1. Hydrogen gas is manufactured by the chemical industry from the reversible reaction of methane and steam, shown below.

$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ $\Delta H = +195$ kJ mol^{-1}

Average bond enthalpies are shown in the table.

Bond	H−H	O−H	C=O
Average bond enthalpy / kJ mol^{-1}	+436	+464	+1077

i. Why do all average bond enthalpies have a positive value?

[1]

ii. Determine the C−H bond enthalpy, in kJ mol^{-1}, using the information above.

C−H bond enthalpy = ... kJ mol^{-1} **[3]**

iii. Hydrogen gas is being considered as a household fuel to replace methane.

The enthalpy change of formation, $\Delta_f H$, for $H_2O(l)$ is −285.8 kJ mol^{-1}.

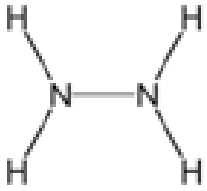
Determine the energy released when 60.0 m^3 of hydrogen is used as a household fuel at RTP.

Give your answer to **3** significant figures and in **standard form**.

energy released = ... kJ **[2]**

2. This question is about covalent compounds of nitrogen.

Hydrazine, N_2H_4, shown below, can be used as a rocket fuel.



As a fuel, N_2H_4 reacts with oxygen as shown below.

$N_2H_4(g) + O_2(g) \rightarrow N_2(g) + 2H_2O(g)$ $\Delta H = -581$ kJ mol^{-1}

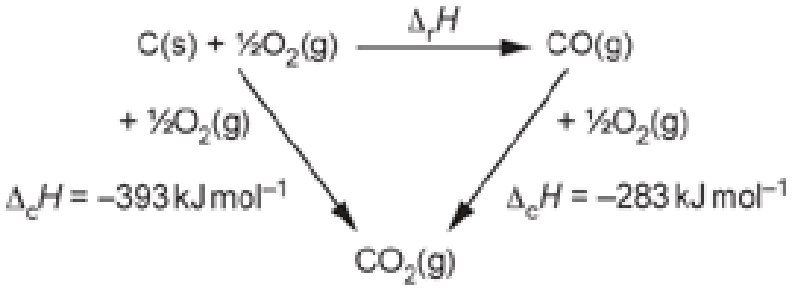
Average bond enthalpies are shown in the table.

Bond	N−N	O=O	N≡N	O−H
Average bond enthalpy / kJ mol^{-1}	+158	+498	+945	+464

Calculate the average bond enthalpy of the N–H bond.

average bond enthalpy of N–H = ... kJ mol^{-1} **[3]**

3. An enthalpy cycle is shown below.



What is $\Delta_r H$, in kJ mol^{-1}, shown in the enthalpy cycle?

A +676
B +110
C -110
D -676

Your answer ☐ **[1]**

4. A mixture of gases is heated in a closed container. The reaction rate increases.

Which statement explains why the rate increases?

A More molecules have an energy greater than the activation energy.
B The activation energy decreases.
C The activation energy increases.
D The concentration of the gases increases.

Your answer ☐ **[1]**

5. This question is about two oxides of sulfur: sulfur dioxide, SO_2, and sulfur trioxide, SO_3.

SO_3 decomposes to form SO_2 and O_2, as shown in **Equilibrium 18.1**.

$$SO_3(g) \rightleftharpoons SO_2(g) + \tfrac{1}{2}O_2(g) \qquad \Delta H = +99 \text{ kJ mol}^{-1} \qquad \textbf{Equilibrium 18.1}$$

i. 2.25 moles of SO_3 is heated to 550 °C in the presence of a catalyst and the resulting mixture allowed to reach equilibrium.

The equilibrium mixture contains 0.900 mol of SO_2 and the total pressure is 2.80 atm.

Calculate the numerical value for K_p for **Equilibrium 18.1** under these conditions and state the units of K_p.

Give your answer to **3** significant figures.

K_p = ...

units ..... **[5]**

ii. The numerical values of K_p for **Equilibrium 18.1** at temperatures T_1 and T_2 are shown below.

Temperature	K_p
T_1	3.3×10^{-5}
T_2	7.7×10^{-2}

Explain why T_2 is a higher temperature than T_1.

[2]

iii. Suggest how the value of K_p would change if the reaction was repeated with no catalyst added and the pressure of the system increased.

Tick (✓) one box in each row.

Change	Decrease	No change	Increase
No catalyst			
Increased pressure			

[2]

6. Standard electrode potentials are measured by comparison with a reference half-cell.

Draw a labelled diagram to show how the standard electrode potential could be measured for the redox system below.

$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$

Include details of the apparatus, solutions and the standard conditions needed when measuring this standard electrode potential.

Standard conditions

[4]

7. The equation for the reaction of sulfuric acid with potassium hydroxide is shown below.

$H_2SO_4(aq) + 2KOH(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l)$

25 cm^3 of 1.00 mol dm^{-3} H_2SO_4 is reacted with excess KOH.
The energy given out is 2.8 kJ.

What is the enthalpy change of neutralisation, in kJ mol^{-1}?

A −56
B −70
C −112
D −224

Your answer ☐ **[1]**

8. Which row in the table explains how a catalyst affects the activation energy (E_a) and the proportion of molecules with energy > E_a?

	How the activation energy changes	**Proportion of molecules with energy > E_a**
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

Your answer ☐ **[1]**

9. Which statement(s) about elements in the periodic table is/are correct?

1 The position of an element is determined by its relative atomic mass.
2 The elements in a group have similar chemical properties.
3 Transition elements are used as catalysts in the manufacture of chemicals.

A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer ☐ **[1]**

10(a). This question is about energy changes.

Hydrogen peroxide decomposes as shown in **Reaction 16.1**.

$$H_2O_2(l) \rightarrow H_2O(l) + \tfrac{1}{2}O_2(g)$$ **Reaction 16.1**

The table shows enthalpy changes of formation and entropies.

	ΔH_f^e/kJ mol^1	S^e / J K^{-1} mol^{-1}
$H_2O_2(l)$	−188	110
$H_2O(l)$	−286	70.0
$O_2(g)$	0	205

i. Calculate the free-energy change, ΔG, in kJ mol^{-1}, of **Reaction 16.1** at 25 °C.

Give your answer to **3** significant figures.

ΔG = ... kJ mol^{-1} **[4]**

ii. The decomposition of hydrogen peroxide shown in **Reaction 16.1** is feasible.

Suggest why **Reaction 16.1** does **not** take place at 25 °C despite being feasible.

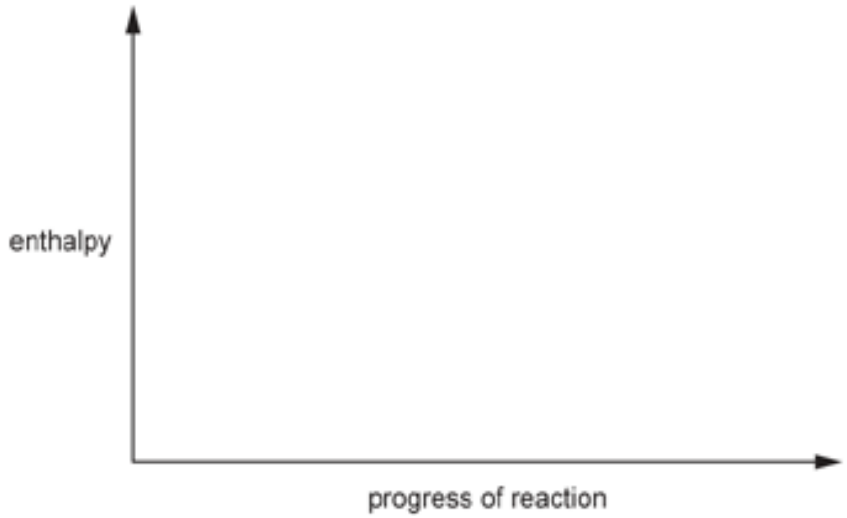
[1]

(b). The rate of decomposition of hydrogen peroxide shown in **Reaction 16.1** can be increased by adding a small amount of powdered manganese(IV) oxide, MnO_2.

The MnO_2 acts as a catalyst.

i. Complete the enthalpy profile diagram for **Reaction 16.1** using formulae for the reactants and products.

- Use E_a to label the activation energy **without** MnO_2.
- Use E_c to label the activation energy **with** MnO_2.
- Use ΔH to label the enthalpy change of reaction.



[3]

ii. Explain why MnO_2 is described as a **heterogeneous** catalyst for this reaction.

_____

[1]

iii. Mn_3O_4 is a compound in which Mn has two different oxidation states. The two oxidation states are different from the Mn in MnO_2.

Suggest the two oxidation states of manganese in Mn_3O_4.

_____

[1]

11. Which statement explains the trend in boiling points down the halogens group?

A The bond enthalpy of the covalent bonds increases.
B The halogens become less electronegative.
C The induced dipole-dipole interactions (London forces) become stronger.
D The reactivity of the halogens decreases.

Your answer ☐ **[1]**

12(a). Enthalpy changes of reaction can be determined by experiment.

What is meant by the term **enthalpy change of reaction**?

[1]

(b). A student carries out an experiment to determine the enthalpy change for the reaction between zinc and copper(II) nitrate solution.

$Zn(s) + Cu(NO_3)_2(aq) \rightarrow Zn(NO_3)_2(aq) + Cu(s)$ $\Delta_r H$ **Equation 3.1**

The student follows the method outlined below.

- Add 100 cm^3 of 0.500 mol dm^{-3} $Cu(NO_3)_2(aq)$ to a beaker.
- Measure the temperature of the solution.
- Add excess zinc to the beaker.
- Stir the mixture and record the maximum temperature.

The temperature of the solution changes from 19.5 °C to 38.1 °C.

Calculate $\Delta_r H$, in kJ mol^{-1}, for **equation 3.1.**

State any assumptions you have made in your calculation.

Suggest improvements for obtaining a more accurate value for $\Delta_r H$.

[6]

(c). The student modifies the experiment using 50 cm^3 instead of 100 cm^3 of 0.500 mol dm^{-3} copper(II) nitrate solution.

The value of $\Delta_r H$ for this modified experiment is the same as in **equation 3.1.**

Explain why.

[2]

13. These questions are from different areas of chemistry.

This question is about two salts of rubidium (atomic number 37): $RbClO_3$ and $RbClO_4$.

i. The oxidation number of chlorine is different in the two rubidium salts, $RbClO_3$ and $RbClO_4$.

What is the name of $RbClO_4$?

[1]

ii. A student carries out an experiment to determine the enthalpy change of solution of $RbCIO_3$ using the method below.

- A 2.00 g sample of solid $RbCIO_3$ is added to water in a well-insulated container. The initial temperature is 23.0 °C.
- The mixture is stirred until all the $RbCIO_3$ has dissolved. The final temperature is 21.5 °C. The final solution has a mass of 102 g.

Determine the enthalpy change of solution, $\Delta_{sol} H$, of $RbCIO_3$ in kJ mol^{-1}.

Assume that the specific heat capacity of the solution is the same as that of pure water.

$\Delta_{sol} H$ ($RbCIO_3$) = ... kJ mol^{-1} **[3]**

14(a). This question is about enthalpy changes of reactions involving hydrocarbons.

A student determines the enthalpy change of combustion, $\Delta_c H$, of heptane, C_7H_{16}, using the method outlined below.

- Add 150 g of water to a beaker and measure its temperature.
- Weigh a spirit burner containing heptane and use it to heat the water.
- Extinguish the flame and record the maximum temperature reached by the water.
- Reweigh the spirit burner.

The temperature of the water increased by 10.5 °C.

The spirit burner decreased in mass by 0.133 g.

Use the student's results to determine the enthalpy change of combustion of heptane, $\Delta_c H$ (C_7H_{16}), in kJ mol^{-1}.

$\Delta_c H$ (C_7H_{16}) = ... kJ mol^{-1} **[3]**

(b). Nonane, C_9H_{20}, can be broken down by heat to form pentane, C_5H_{12}, and ethene, C_2H_4.

$C_9H_{20}(g) \rightarrow C_5H_{12}(g) + 2C_2H_4(g)$ ΔH = +186 kJ mol^{-1} **Reaction 1**

The enthalpy changes of combustion of $C_9H_{20}(g)$ and $C_2H_4(g)$ are shown in the table below.

Hydrocarbon	**$\Delta_c H$ / kJ mol^{-1}**
$C_9H_{20}(g)$	–6171
$C_2H_4(g)$	–1411

Use ΔH in **Reaction 1** and the enthalpy changes of combustion in the table to determine the enthalpy change of combustion of $C_5H_{12}(g)$.

$\Delta_c H$ ($C_5H_{12}(g)$) = ... kJ mol^{-1} **[2]**

15(a). This question is about enthalpy changes.

In a petrol engine, alkanes undergo combustion.

i. Heptane is one of the alkanes in petrol.

Write the equation for the complete combustion of heptane.

State symbols are **not** required.

[2]

ii. In a petrol engine, polluting gases such as CO and NO are formed. These are mostly removed before being emitted from the exhaust.

The equation for the removal of CO and NO is shown below.

$2CO(g) + 2NO(g) \rightarrow 2CO_2(g) + N_2(g)$ $\Delta H = -746$ kJ mol^{-1}

Complete the enthalpy profile diagram in **Fig. 23.1** for this reaction.

On your diagram:

- Label the enthalpy change of reaction, ΔH.
- Include the formulae of the reactants and products.
- Label the activation energy, E_a.

Fig. 23.1

[2]

iii. CO and NO are removed by use of a catalyst.

Explain the role of the catalyst.

Refer to your enthalpy profile diagram in **Fig. 23.1** in your answer.

[2]

(b). Iron(III) oxide reacts with carbon monoxide as shown:

$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$ $\Delta H = -25$ kJ mol^{-1}

Standard enthalpy changes of formation, $\Delta_f H^\theta$, are given in the table.

Substance	$\Delta_f H^\theta$ / kJ mol^{-1}
$Fe_2O_3(s)$	–824
$CO(g)$	–111

i. State the conditions of temperature and pressure for standard enthalpy changes.

Temperature _____

Pressure _____ **[1]**

ii. Calculate the standard enthalpy change of formation for $CO_2(g)$.

$\Delta_f H^\theta(CO_2(g))$ = ... kJ mol^{-1} **[3]**

16. The standard enthalpy change of formation of water is –286 kJ mol^{-1}.

Which statement or equation is correct?

A $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ $\Delta H^{\ominus} = -143$ kJ mol^{-1}

B $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$ $\Delta H^{\ominus} = -286$ kJ mol^{-1}

C The O–H bond enthalpy is –143 kJ mol^{-1}.

D The standard enthalpy change of combustion of hydrogen is –286 kJ mol^{-1}.

Your answer ☐ **[1]**

17. Which statement about energy changes is correct?

A Combustion of an alkane is endothermic.

B In an exothermic reaction, more energy is needed to break bonds than is given out when bonds are made.

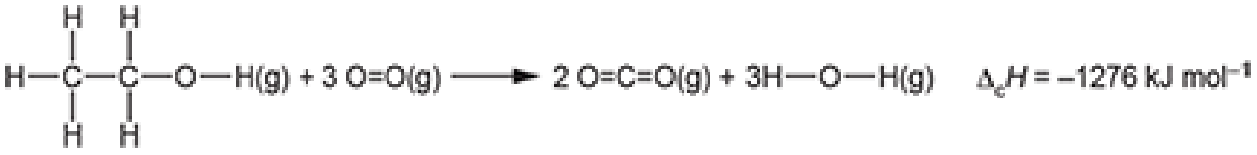
C The activation energy is a negative value.

D The enthalpy change for the condensation of a gas to a liquid is a negative value.

Your answer ☐ **[1]**

18(a). This question is about the enthalpy change of combustion of alcohols.

The enthalpy change of combustion of ethanol, $\Delta_c H$, in the gaseous state can be calculated using average bond enthalpies.



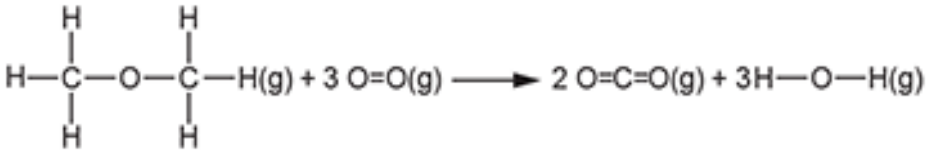
i. Use this value of $\Delta_c H$ and the average bond enthalpies below to calculate the average bond enthalpy of C=O.

Bond	Average bond enthalpy / kJ mol^{-1}
C–H	+413
C–C	+347
C–O	+358
O–H	+464
O=O	+498

C=O bond enthalpy = ...kJ mol^{-1} **[4]**

ii. Methoxymethane, CH_3OCH_3, is an isomer of ethanol.

On combustion, methoxymethane, in the gaseous state, produces carbon dioxide and steam.



$\Delta_c H$ for methoxymethane is more negative than $\Delta_c H$ for ethanol.

Explain why the $\Delta_c H$ values are different, in terms of the bonds broken and the bonds formed.

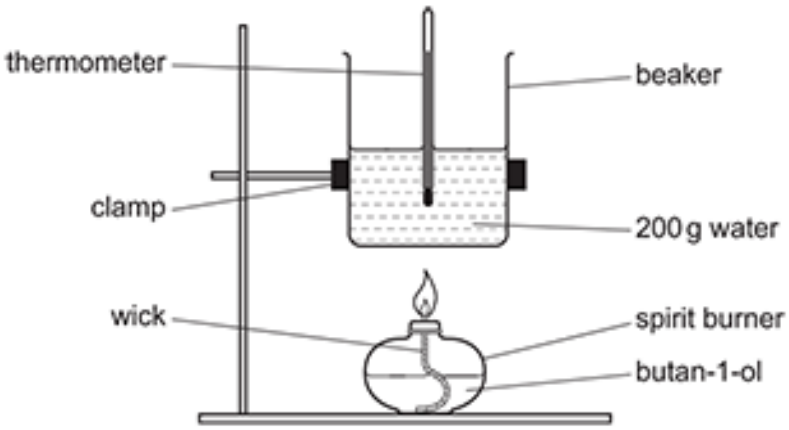
[2]

(b). Explain the term **enthalpy change of combustion**.

[2]

(c). A student carries out an experiment to determine the enthalpy change of combustion, $\Delta_c H$, of butan-1-ol, $CH_3CH_2CH_2CH_2OH$.

The student sets up the apparatus as shown below.



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

Initial temperature of water / °C	18.5
Final temperature of water / °C	49.5
Mass of burner before heating / g	212.38
Mass of burner after heating / g	211.07

i. The thermometer had an uncertainty of ± 0.25 °C in each temperature reading.

Calculate the percentage uncertainty in the temperature change.

percentage uncertainty = ... % **[1]**

ii. Use the student's results to determine $\Delta_c H$ of butan-1-ol in kJ mol^{-1}.

Explain why this value of $\Delta_c H$ is different from the data book value and suggest how the experimental design could be modified to improve the accuracy of the $\Delta_c H$ value obtained.

[6]

iii. Another student carries out the experiment in **4(b)** using 150 g of water in the beaker instead of 200g.

Calculate the mass of butan-1-ol that would produce the same temperature rise as in the experiment in **4(b)**.

Assume the same heat losses.

mass of butan-1-ol = ... g **[1]**

19. This question is about enthalpy changes and reaction rates.

Aqueous barium hydroxide, $Ba(OH)_2(aq)$, reacts with dilute nitric acid, $HNO_3(aq)$, as in **Equation 25.1**.

$Ba(OH)_2(aq) + 2HNO_3(aq) \rightarrow Ba(NO_3)_2(aq) + 2H_2O(l)$ **Equation 25.1**

A student carries out an experiment to determine the enthalpy change of this reaction, $\Delta_r H$.

The student measures out:

• 25.0 cm^3 of 2.00 mol dm^{-3} $Ba(OH)_2(aq)$ and

• 50.0 cm^3 of 2.00 mol dm^{-3} $HNO_3(aq)$.

The temperature of each solution is the same.

The student mixes both solutions in a polystyrene cup, stirs the mixture and records the maximum temperature.

Temperature readings

Initial temperature	= 20.5 °C
Maximum temperature	= 39.0 °C

i. Calculate $\Delta_r H$, in kJ mol^{-1}, for the reaction shown in **Equation 25.1**.
Give your answer to **3** significant figures.
Assume that the density and specific heat capacity, *c*, of the solutions are the same as for water.

$\Delta_r H$ = ... kJ mol^{-1} **[4]**

ii. The student looked back at **Equation 25.1** and noticed that the reaction was a neutralisation.
The student concluded that $\Delta_r H$ is the enthalpy change of neutralisation.
Explain why the student's conclusion is **incorrect** and determine the correct value for the enthalpy change of neutralisation.

enthalpy change of neutralisation = ... kJ mol ^{1} **[2]**

20. Combustion of hydrazine, N_2H_4, produces NO_2 and H_2O as in the equation below.

$N_2H_4(l) + 3O_2(g) \rightarrow 2NO_2(g) + 2H_2O(l)$

The table shows standard enthalpy changes of formation, $\Delta_f H^o$

Substance	$\Delta_f H^o$/kJ mol^{-1}
$N_2H_4(l)$	+50.6
$O_2(g)$	0
$NO_2(g)$	+33.2
$H_2O(l)$	−285.8

What is the enthalpy change of combustion, in kJ mol^{-1}, for hydrazine, $N_2H_4(l)$?

A −555.8
B −303.2
C +303.2
D +555.8

Your answer ☐ **[1]**

21(a). This question is about energy changes.

Magnesium reacts with aqueous silver nitrate, $AgNO_3(aq)$ as shown below.

$Mg(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Mg(NO_3)_2(aq)$ $\Delta H = -678 kJmol^{-1}$

A student adds an excess of magnesium to 100.0 cm^3 of 0.400 mol dm^{-3} $AgNO_3(aq)$.

The initial temperature is 20.0°C.

i. Determine the maximum temperature reached in this reaction.

Give your answer to **3** significant figures.

Assume that the specific heat capacity and density of the solution are the same as for water, and that there are no heat losses.

maximum temperature reached = ... °C **[4]**

ii. The student wants to repeat the experiment, but there is not enough $AgNO_3(aq)$ left to use another 100.0 cm^3 portion.

The student decides to modify the method by adding an excess of magnesium to 50.0 cm^3 of 0.400 mol $dm^{-3}AgNO_3(aq)$.

Predict, with reasons, how this modification would affect the maximum temperature reached. Assume that there are no heat losses.

[1]

(b). Nitric acid is manufactured from ammonia in a multi-stage process.

The equation for the first stage in this process is shown in **Reaction 17.1**.

$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(l)$ $\Delta H^e = -1172$ kJ mol^{-1} **Reaction 17.1**

Some standard enthalpy changes of formation are shown in the table.

Compound	$\Delta_f H^e$/kJ mol^{-1}
$NH_3(g)$	−46
$H_2O(l)$	−286

i. Explain the term **enthalpy change of formation**.

[1]

ii. Calculate the standard enthalpy change of formation, $\Delta_f H^e$, of NO(g).

$\Delta_f H^e$ og NO(g) = ... kJmol^{-1} **[2]**

22. Bond enthalpies are shown in the table.

Bond	C−C	C−H	O−H	C−O	C=O	O−O	O=O
Bond enthalpy /kJmol^{-1}	347	435	464	358	805	144	498

What is the enthalpy change, in kJ mol-1, for the reaction below?

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

A −730
B −544
C +544
D +730

Your answer ☐ **[1]**

23. For the condensation of ammonia gas, what are the signs of Δ*H* and Δ*S*?

A Δ*H* −ve ΔS −ve
B Δ*H* −ve ΔS +ve
C Δ*H* +ve ΔS +ve
D Δ*H* +ve ΔS −ve

Your answer ☐ **[1]**

24. A student investigates some reactions of zinc compounds and zinc metal.

The student investigates the reaction between zinc and dilute sulfuric acid.

$$Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g) \qquad \Delta H = -140 \text{ kJ mol}^{-1}$$

Copper(II) sulfate is a catalyst for this reaction.

- The student adds a piece of zinc to each of two test tubes.
- The student adds a few drops of aqueous copper(II) sulfate to one of the test tubes, forming a pale blue solution.
- The student adds an excess of dilute sulfuric acid to each test tube.

i. Describe two differences the student would observe between the test tubes.

1 _____

_____

2 _____

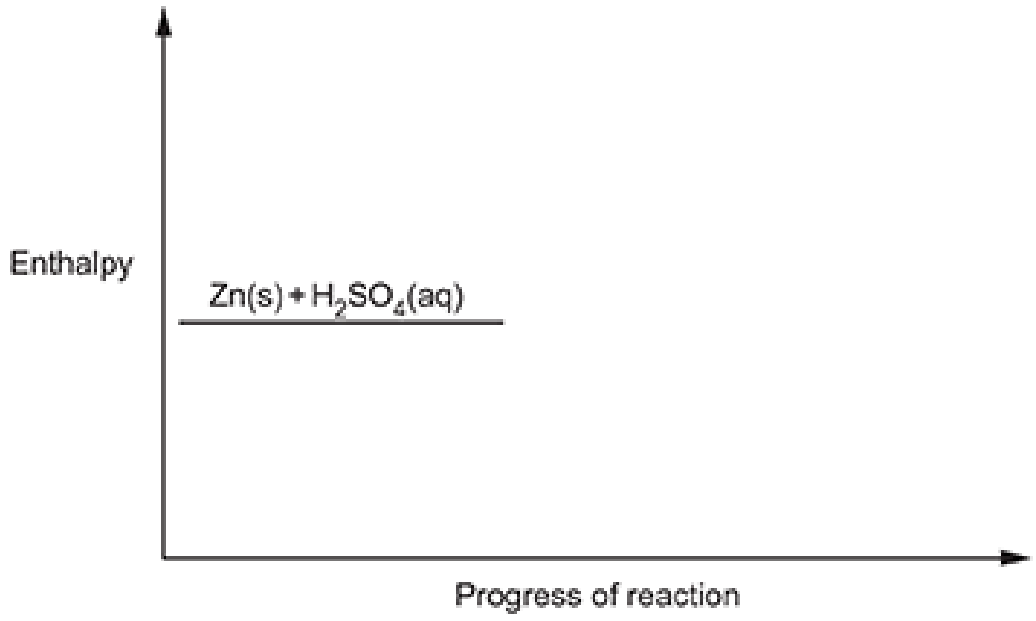
_____

[2]

ii. Using the axes below, sketch an enthalpy profile diagram for the reaction with and without the catalyst.

On your diagram, include the following labels:

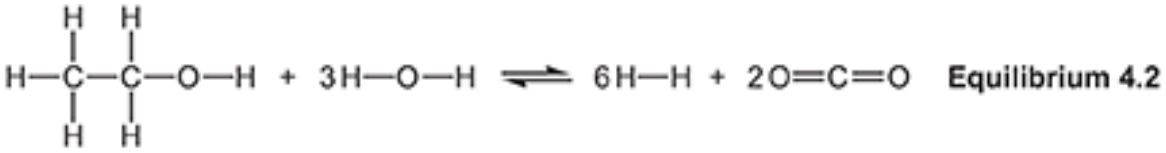
- ΔH, the enthalpy change
- E_a, the activation energy **without** a catalyst
- E_c, the activation energy **with** a catalyst.



[3]

25. This question is about the manufacture of hydrogen, H_2.

Hydrogen can be manufactured by reacting ethanol with steam, as shown in **Equilibrium 4.2.**



Equilibrium 4.2

Average bond enthalpies are shown in the table below.

Bond	C−H	C−C	C−O	O−H	H−H	C=O
Average bond enthalpy/kJ mol^{-1}	+415	+347	+358	+464	+435	+805

Calculate Δ*H*, in kJ mol^{-1}, for the forward reaction in **Equilibrium 4.2**.

Δ*H* = ... kJ mol^{-1} **[3]**

26(a). This question is about energy changes.

***** A student plans to determine the enthalpy change of hydration of calcium ions.

The student finds the information below from data tables.

Enthalpy change	***ΔH* / kJ mol^{-1}**
Lattice enthalpy of calcium chloride	-2223
Enthalpy change of hydration of chloride ions	-378

The student carries out an experiment to find the enthalpy change of solution of calcium chloride.

Student's method:

- Weigh a bottle containing calcium chloride and weigh a polystyrene cup.
- Add water from a measuring cylinder to the polystyrene cup and measure its temperature.
- Add the calcium chloride, stir the mixture, and measure the maximum temperature of the final solution.
- Weigh the empty bottle and weigh the polystyrene cup with the final solution.

Mass readings

Mass of bottle + calcium chloride / g	27.45
Mass of empty bottle / g	18.17
Mass of polystyrene cup / g	21.24
Mass of polystyrene cup + final solution / g	127.84

Temperature readings

Initial temperature of water / °C	21.0
Maximum temperature of final solution / °C	39.5

Calculate the enthalpy change of solution of calcium chloride and determine the enthalpy change of hydration of calcium ions.

Show your working, including an energy cycle linking the energy changes.

Assume that the density and specific heat capacity, *c,* of the solution are the same as for water.

[6]

(b). Internal combustion engines have historically used fuels obtained from crude oil as a source of power.

The environmental effects of fossil fuel use can be reduced by blending petrol with biofuels such as ethanol.

A fuel is being developed using a 1:1 molar ratio of octane and ethanol.

i. Write the equation for the complete combustion of this fuel.

[1]

ii. Calculate the energy released, in kJ, by the complete combustion of 8.00 kg of this fuel.
$\Delta_c H(C_8H_{18})$ = -5470 kJ mol^{-1} ; $\Delta_c H(C_2H_5OH)$ = -1367 kJ mol^{-1}.

energy released = ... kJ **[3]**

END OF QUESTION PAPER