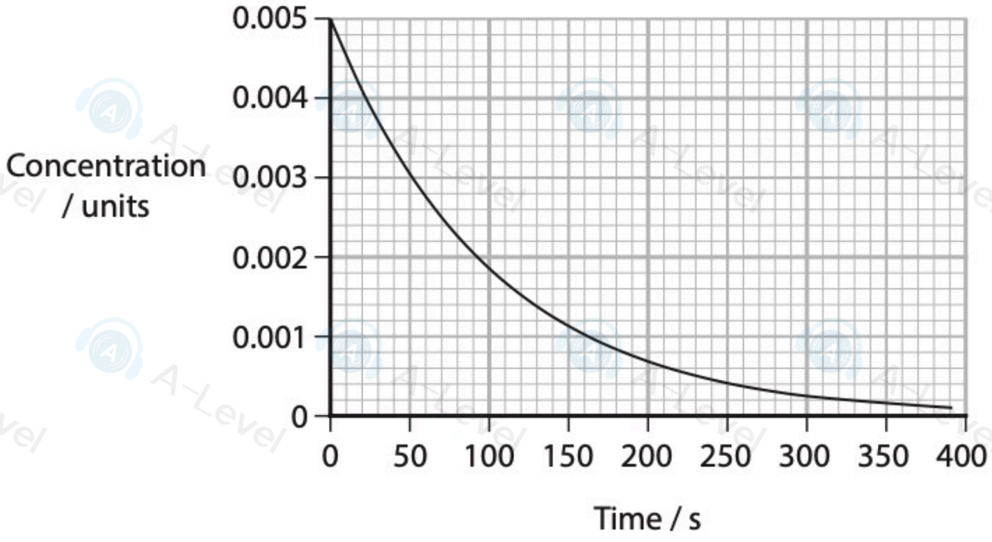
7 Sulfuric acid and sodium hydroxide react as shown.

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$$

Which sample of sulfuric acid solution will be exactly neutralised by $20\,cm^3$ of $0.5\,mol\,dm^{-3}$ sodium hydroxide?

		Volume of sulfuric acid / cm^3	Concentration of sulfuric acid / $mol\,dm^{-3}$
☒	**A**	20	0.25
☒	**B**	20	0.5
☒	**C**	40	0.5
☒	**D**	10	1.0

8 An experiment measuring the concentration of a reactant over time produced the graph shown.



(a) What is the approximate value of the initial rate of reaction?

(1)

☒ **A** 4.5×10^{-5}

☒ **B** 1.8×10^{-5}

☒ **C** 1.3×10^{-5}

☒ **D** 2.0×10^{-6}

(b) What are the units for the rate of reaction?

(1)

☒ **A** $mol\,s^{-1}$

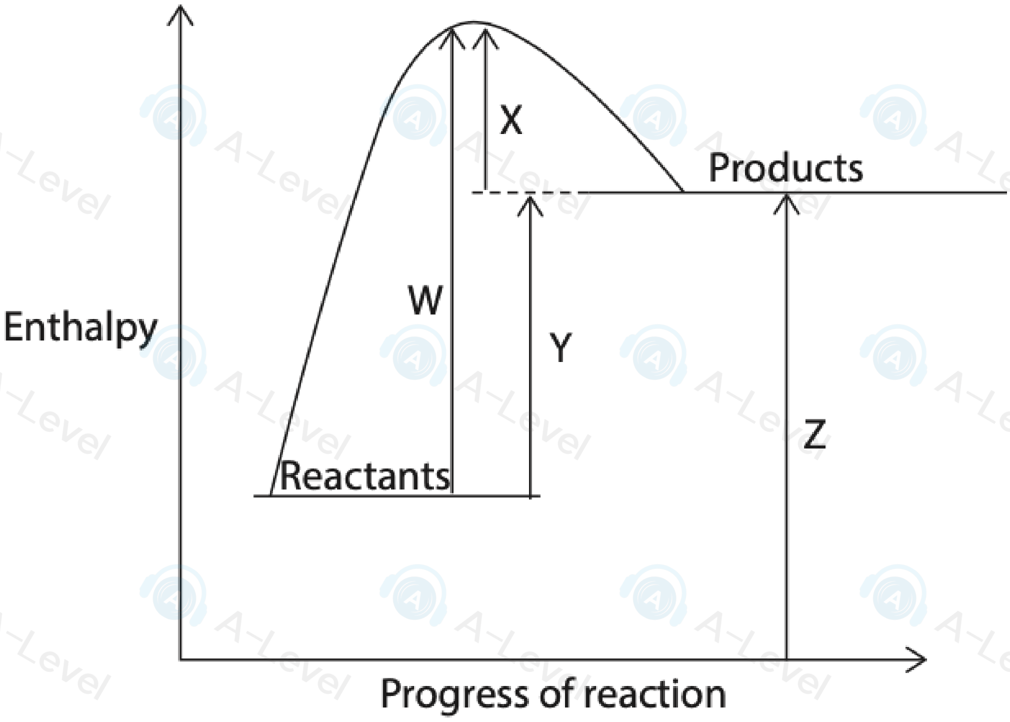
☒ **B** $mol\,dm^{-3}\,s^{-1}$

☒ **C** $mol\,dm^{3}\,s^{-1}$

☒ **D** $dm^{3}\,mol^{-1}\,s$

(Total for Question 8 = 2 marks)

2 The reaction profile for a reaction is shown.



Which arrow represents the activation energy of the forward reaction?

☒ **A** letter W

☒ **B** letter X

☒ **C** letter Y

☒ **D** letter Z

2 Which expression gives the standard enthalpy change, in kJ mol^{-1}, for the reaction shown?

$$BaCO_3(s) \rightarrow BaO(s) + CO_2(g)$$

$\Delta_f H^\ominus$ values: $BaCO_3(s) = -1216\ kJ\ mol^{-1}$

$BaO(s) = -554\ kJ\ mol^{-1}$

$CO_2(g) = -394\ kJ\ mol^{-1}$

☒ **A** –554 – 394 + 1216

☒ **B** –554 – 394 – 1216

☒ **C** 554 + 394 + 1216

☒ **D** 554 + 394 – 1216

(Total for Question 2 = 1 mark)

---

3 The enthalpy changes for two reactions are shown.

$$2Fe(s) + 1\tfrac{1}{2}O_2(g) \rightarrow Fe_2O_3(s) \qquad \Delta_r H^\ominus = -824\ kJ\ mol^{-1}$$

$$C(s) + \tfrac{1}{2}O_2(g) \rightarrow CO(g) \qquad \Delta_r H^\ominus = -111\ kJ\ mol^{-1}$$

What is the enthalpy change for the reaction between iron(III) oxide and carbon?

$$Fe_2O_3(s) + 3C(s) \rightarrow 2Fe(s) + 3CO(g)$$

☒ **A** +491 kJ mol^{-1}

☒ **B** +713 kJ mol^{-1}

☒ **C** –491 kJ mol^{-1}

☒ **D** –713 kJ mol^{-1}

(Total for Question 3 = 1 mark)

8: 20 g of an impure sample of calcium carbonate is heated and decomposes completely.
$3.6\,dm^3$ of carbon dioxide is produced at room temperature and pressure (r.t.p.).

What is the percentage purity of the sample?
Assume that the impurities do not produce carbon dioxide when heated.

[M_r $CaCO_3$ = 100 molar volume of a gas = $24\,dm^3\,mol^{-1}$ at r.t.p.]

☒ **A** 15%

☒ **B** 20%

☒ **C** 25%

☒ **D** 75%

14 What is the concentration, in $mol\,dm^{-3}$, when 64.5 g of sodium nitrate is dissolved in water to form $750\,cm^3$ of solution?

[M_r $NaNO_3$ = 85.0]

☒ **A** 0.086

☒ **B** 0.113

☒ **C** 0.759

☒ **D** 1.012

2 Which equation represents the standard enthalpy change of atomisation, $\Delta_{at}H^{\ominus}$, of bromine?

☒ **A** $\frac{1}{2}Br_2(l) \rightarrow Br(g)$

☒ **B** $\frac{1}{2}Br_2(g) \rightarrow Br(g)$

☒ **C** $Br_2(l) \rightarrow 2Br(g)$

☒ **D** $Br_2(g) \rightarrow 2Br(g)$

(Total for Question 2 = 1 mark)

12 A sample of 25.0 cm^3 of 0.205 mol dm^{-3} sulfuric acid was titrated with sodium hydroxide solution. The titre obtained was 14.60 cm^3.

(a) What is the concentration of the sodium hydroxide solution?

(1)

☒ **A** 0.176 mol dm^{-3}

☒ **B** 0.239 mol dm^{-3}

☒ **C** 0.351 mol dm^{-3}

☒ **D** 0.702 mol dm^{-3}

(b) What is the percentage error in the titre?

[The burette is accurate to 0.05 cm^3 per reading]

(1)

☒ **A** 0.10%

☒ **B** 0.34%

☒ **C** 0.40%

☒ **D** 0.68%

2 Excess zinc powder is added to 50.00 g of 0.500 mol dm^{-3} copper(II) sulfate solution in a polystyrene cup.
The mixture is stirred and the maximum temperature change determined.

The enthalpy change for the reaction is calculated to be −185 kJ mol^{-1}.

The data book value for this reaction is −217 kJ mol^{-1}.

(a) The percentage error in this experiment is

(1)

☒ **A** ±7.37 %

☒ **B** ±8.65 %

☒ **C** 14.7 %

☒ **D** 17.3 %

(b) In the calculation, the specific heat capacity of the liquid is taken to be 4.18 J g^{-1} °C^{-1} rather than the true value of 3.85 J g^{-1} °C^{-1}.

The use of 4.18 J g^{-1} °C^{-1} in the calculation

(1)

☒ **A** is partly responsible for the error in the final value obtained

☒ **B** lowers the error in the final value obtained

☒ **C** has a negligible effect on the final value obtained

☒ **D** has a negligible effect compared with the measurement uncertainties

(Total for Question 2 = 2 marks)

---

1 The mean C–F bond enthalpy is +485 kJ mol^{-1}.

Which process has an enthalpy change of +1940 kJ mol^{-1}?

☒ **A** $C(g) + 4F(g) \rightarrow CF_4(g)$

☒ **B** $C(s) + 2F_2(g) \rightarrow CF_4(g)$

☒ **C** $CF_4(g) \rightarrow C(g) + 4F(g)$

☒ **D** $CF_4(g) \rightarrow C(s) + 2F_2(g)$

(Total for Question 1 = 1 mark)

15 A volume of 10.0 cm^3 of magnesium chloride solution was added to an excess of sodium hydroxide solution, forming a precipitate of magnesium hydroxide. After filtering and drying, 0.398 g of magnesium hydroxide was obtained.

What was the concentration of the magnesium chloride solution?

[M_r $Mg(OH)_2$ = 58.3]

☒ **A** 0.00683 mol dm^{-3}

☒ **B** 0.0137 mol dm^{-3}

☒ **C** 0.683 mol dm^{-3}

☒ **D** 1.37 mol dm^{-3}

(Total for Question 15 = 1 mark)

---

7 Which equation shows the reaction that occurs when the standard enthalpy change of atomisation of iodine is measured?

☒ **A** $I_2(s) \rightarrow 2I(g)$

☒ **B** $\frac{1}{2}I_2(s) \rightarrow I(g)$

☒ **C** $I_2(g) \rightarrow 2I(g)$

☒ **D** $\frac{1}{2}I_2(g) \rightarrow I(g)$

16 Magnesium nitrate decomposes on heating according to the equation shown.

$$2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$$

One mole of magnesium nitrate is completely decomposed.

(a) What is the maximum volume of gas formed at 600 K and 101 000 Pa?

[$pV = nRT$ $R = 8.31\ \text{J mol}^{-1}\,\text{K}^{-1}$]

(1)

☒ **A** 0.025 m^3

☒ **B** 0.099 m^3

☒ **C** 0.123 m^3

☒ **D** 0.247 m^3

(b) What is the percentage yield if 25.0 g of magnesium oxide is produced?

[M_r MgO = 40.3]

(1)

☒ **A** 13.6 %

☒ **B** 16.9 %

☒ **C** 31.0 %

☒ **D** 62.0 %

1: 25 cm^3 of sodium hydroxide solution, of concentration 2.00 mol dm^{-3}, was added to 30 cm^3 of ethanoic acid solution, of concentration 1.00 mol dm^{-3}, in a polystyrene cup. The mixture was stirred, causing the temperature to increase by 6.5 °C.

(a) What is the expression for the enthalpy change of neutralisation of sodium hydroxide and ethanoic acid, in J mol^{-1}?

[Assume: the specific heat capacity of the mixture = 4.18 J g^{-1} °C^{-1}
the density of the mixture = 1.00 g cm^{-3}]

(1)

☒ **A** $-(25 \times 4.18 \times 6.5) \div 0.05$

☒ **B** $-(30 \times 4.18 \times 6.5) \div 0.03$

☒ **C** $-(55 \times 4.18 \times 6.5) \div 0.05$

☒ **D** $-(55 \times 4.18 \times 6.5) \div 0.03$

(b) The measurement uncertainty in the thermometer used in the experiment is ±0.5 °C for each reading.

What is the percentage uncertainty in the temperature change of 6.5 °C?

(1)

☒ **A** 3.8%

☒ **B** 7.7%

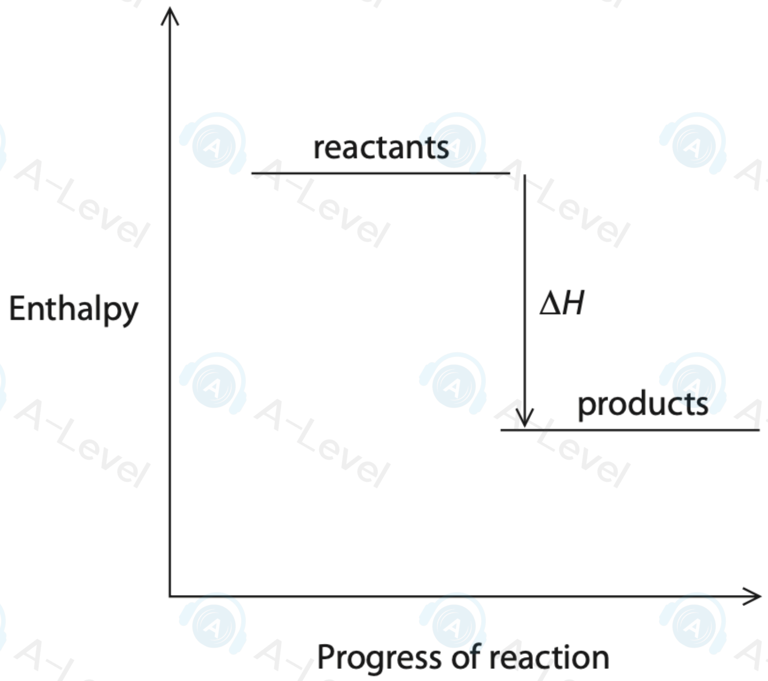
☒ **C** 15.4%

☒ **D** 30.8%

(Total for Question 1 = 2 marks)

Use this space for any rough working. Anything you write in this space will gain no credit.

1 The enthalpy level diagram for a reaction is shown.



Which is represented by this diagram?

☒ **A** $Na(s) \rightarrow Na(g)$

☒ **B** $Na(g) \rightarrow Na^+(g) + e^-$

☒ **C** $2Cl(g) \rightarrow Cl_2(g)$

☒ **D** $NH_4NO_3(s) + aq \rightarrow NH_4^+(aq) + NO_3^-(aq)$

(Total for Question 1 = 1 mark)

---

3 Which equation shows the reaction that occurs when the standard enthalpy change of formation of copper(II) carbonate is measured?

☒ **A** $Cu(s) + C(s) + 3O(g) \rightarrow CuCO_3(s)$

☒ **B** $2Cu(s) + 2C(s) + 3O_2(g) \rightarrow 2CuCO_3(s)$

☒ **C** $Cu(g) + C(g) + 1\frac{1}{2}O_2(g) \rightarrow CuCO_3(s)$

☒ **D** $Cu(s) + C(s) + 1\frac{1}{2}O_2(g) \rightarrow CuCO_3(s)$

(Total for Question 3 = 1 mark)

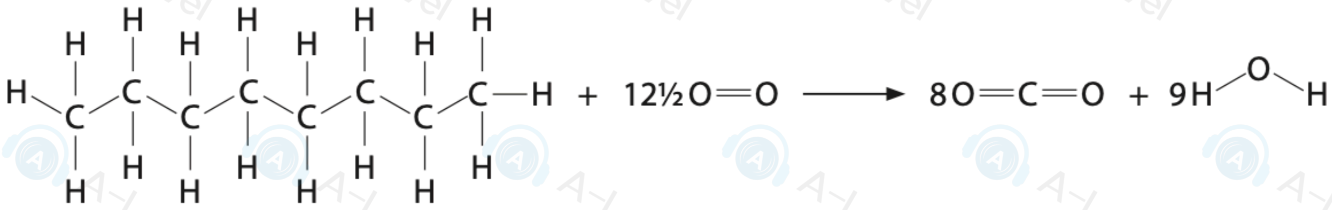
20 This question is about fuels.

The enthalpy change of combustion is the maximum amount of heat energy that can be obtained by the complete combustion of a substance.

Values for the enthalpy change of combustion may be obtained by direct measurement or from mean bond enthalpies. These data may be used to assess the efficiency of fuels.

Petrol is a mixture of a large number of different hydrocarbons containing between four and twelve carbon atoms. Octane, C_8H_{18}, is a typical component of petrol.

(a) The equation for the combustion of octane is shown.



(i) Use mean bond enthalpies to calculate a value for the enthalpy change of combustion of octane.

(4)

Bond	C—C	C—H	O—H	O=O	C=O
Mean bond enthalpy / kJ mol^{-1}	347	413	464	498	805

(ii) The standard enthalpy change of combustion, $\Delta_c H^\ominus$, of octane is $-5470\,\text{kJ}\,\text{mol}^{-1}$.

Give **two** reasons why this value, measured under standard conditions, is different from the value obtained using bond enthalpy data.

(2)

....

....

....

....

(iii) When petrol is used to power a car, the energy available is less than the theoretical maximum.
When one kilogram of petrol powers a car, the energy used to move the car is 11 MJ.

Calculate the percentage of the maximum energy that is available to move a car, assuming that this fuel is pure octane.

Use $\Delta_c H^\ominus = -5470\,\text{kJ}\,\text{mol}^{-1}$.

(2)

(iv) Give **two** reasons why the energy used to move the car is less than the theoretical maximum.

(2)

....

....

....

....

*(b) Two alternatives to hydrocarbon fuels are hydrogen and ammonia. Hydrogen burns to form water as the only product but hydrogen is extremely hard to liquefy. Ammonia is easily liquefied but it is toxic.

Compare and contrast the intermolecular forces involved when hydrogen and ammonia liquefy, by describing how these forces are formed.

(6)

18 This question is about sodium hydroxide.

(a) (i) Write an **ionic** equation for the neutralisation reaction between aqueous sodium hydroxide and hydrochloric acid.
State symbols are not required.

(1)

(ii) State what is meant by standard enthalpy change of neutralisation, $\Delta_{neut}H^{\ominus}$.

(2)

....

....

....

....

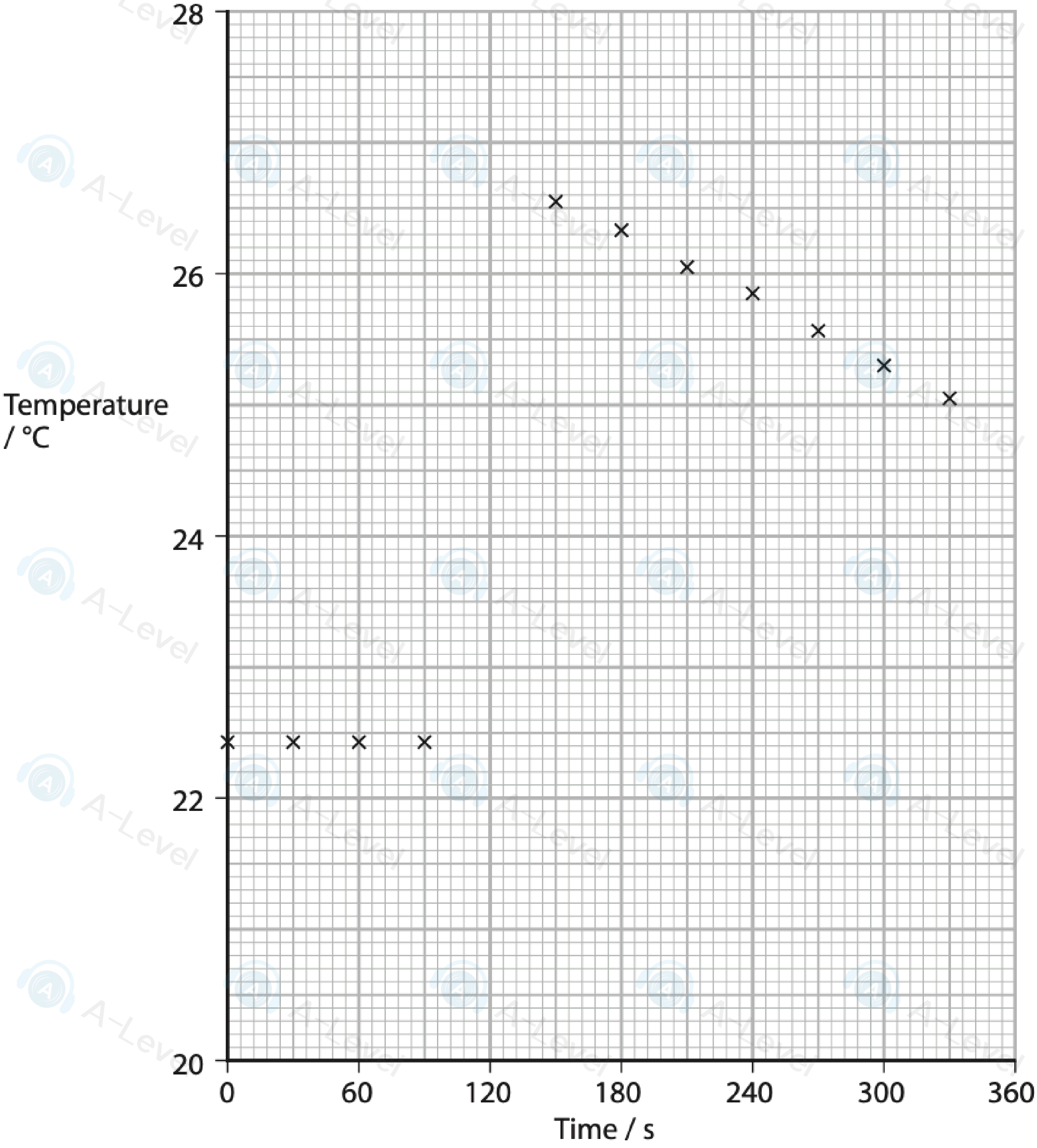
(b) A student carried out an investigation to determine the enthalpy change of neutralisation of aqueous sodium hydroxide by hydrochloric acid.

Method

- separate 25.0 cm^3 samples of 0.80 mol dm^{-3} sodium hydroxide and 0.80 mol dm^{-3} hydrochloric acid were left to reach room temperature
- after two minutes, the solutions were mixed in a copper calorimeter and the temperature was noted at 30 s intervals.

(i) Use the graph shown to determine the maximum temperature change, ΔT, in this experiment. You **must** show your working on the graph.

(2)



(ii) Calculate the enthalpy change of neutralisation using your answers to (a) and (b)(i). Give a sign and units with your answer.

Assume: no energy is used to heat the container.

the specific heat capacity of the solution = 4.2 J °C^{-1} g^{-1}.

the densities of the solutions of NaOH and HCl are 1.0 g cm^{-3}.

(3)

(iii) Explain how, if at all, the enthalpy change of neutralisation obtained in (b)(ii) would differ if the heat capacity of the calorimeter was included in the calculation.

(2)

(c) Aqueous sodium hydroxide reacts with 1-bromopropane to produce propan-1-ol.

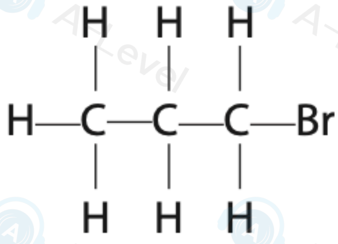
(i) State the type and mechanism of this reaction.

(1)

(ii) Complete the mechanism for this reaction.

Include curly arrows, and relevant lone pairs and dipoles.

(3)



$CH_3CH_2CH_2Br$

(iii) Under different conditions, sodium hydroxide reacts with 1-bromopropane to form propene.
Name the type of reaction and a suitable solvent.

(2)

Type of reaction ....

Suitable solvent ....

(Total for Question 18 = 16 marks)

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22 Ammonia, ammonium nitrate and urea are nitrogen-based fertilisers.
The nitrogen in the fertiliser is taken up by the roots of plants and promotes growth.

Ammonia, NH_3, is manufactured by the reaction between nitrogen and hydrogen.
The nitrogen is obtained from the air.

Hydrogen can be obtained by two methods.

Method 1

The hydrogen is usually obtained by reacting methane gas with steam.

$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$$

Method 2

Hydrogen can also be obtained using solar power to split water into hydrogen and oxygen.

$$2H_2O \rightarrow O_2 + 2H_2$$

(a) Evaluate which of these two methods used to obtain hydrogen is more sustainable.

(3)

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(b) Ammonia can be used directly as a fertiliser or converted to other compounds such as ammonium nitrate and urea.

Name of fertiliser	ammonia	ammonium nitrate	urea
Formula	NH_3	NH_4NO_3	NH_2CONH_2
% nitrogen by mass	82.4		46.7

(i) Complete the table by calculating the percentage by mass of nitrogen in ammonium nitrate.

(1)

(ii) Give **one** advantage and **one** disadvantage of applying ammonia directly into the soil as a fertiliser.
Use information in the table and your knowledge of ammonia.

(2)

Advantage

....

....

Disadvantage

....

....

(c) Ammonium nitrate, NH_4NO_3, can be made by reacting ammonia with nitric acid.

(i) Give the equation for this reaction. State symbols are not required.

(1)

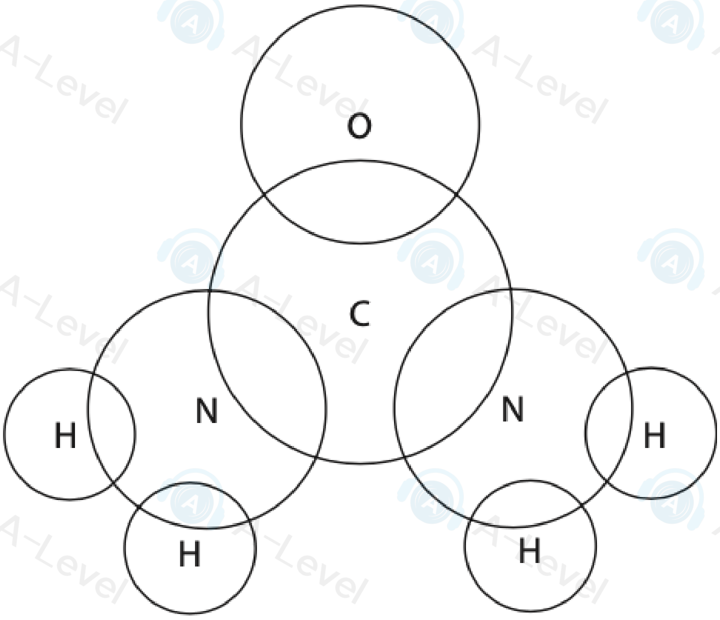
(ii) Name the type of reaction occurring.

(1)

(d) Urea, NH_2CONH_2, can also be made from ammonia.

Complete the dot-and-cross diagram for the urea molecule.

(2)



*(e) Both urea and ammonium nitrate are soluble in water.

Discuss the differences in the interactions of water molecules with both urea and ammonium nitrate.

Include **three** diagrams showing these interactions.

(6)

(f) A field needs 160 kg of N per hectare to be applied using urea fertiliser.
The field size is 500 m × 640 m.

[1 hectare (ha) = 10 000 m^2, molar mass of urea = 60 g mol^{-1}]

Urea contains 46.7 % N by mass.

Calculate the mass of urea, in tonnes, that needs to be applied to the field.

Give your answer to an appropriate number of significant figures.

(4)

SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

22 Ammonium nitrate, NH_4NO_3, is used in the manufacture of fertilisers and explosives.
It is produced on a large scale using only methane, water and air.
The process has four stages.

(a) The first two reactions in Stage **1** involve the production of hydrogen.

At temperature T_1, methane reacts with excess steam to give hydrogen.

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

At a different temperature, T_2, the carbon monoxide reacts with more steam.

$$CO(g) + H_2O(g) \rightleftharpoons H_2(g) + CO_2(g) \qquad \Delta H = -42\,kJ\,mol^{-1}$$

(i) Give the reason why excess steam is used in the first reaction.

(1)

....

....

....

....

(ii) Predict which of T_1 and T_2 is the **higher** temperature.
Justify your answer.

(1)

....

....

....

....

(iii) Derive the **overall** equation for the production of H_2 in Stage **1**.
State symbols are not required.

(1)

(b) The third reaction in Stage **1** involves the removal of carbon dioxide, using an aqueous solution of N-methyldiethanolamine, $CH_3N(CH_2CH_2OH)_2$.

$$CO_2(g) \; + \; H_2O(l) \; + \; 2CH_3N(CH_2CH_2OH)_2(aq) \rightleftharpoons (CH_3NH(CH_2CH_2OH)_2)_2CO_3(aq)$$

(i) Suggest **one** reason why CO_2 is removed.

(1)

(ii) Name the type of reaction occurring.

(1)

(iii) Draw the **displayed** formula of N-methyldiethanolamine, $CH_3N(CH_2CH_2OH)_2$.

(1)

(c) In Stage **2**, the hydrogen from Stage **1** reacts with nitrogen (from the air) to produce ammonia. The conditions for this reaction are:

- a temperature of 700 K
- a pressure in the range 100–200 atm
- an iron catalyst

$$N_2(g) \; + \; 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

Give **one** advantage and **one** disadvantage of using a pressure of 200 atm, compared to a pressure of 100 atm, in Stage **2**.

(2)

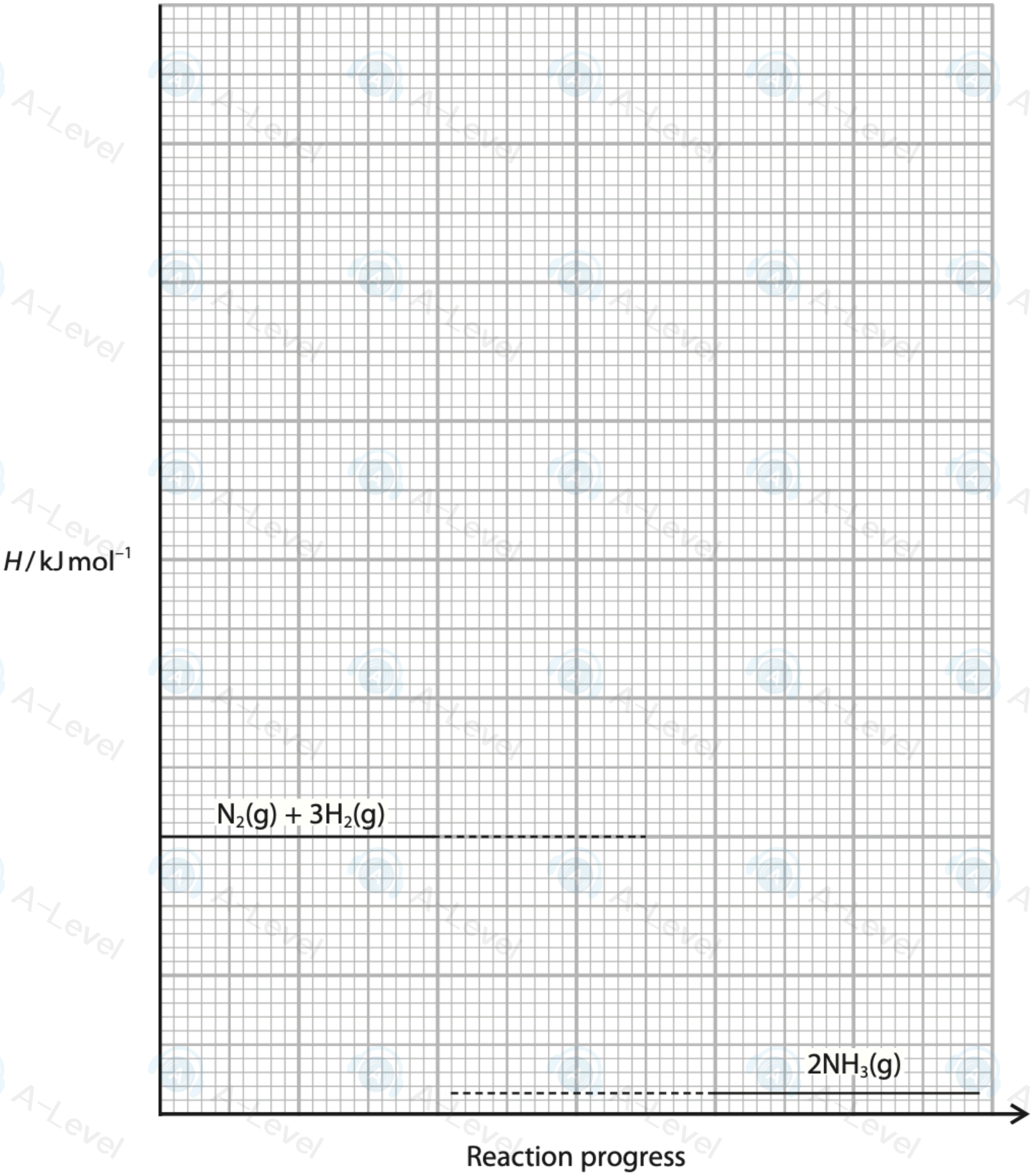
(d) The reaction in Stage **2** has an activation energy, $E_{cat} = +70\,kJ\,mol^{-1}$.

The **uncatalysed** reaction between N_2 and H_2 has an activation energy, $E_a = +290\,kJ\,mol^{-1}$.

(i) Complete the profile for the catalysed and uncatalysed reactions. Label the activation energies and the enthalpy change of reaction, Δ*H*.

Your diagram **must** match the scale shown for the production of NH_3.

(3)



(ii) Suggest why the use of the catalyst makes Stage **2** more sustainable.

(1)

(e) In Stage **3**, nitrogen monoxide, NO, is produced in the reaction between NH_3 (from Stage **2**) and O_2 (from the air). The conditions used are a temperature of 1100 K in the presence of a platinum-rhodium catalyst.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H = -905\,\text{kJ mol}^{-1}$$

(i) Give **one** reason why a high temperature is needed in this reaction.

(1)

(ii) Suggest why only a small amount of energy is used to maintain the temperature at 1100 K.

(1)

(f) The NO from the first reaction in Stage **3** is cooled and then converted to nitrogen dioxide, NO_2, by reaction with more O_2.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$$

Nitric acid, $HNO_3(aq)$, is produced by the addition of water.

$$3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(aq) + NO(g)$$

Explain how adding water in the second reaction affects the yield of NO_2 in the first reaction.

(2)

(g) In Stage **4**, a solution of NH_4NO_3 is produced by reacting NH_3 (from Stage **2**) with HNO_3 (from Stage **3**).

$$NH_3(g) + HNO_3(aq) \rightarrow NH_4NO_3(aq)$$

Data

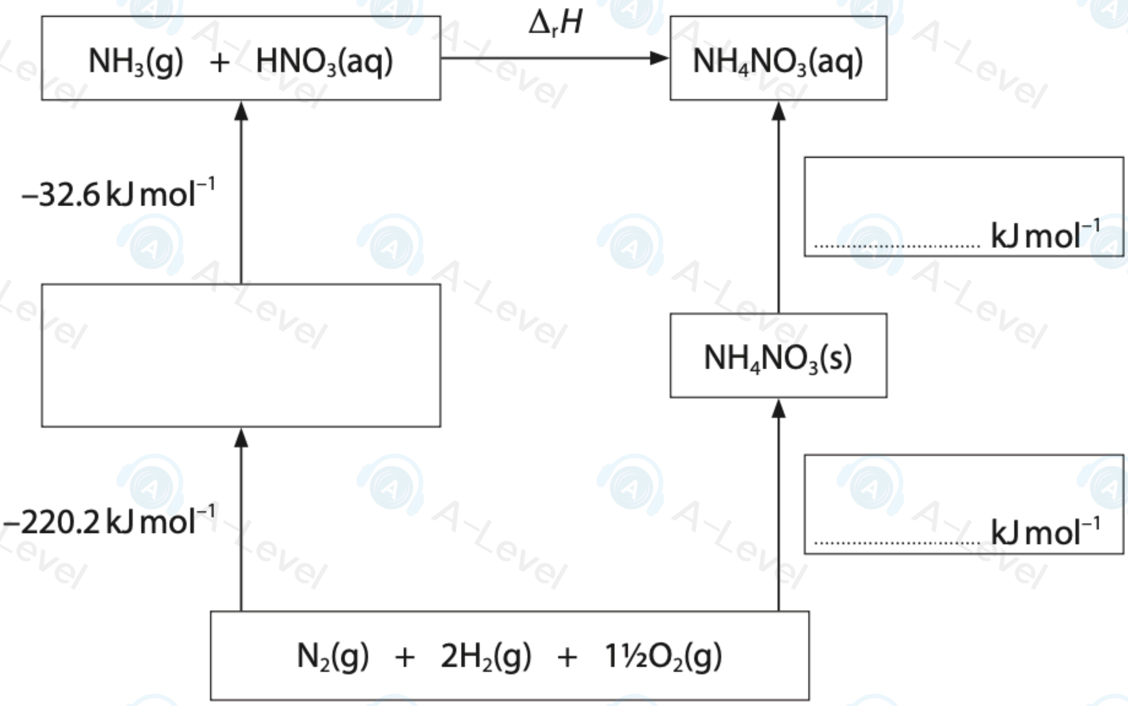
Species	$NH_3(g)$	$HNO_3(l)$	$NH_4NO_3(s)$
$\Delta_f H^\ominus$ / kJ mol^{-1}	–46.1	–174.1	–365.6

Equation	ΔH / kJ mol^{-1}
$HNO_3(l) + aq \rightarrow HNO_3(aq)$	–32.6
$NH_4NO_3(s) + aq \rightarrow NH_4NO_3(aq)$	+25.6

(i) Complete the enthalpy cycle.

(2)

Enthalpy cycle



(ii) Calculate the enthalpy change, $\Delta_r H$, in kJ mol^{-1}, for the reaction of $NH_3(g)$ with $HNO_3(aq)$.

(1)

(h) Suggest **two** reasons why it is more profitable to carry out all four stages at the **same** site, instead of using different sites for each stage in the industrial production of ammonium nitrate.

(2)

(Total for Question 22 = 21 marks)

TOTAL FOR SECTION C = 21 MARKS
TOTAL FOR PAPER = 80 MARKS

22 This question is about enthalpy changes.

A student wanted to use Hess's Law to determine the enthalpy change, $\Delta_r H_1$, in kJ mol^{-1}, for Reaction **1**.

Reaction **1** $Mg(s) + ½O_2(g) \rightarrow MgO(s)$ $\Delta_r H_1$

(a) Explain why $\Delta_r H_1$ can also be described as an enthalpy change of formation.

(2)

....

....

....

(b) The student carried out an experiment to determine the enthalpy change of reaction, $\Delta_r H_2$, in kJ mol^{-1}, for Reaction **2**.

Reaction **2** $MgO(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l)$ $\Delta_r H_2$

0.189 g of solid magnesium oxide was added to excess hydrochloric acid in a polystyrene cup and stirred until the reaction was complete.

The total mass of the solution formed was 25.0 g.

During the experiment, the temperature increased from 21.5°C to 28.0°C.

Calculate $\Delta_r H_2$, in kJ mol^{-1}, including a sign.

Give your answer to an appropriate number of significant figures.

[Specific heat capacity of the solution = 4.18 J g^{-1} °C^{-1}.]

(4)

(c) Calculate the enthalpy change of reaction, $\Delta_r H_1$, for Reaction **1**.
Use your answer to (b), the data provided and the enthalpy cycle shown.

[If you did not calculate an answer to (b), use a value of $-100\,\text{kJ mol}^{-1}$.
This is **not** the correct answer.]

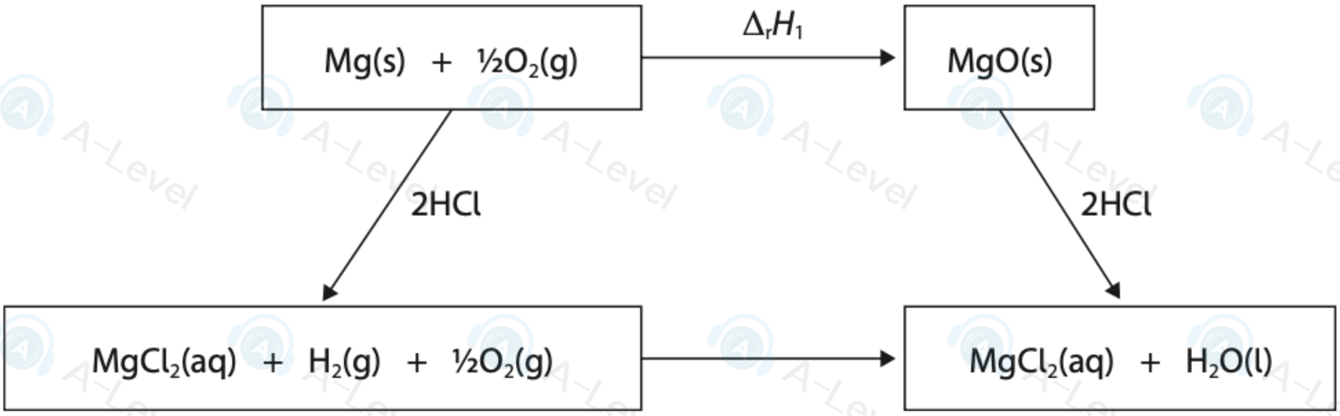
(2)

Data

$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$ $\Delta_r H = -462\,\text{kJ mol}^{-1}$

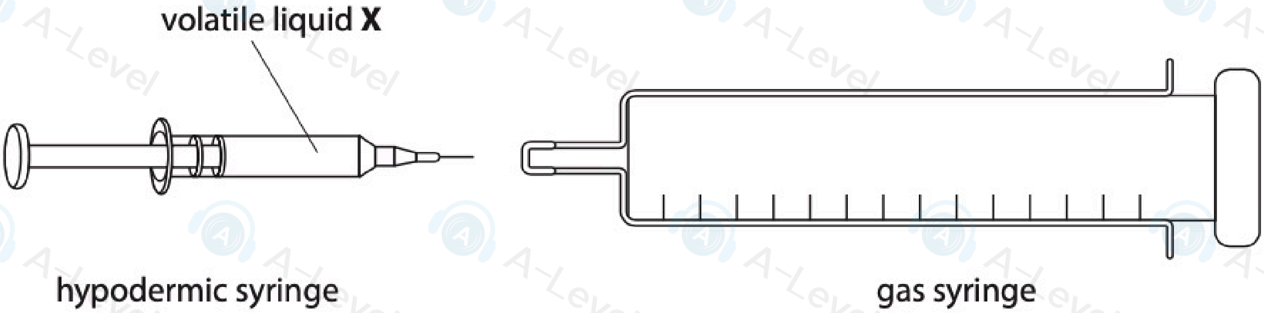
$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ $\Delta_f H = -286\,\text{kJ mol}^{-1}$

Enthalpy cycle



(Total for Question 22 = 8 marks)

18 A student determined the molecular mass of an unknown volatile organic liquid, **X**, using the apparatus shown.
The student used a hypodermic syringe to inject a sample of liquid **X** into a gas syringe.
The gas syringe was placed in an oven and liquid **X** vaporised.



Results

Mass of hypodermic syringe and liquid **X** before injection	5.71 g
Mass of hypodermic syringe and liquid **X** after injection	5.59 g
Mass of **X** added to the gas syringe	0.12 g
Temperature of oven	95 °C
Pressure of gas in the gas syringe	99 kPa
Volume of gas syringe after **X** had been vaporised	81 cm^3

(a) Calculate the relative molecular mass of liquid **X**.

$$pV = nRT \qquad \text{Gas constant } R = 8.31\ \text{J K}^{-1}\,\text{mol}^{-1}$$

(5)

(b) Each molecule of **X** contains carbon atoms, hydrogen atoms, and **one** atom of oxygen.
Identify **X**, by name or formula, using your answer from (a).

(1)

17: Magnesium carbonate has been studied recently as a potential material for the removal of carbon dioxide from the atmosphere.

(a) The value of n in a sample of a hydrated magnesium carbonate, $MgCO_3{\cdot}nH_2O$, can be determined by the reaction with hydrochloric acid.
The equation for the reaction is shown.

$$MgCO_3{\cdot}nH_2O(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + CO_2(g) + (n+1)H_2O(l)$$

Procedure Step **1** Add 0.0600 mol of hydrochloric acid (an excess) to a 2.35 g sample of the hydrated magnesium carbonate.

Step **2** When the reaction is complete, transfer the resulting solution to a 250 cm^3 volumetric flask, make up to the mark with deionised water, and mix thoroughly.

Step **3** Titrate 25.0 cm^3 portions of the solution with sodium hydroxide solution of concentration 0.0960 $mol\,dm^{-3}$.

Data The mean titre volume = 27.15 cm^3

Determine the value of n in the hydrated salt.

(7)

(b) The enthalpy change for the thermal decomposition of anhydrous magnesium carbonate, $\Delta_r H$, was measured indirectly using the enthalpy changes for the two reactions shown and applying Hess's Law.

Reaction **1**

$MgO(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l)$ $\Delta_r H_1$

Reaction **2**

$MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l) + CO_2(g)$ $\Delta_r H_2 = +3.58\,kJ\,mol^{-1}$

An experiment was carried out to measure the enthalpy change of reaction, $\Delta_r H_1$, for Reaction **1**.

1.92 g of magnesium oxide was added, with stirring, to
40.0 cm^3 dilute hydrochloric acid (an excess) in an insulated container.
The temperature rise was 30.8 °C.

(i) Calculate $\Delta_r H_1$ for Reaction **1**. Include a sign and units in your answer.

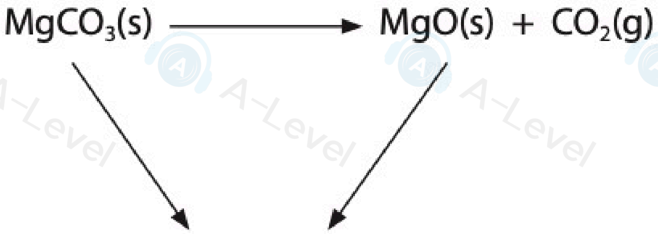
[Assume the specific heat capacity of the solution = 4.18 $J\,g^{-1}\,°C^{-1}$
the density of the solution = 1.00 $g\,cm^{-3}$]

(3)

(ii) The enthalpy change of decomposition, $\Delta_r H$, of magnesium carbonate can be found using a Hess cycle.
Calculate the enthalpy change of decomposition by using a completed Hess cycle, your answer to (b)(i) and the enthalpy change of reaction for Reaction **2**.

Give your answer to an appropriate number of significant figures.

(3)



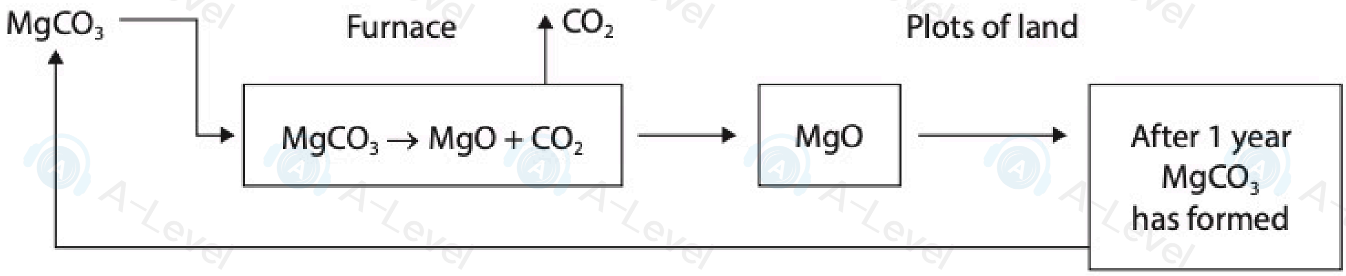
(iii) Give a reason why it is not possible to measure the enthalpy change for the decomposition directly.

(1)

....

....

(c) The steps involved in using magnesium carbonate ore in a process to capture carbon dioxide from the air are shown.



- the magnesium carbonate ore is heated in a furnace and decomposes and the carbon dioxide produced is stored
- the magnesium oxide produced is transported to plots of land where it is spread to a depth of 0.1 m and reacts with carbon dioxide over a year
- the magnesium carbonate formed is then returned to the furnace and the process repeated.

Heating the furnace to decompose the magnesium carbonate accounts for most of the energy requirements of the process.

(i) Explain, with reference to the thermal stability of the Group 2 carbonates, why the use of calcium carbonate rather than magnesium carbonate would increase the cost of the process.

(3)

....

....

(ii) Methanol can be produced from the captured carbon dioxide by reaction with hydrogen using a copper catalyst.
The equation for the reaction is shown.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \qquad \Delta H = -49.5\,\text{kJ mol}^{-1}$$

Explain why the conditions for the industrial production of methanol are a pressure of 50 atmospheres and a temperature of 250 °C.

(4)