4 Nitrogen reacts with hydrogen to form ammonia.

$$\tfrac{1}{2}N_2(g) \ + \ 1\tfrac{1}{2}H_2(g) \ \rightleftharpoons \ NH_3(g) \qquad \Delta_f H = -46 \text{ kJ mol}^{-1}$$

Bond	Bond enthalpy/kJ mol^{-1}
H—H	436
N≡N	945

What is the bond enthalpy, in kJ mol^{-1}, of the N—H bond?

☒ **A** 360

☒ **B** 391

☒ **C** 548

☒ **D** 1173

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** $\tfrac{1}{2}I_2(s) \rightarrow I(g)$

☒ **C** $I_2(g) \ \rightarrow \ 2I(g)$

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

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)

5 The boiling temperature of hexane is 69 °C and that of cyclohexane is 81 °C.

The main reason that cyclohexane has a higher boiling temperature is that cyclohexane molecules

☒ **A** have more electrons

☒ **B** have strong permanent dipole-permanent dipole forces

☒ **C** have a larger surface area of contact

☒ **D** form hydrogen bonds

(Total for Question 5 = 1 mark)

4 Which alkane has the strongest London forces in the liquid phase?

☒ **A** $(CH_3)_4C$

☒ **B** $CH_3CH_2CH_2CH_2CH_3$

☒ **C** $(C_2H_5)_4C$

☒ **D** $CH_3(CH_2)_7CH_3$

(Total for Question 4 = 1 mark)

4 Which compound has London forces as the **only** intermolecular force?

☒ **A** HF

☒ **B** OF_2

☒ **C** PF_3

☒ **D** CF_4

(Total for Question 4 = 1 mark)

3 A compound contains

- molecules with non-polar bonds
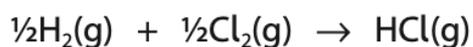- permanent dipole-permanent dipole forces between its molecules.

What could be the formula of this compound?
Use the Data Booklet as a source of information.

☒ **A** NO

☒ **B** $BeCl_2$

☒ **C** PH_3

☒ **D** CI_4

(Total for Question 3 = 1 mark)

3 The enthalpy change of reaction, $\Delta_r H$, for the equation shown can be calculated using bond enthalpy data.

$$\frac{1}{2}H_2(g) + \frac{1}{2}Cl_2(g) \rightarrow HCl(g)$$

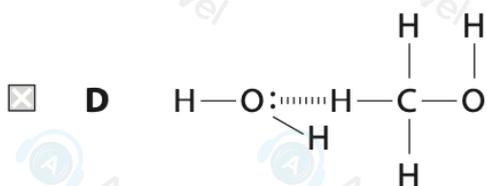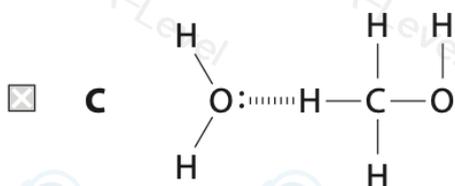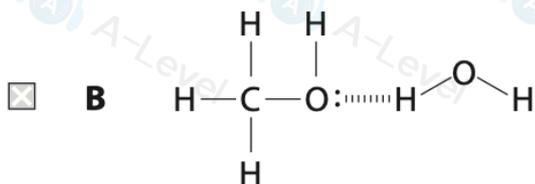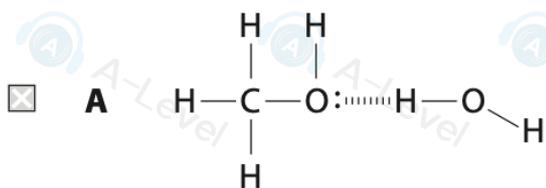| Bond	Bond enthalpy / kJ mol^{-1}
H—H	436
Cl—Cl	242
H—Cl	431

The expression that should be used in the calculation is

☒ **A** $(0.5 \times 436 + 0.5 \times 242) - 431$

☒ **B** $(2 \times 431) - (436 + 242)$

☒ **C** $431 - (0.5 \times 436 + 0.5 \times 242)$

☒ **D** $(436 + 242) - (2 \times 431)$

(Total for Question 3 = 1 mark)

7 Hydrogen bonds are formed when methanol dissolves in water.

Which structure best represents a hydrogen bond between methanol and water?

☒ **A**

$$
\begin{array}{c}
\quad\ \ \text{H}\quad\ \text{H} \\
\quad\ \ | \qquad | \\
\text{H}-\text{C}-\ddot{\text{O}}\text{:}\cdots\cdots\text{H}-\text{O} \\
\quad\ \ | \qquad\qquad\qquad \backslash \\
\quad\ \ \text{H} \qquad\qquad\qquad\ \text{H}
\end{array}
$$

☒ **B**

$$
\begin{array}{c}
\quad\ \ \text{H}\quad\ \text{H} \\
\quad\ \ | \qquad | \\
\text{H}-\text{C}-\ddot{\text{O}}\text{:}\cdots\cdots\text{H}\quad\ \text{O}-\text{H} \\
\quad\ \ | \qquad\qquad\qquad\ \nearrow \\
\quad\ \ \text{H}
\end{array}
$$

☒ **C**

$$
\begin{array}{c}
\text{H}\qquad\qquad\quad\ \text{H}\quad\ \text{H} \\
\ \backslash\qquad\qquad\quad\ | \qquad | \\
\quad\ \ \ddot{\text{O}}\text{:}\cdots\cdots\text{H}-\text{C}-\text{O} \\
\ /\qquad\qquad\qquad\ | \\
\text{H}\qquad\qquad\qquad\ \text{H}
\end{array}
$$

☒ **D**

$$
\begin{array}{c}
\qquad\qquad\qquad\quad \text{H}\quad\ \text{H} \\
\qquad\qquad\qquad\quad | \qquad | \\
\text{H}-\ddot{\text{O}}\text{:}\cdots\cdots\text{H}-\text{C}-\text{O} \\
\qquad\quad \backslash\qquad\qquad\quad | \\
\qquad\qquad \text{H}\qquad\qquad\ \text{H}
\end{array}
$$

(Total for Question 7 = 1 mark)

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)

---

2 In which process are intermolecular hydrogen bonds broken?

☒ **A** $H_2(g) \rightarrow 2H(g)$

☒ **B** $H_2O(l) \rightarrow H_2O(g)$

☒ **C** $H_2(l) \rightarrow H_2(g)$

☒ **D** $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g)$

(Total for Question 2 = 1 mark)

15 The compounds **W**, **X**, **Y** and **Z** have different boiling temperatures.

$CH_3CH_2CH_2CH_3$

$H_3C-\underset{\underset{H}{|}}{\overset{\overset{CH_3}{|}}{C}}-CH_3$

Compound W

Compound X

$CH_3CH_2CH_2CH_2Br$

$H_3C-\underset{\underset{Br}{|}}{\overset{\overset{CH_3}{|}}{C}}-CH_3$
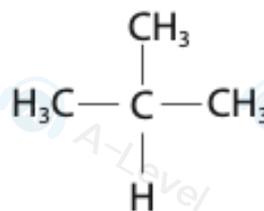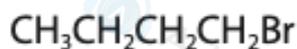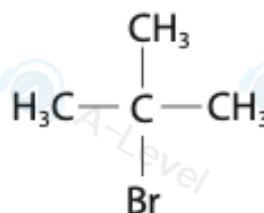
Compound Y

Compound Z

Which is the correct order of **increasing** boiling temperature?

☒   **A**   X < W < Z < Y

☒   **B**   X < Z < W < Y

☒   **C**   W < X < Y < Z

☒   **D**   X < W < Y < Z

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 $4.18\ J\ g^{-1}\ ^{\circ}C^{-1}$ rather than the true value of $3.85\ J\ g^{-1}\ ^{\circ}C^{-1}$.

The use of $4.18\ J\ g^{-1}\ ^{\circ}C^{-1}$ 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)

---

5 Which compound has intermolecular hydrogen bonding?

☒ **A** $(CH_3)_3N$

☒ **B** $(CH_3)_3CF$

☒ **C** $(CH_3)_3COH$

☒ **D** $(CH_3)_3CCHO$

(Total for Question 5 = 1 mark)

6 In an experiment to calculate the enthalpy change of neutralisation, $\Delta_{neut}H$, 25 cm³ of 0.1 mol dm⁻³ hydrochloric acid, HCl, was reacted with 25 cm³ of 0.1 mol dm⁻³ sodium hydroxide solution. The increase in temperature, ΔT, was recorded.

[Assume the density of the solutions = 1.00 g cm⁻³

Specific heat capacity of solutions = 4.2 J g⁻¹ °C⁻¹]

(a) Which is the correct expression to calculate the enthalpy change of neutralisation for this reaction, in J mol⁻¹?

(1)

☒ **A** $\dfrac{\Delta T \times 4.2 \times 50}{5.0 \times 10^{-3}}$

☒ **B** $\dfrac{\Delta T \times 4.2 \times 25}{2.5 \times 10^{-3}}$

☒ **C** $\dfrac{-\Delta T \times 4.2 \times 50}{5.0 \times 10^{-3}}$

☒ **D** $\dfrac{-\Delta T \times 4.2 \times 50}{2.5 \times 10^{-3}}$

(b) The table below shows the measurement uncertainty of some laboratory apparatus.

Apparatus	Measurement uncertainty on each reading /cm³
burette	+/− 0.05
25 cm³ measuring cylinder	+/− 0.5
25 cm³ volumetric flask	+/− 0.1
25 cm³ pipette	+/− 0.06

Which piece of apparatus would measure 25 cm³ of hydrochloric acid with the **lowest** percentage uncertainty?

(1)

☒ **A** burette

☒ **B** measuring cylinder

☒ **C** volumetric flask

☒ **D** pipette

2 The reaction profile for a reaction is shown.
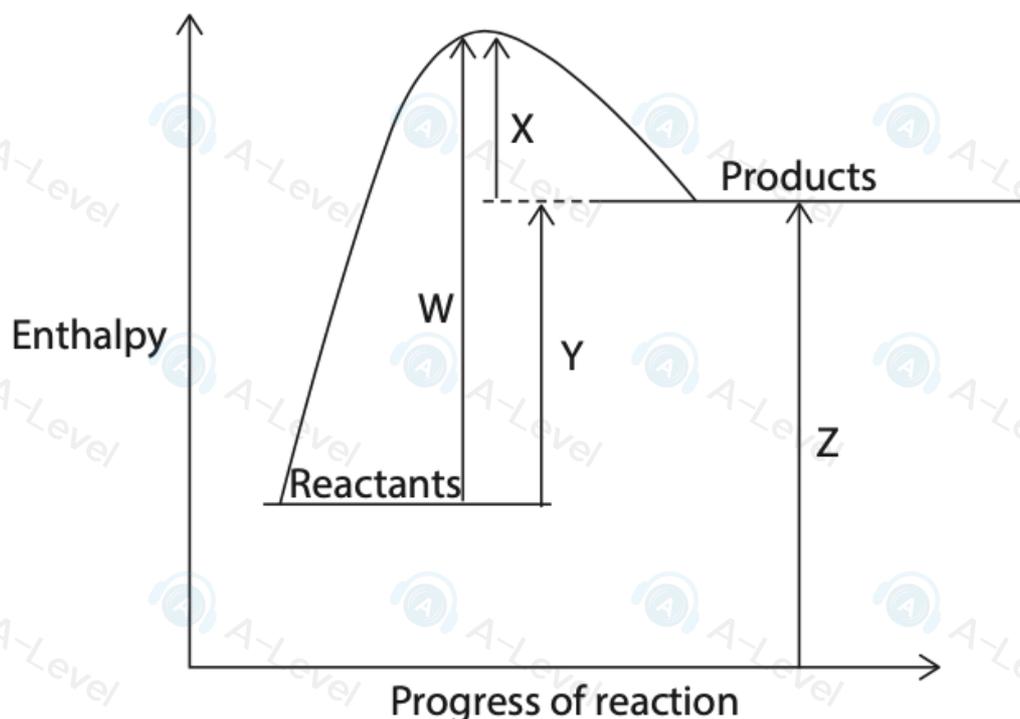
Which arrow represents the activation energy of the forward reaction?

☒ **A** letter W

☒ **B** letter X

☒ **C** letter Y

☒ **D** letter Z

11 Which alkane has the **highest** boiling temperature?

☒ **A** hexane

☒ **B** pentane

☒ **C** 2-methylpentane

☒ **D** 2,3-dimethylbutane

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)

4 Which of these alkanes would be expected to have the **highest** boiling temperature?

☒ **A**

☒ **B**

☒ **C**

☒ **D**
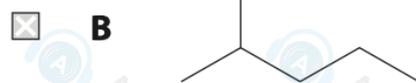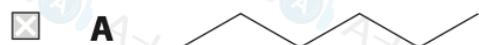
(Total for Question 4 = 1 mark)

3: Which amine, with molecular formula C_3H_9N, has the **lowest** boiling temperature?

☒ **A** $(CH_3)_3N$

☒ **B** $CH_3CH_2NHCH_3$

☒ **C** $CH_3CH_2CH_2NH_2$

☒ **D** $CH_3CH(NH_2)CH_3$

(Total for Question 3 = 1

18 Water is a molecule that is essential for life and it has some unusual properties.

(a) Draw a diagram to show hydrogen bonding between two H_2O molecules in ice.

Include bond angles and relevant dipoles and lone pairs in your answer.

(3)

(b) Compare and contrast the effect of intermolecular forces on the properties of water and ammonia, using the data shown.

(3)

Molecule	M_r	Boiling temperature /K	Density at 223 K /kg m^{-3}	Density at 278 K /kg m^{-3}
NH$_3$	16.0	240	698	0.763
H$_2$O	18.0	373	926	1000

16 This question is about magnesium sulfate, a white ionic solid that is very soluble in water.

Hydrated magnesium sulfates have the general formula of $MgSO_4 \cdot xH_2O$, where x is the number of water molecules of crystallisation.

(a) A sample of hydrated magnesium sulfate was heated until all the water had been removed from the crystals.

The mass of the sample decreased from 6.92 g to 6.04 g.

[M_r $MgSO_4$ = 120.4]

(i) State how you could ensure that all the water had been removed from the crystals.

(1)

....

....

....

(ii) Calculate the number of water molecules of crystallisation, x, in the formula of this sample of hydrated magnesium sulfate.

(3)

(b) The most common form of hydrated magnesium sulfate is $MgSO_4 \cdot 7H_2O$.
A student carried out two experiments to determine the enthalpy change when anhydrous magnesium sulfate forms $MgSO_4 \cdot 7H_2O$.

$$MgSO_4(s) + 7H_2O(l) \rightarrow MgSO_4 \cdot 7H_2O(s)$$
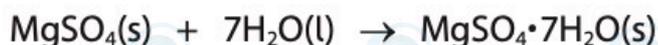
(i) In the first experiment, the student determined the enthalpy change when dissolving anhydrous magnesium sulfate.

$$MgSO_4(s) + (aq) \rightarrow MgSO_4(aq)$$
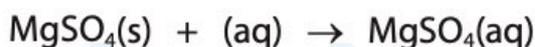
100.0 g of distilled water was placed in a polystyrene cup and the temperature recorded.

0.0628 mol of anhydrous magnesium sulfate was added to the distilled water, the mixture stirred and the maximum temperature recorded.

Results

Starting temperature of distilled water / °C	16.6
Maximum temperature of solution / °C	29.4

Calculate the enthalpy change for this reaction.
Give your answer to an appropriate number of significant figures and include a sign and units.

[Assume: Specific heat capacity of the solution is $4.18\,J\,g^{-1}\,°C^{-1}$
Density of the solution is $1.00\,g\,cm^{-3}$]

(4)

(ii) In the second experiment, the student determined the enthalpy change when dissolving hydrated magnesium sulfate.

$$MgSO_4 \cdot 7H_2O(s) + (aq) \rightarrow MgSO_4(aq) \qquad \Delta H = +15.8 \, kJ \, mol^{-1}$$

Complete the Hess cycle.

(2)

| $MgSO_4(s) + 7H_2O(l)$ | $\longrightarrow$ | $MgSO_4 \cdot 7H_2O(s)$ |
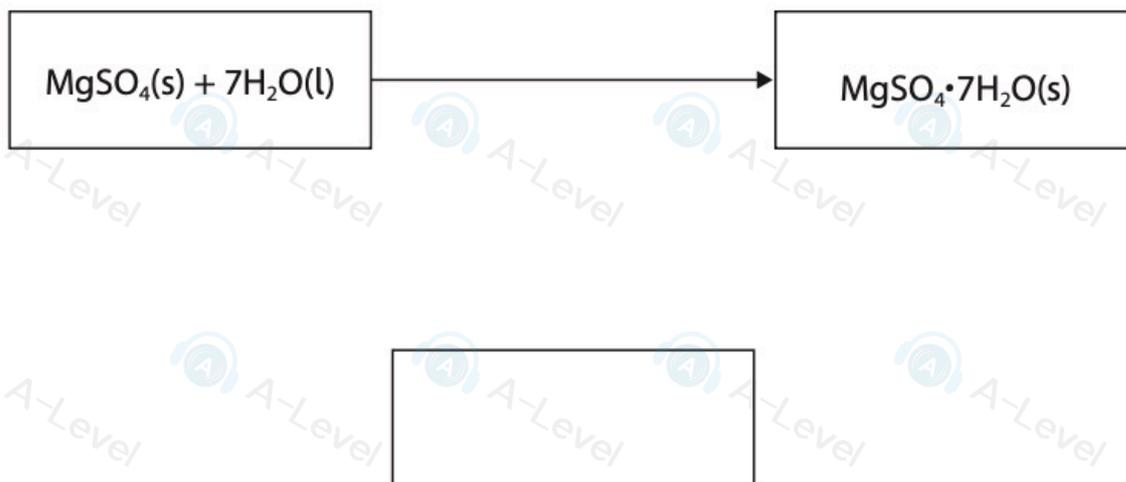
(iii) Calculate the enthalpy change when anhydrous magnesium sulfate forms hydrated magnesium sulfate, using the completed Hess cycle and your answer in (b)(i).

(2)

(c) Magnesium sulfate is very soluble in water.

   (i) Draw a labelled diagram showing how both the magnesium ion and the
        sulfate ion interact with water molecules.

                                                                            (2)

   (ii) Barium ions are toxic in aqueous solution. If a solution containing barium ions
         enters the body, barium poisoning occurs.

         Describe how drinking magnesium sulfate solution can reduce the extent of
         the poisoning.
         Include an ionic equation with state symbols in your answer.

                                                                            (2)

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                                                  (Total for Question 16 = 16 marks)

18 This question is about Group 2 carbonates.

Group 2 carbonates decompose on heating to form the corresponding metal oxide and carbon dioxide. The general equation is shown.

$$MCO_3(s) \rightarrow MO(s) + CO_2(g)$$

(a) A sample of magnesium carbonate was heated for 4 minutes.
The mass of the sample decreased from 4.17 g to 2.35 g.

Calculate the percentage of magnesium carbonate that has decomposed.

[Molar mass of magnesium carbonate = 84.3 g mol^{-1}]

(3)

(b) The enthalpy change, $\Delta_r H$, for the thermal decomposition of magnesium carbonate, $MgCO_3$, can be calculated using the data in the table.

Substance	Enthalpy change of formation / kJ mol^{-1}
$MgCO_3$	−1095.8
MgO	−601.7
CO_2	−393.5

(i) Complete the Hess cycle with two arrows and correct species and state symbols in the box.

(2)

```
┌─────────────────────┐        Δ,H        ┌─────────────────────┐
│                     │ ────────────────► │                     │
│     MgCO₃(s)        │                   │   MgO(s) + CO₂(g)   │
│                     │                   │                     │
└─────────────────────┘                   └─────────────────────┘
```

```
┌─────────────────────────────────┐
│                                 │
│                                 │
│                                 │
│                                 │
│                                 │
└─────────────────────────────────┘
```
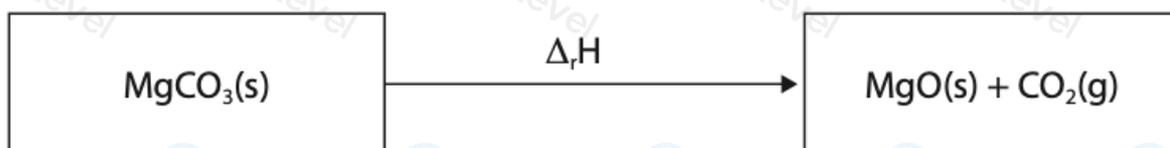
(ii) Calculate the enthalpy change for the thermal decomposition of magnesium carbonate, $\Delta_r H$. Include a sign and units in your answer.

(2)

(c) Explain how the enthalpy change for the thermal decomposition of calcium carbonate, $CaCO_3$, compares to that for magnesium carbonate in (b)(ii).

(3)

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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.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g) \qquad \Delta H = +206\,kJ\,mol^{-1}$$
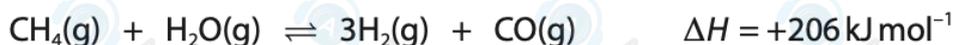
At a different temperature, T_2, the carbon monoxide reacts with more steam.

$$CO(g) + H_2O(g) \rightleftharpoons H_2(g) + CO_2(g) \qquad \Delta H = -42\,kJ\,mol^{-1}$$
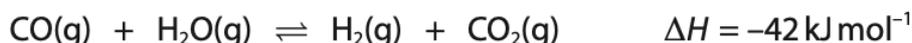
(i) Give the reason why excess steam is used in the first reaction.

(1)

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

(1)

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(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, $CH_3N(CH_2CH_2OH)_2$.

$$CO_2(g) + H_2O(l) + 2CH_3N(CH_2CH_2OH)_2(aq) \rightleftharpoons (CH_3NH(CH_2CH_2OH)_2)_2CO_3(aq)$$
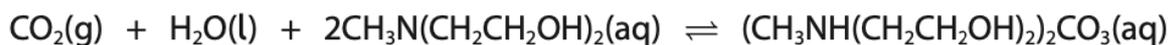
(i) Suggest **one** reason why CO_2 is removed.

(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

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92 \, kJ \, mol^{-1}$$
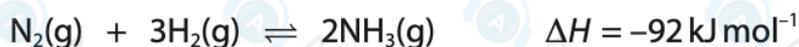
Give **one** advantage and **one** disadvantage of using a pressure of 200 atm, compared to a pressure of 100 atm, in Stage **2**.

(2)

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....

....

....

(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, ΔH.

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

(3)

$H/kJ\,mol^{-1}$

$N_2(g) + 3H_2(g)$

$2NH_3(g)$

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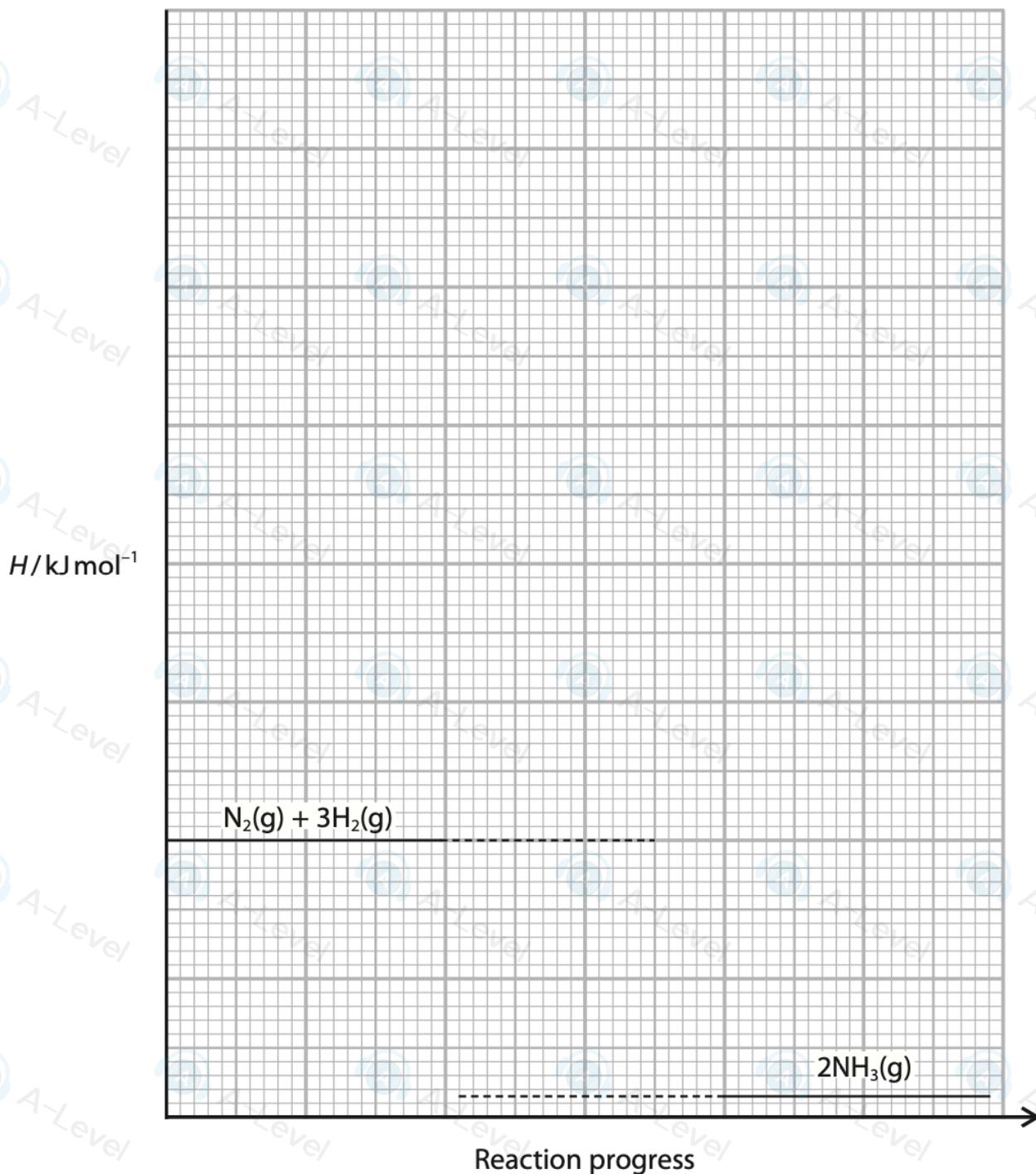
(ii) Suggest why the use of the catalyst makes Stage **2** more sustainable.

(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.

$$4NH_3(g) \ + \ 5O_2(g) \ \rightleftharpoons \ 4NO(g) \ + \ 6H_2O(g) \qquad \Delta H = -905 \, kJ \, mol^{-1}$$
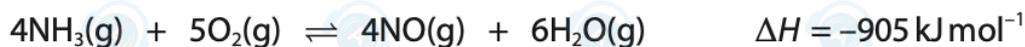
(i) Give **one** reason why a high temperature is needed in this reaction.

(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.

$$2NO(g) \ + \ O_2(g) \ \rightleftharpoons \ 2NO_2(g)$$
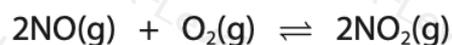
Nitric acid, $HNO_3(aq)$, is produced by the addition of water.

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

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

(2)

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

Equation	$\Delta H/\text{kJ mol}^{-1}$
$HNO_3(l) \; + \; aq \; \rightarrow \; HNO_3(aq)$	−32.6
$NH_4NO_3(s) \; + \; aq \; \rightarrow \; NH_4NO_3(aq)$	+25.6

(i) Complete the enthalpy cycle.

(2)

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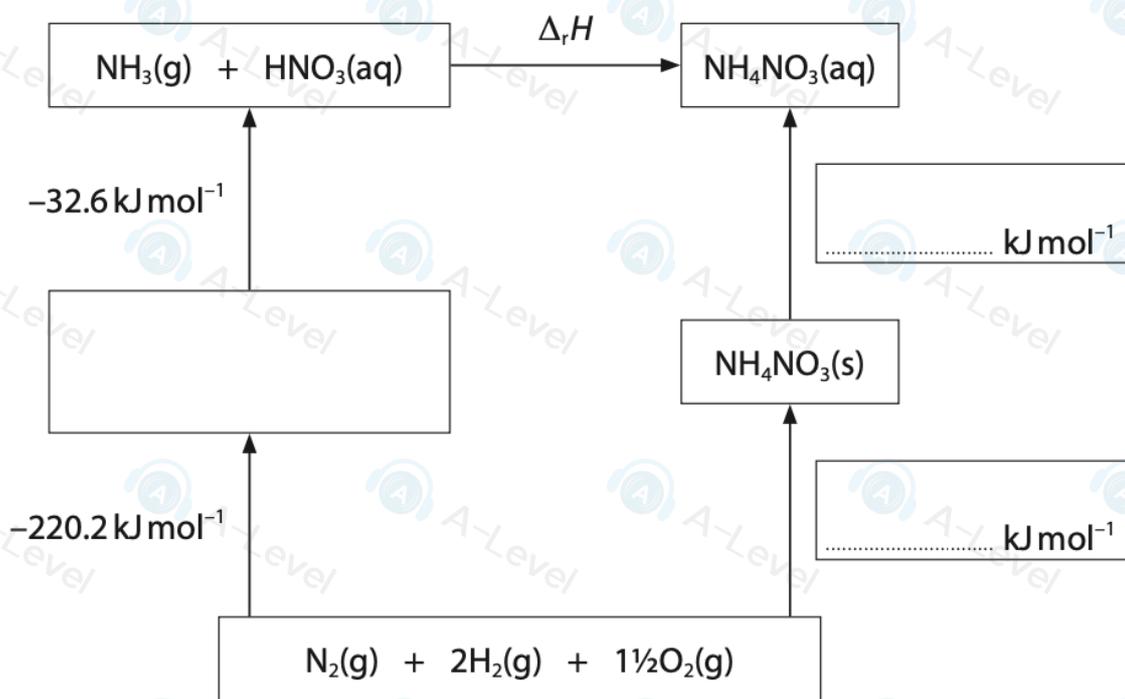
(ii) Calculate the enthalpy change, $\Delta_r H$, in kJ mol^{-1}, for the reaction of $NH_3(g)$ with $HNO_3(aq)$.

(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)

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(Total for Question 22 = 21 marks)

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

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)

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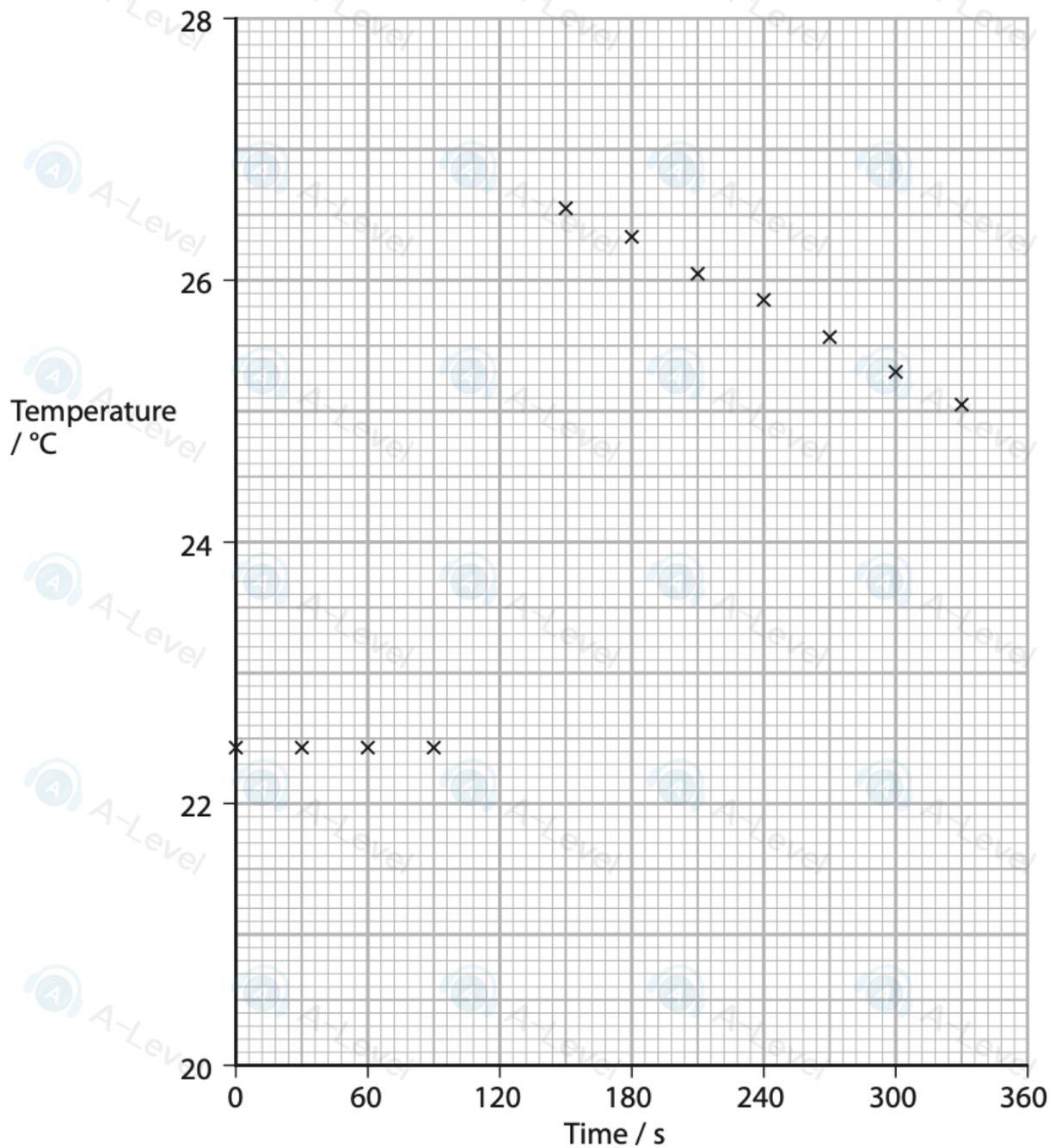
(ii) Calculate the enthalpy change of neutralisation using your answers to (a) and (b)(i). Give a sign and units with your answer.

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)

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

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

(1)

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(ii) Complete the mechanism for this reaction.

Include curly arrows, and relevant lone pairs and dipoles.

(3)
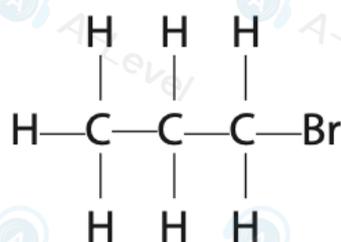
(iii) Under different conditions, sodium hydroxide reacts with 1-bromopropane to form propene.
Name the type of reaction and a suitable solvent.

(2)

Type of reaction

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Suitable solvent

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(Total for Question 18 = 16 marks)