Questions

Q1.

A thermometric titration is a method for finding the end-point of a titration between aqueous solutions of ammonia and ethanoic acid.

A thermometric titration was carried out using the following steps:

- the temperatures of the aqueous ammonia and ethanoic acid solutions were measured and found to be 20.1 °C
- 30 cm^3 of the aqueous ammonia was placed in a polystyrene cup
- a 10 cm^3 portion of an ethanoic acid solution, concentration 1.10 mol dm^{-3} , was added to the polystyrene cup, the mixture stirred and the temperature measured
- further 10 cm^3 portions of ethanoic acid solution were added, the mixture stirred, and the temperature measured immediately after each addition, until a total of 80 cm^3 had been added.

Results for this experiment are shown in the table.

Volume of ethanoic acid added / cm^3	0	10	20	30	40	50	60	70	80
Temperature / °C	20.1	21.8	23.5	25.1	26.4	25.8	24.9	24.1	23.3

(i) The temperature of the reaction mixture initially increased because the reaction is

(1)

- ☒ **A** endothermic so energy is absorbed by the water
- ☒ **B** endothermic so energy is released by the water
- ☒ **C** exothermic so energy is absorbed by the water
- ☒ **D** exothermic so energy is released by the water

(ii) Give the main reason why, after the end-point was reached, the temperature of the solution decreased.

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(Total for question = 2 marks)

Q2.

A thermometric titration is a method for finding the end-point of a titration between aqueous solutions of ammonia and ethanoic acid.

A thermometric titration was carried out using the following steps:

- the temperatures of the aqueous ammonia and ethanoic acid solutions were measured and found to be 20.1 °C
- 30 cm^3 of the aqueous ammonia was placed in a polystyrene cup
- a 10 cm^3 portion of an ethanoic acid solution, concentration 1.10 mol dm^{-3} , was added to the polystyrene cup, the mixture stirred and the temperature measured
- further 10 cm^3 portions of ethanoic acid solution were added, the mixture stirred, and the temperature measured immediately after each addition, until a total of 80 cm^3 had been added.

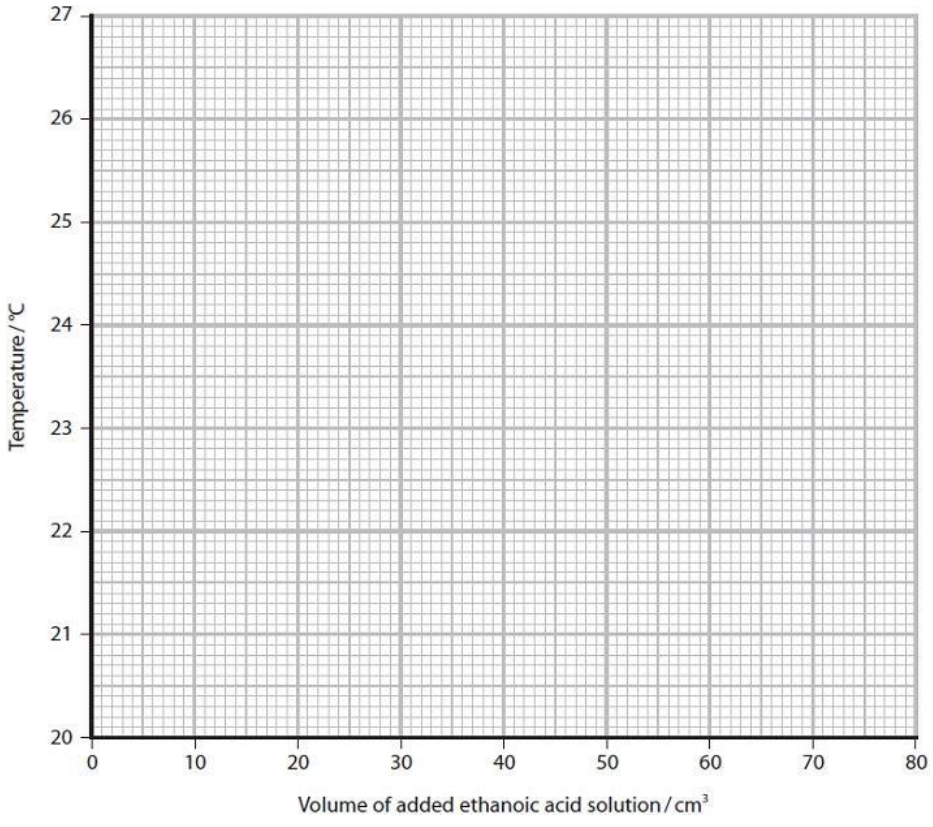
Results for this experiment are shown in the table.

Volume of ethanoic acid added / cm^3	0	10	20	30	40	50	60	70	80
Temperature / °C	20.1	21.8	23.5	25.1	26.4	25.8	24.9	24.1	23.3

(i) Plot the results using the axes provided.

Include two straight lines of best fit, extrapolated until they meet.

(2)



(ii) Determine the maximum temperature rise from your graph.

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(iii) Calculate the number of moles of ethanoic acid, with a concentration of 1.10 mol dm^{-3} , added at the end-point of the reaction.

(2)

(iv) The reaction that occurs is

$$NH_3(aq) + CH_3COOH(aq) \rightarrow NH_4^+(aq) + CH_3COO^-(aq)$$

Calculate the enthalpy change per mole for this reaction.
Include a sign and units in your answer.
[Assume:
specific heat capacity of the solution at the end-point = 4.18 J g^{-1} $°C^{-1}$ 1.00 cm^3 of the solution at the end-point has a mass of 1.00 g]

(3)

(Total for question = 8 marks)

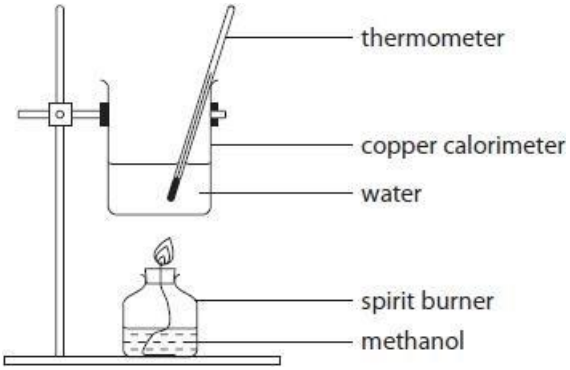
Q3.

This question is about the enthalpy change of combustion of methanol.

A teacher asked two students to carry out a practical task to determine the enthalpy change of combustion of methanol.
Both students were provided with the same apparatus and chemicals.
The following procedure was provided for the students.

Procedure

- Measure out 150 cm^3 of distilled water, using a 250 cm^3 measuring cylinder.
- Transfer the water to a copper calorimeter and note the initial temperature of the water (to the nearest 0.5°C) in **Table 1**.
- Weigh the spirit burner containing methanol and record its mass in **Table 1**.
- Place the spirit burner under the copper calorimeter, as shown in the diagram.
- Ignite the spirit burner and burn the methanol, whilst stirring the water with the thermometer.
- After heating the water for three minutes, extinguish the flame and immediately record the **highest** temperature reached by the water.
- As soon as possible, reweigh the spirit burner containing the methanol and record its mass in **Table 1**.



The results of Student 1 are recorded in **Table 1**.

Mass of spirit burner plus methanol before burning / g	213.47
Mass of spirit burner plus methanol after burning / g	211.87
Mass of methanol burned / g	
Highest temperature of the water / °C	64.5
Initial temperature of the water / °C	22.0
Temperature change of the water / °C	

Table 1

(a) Complete **Table 1**, giving the values to an appropriate number of decimal places.

(2)

(b) Write the equation that represents the reaction that occurs when the standard enthalpy change of combustion of methanol, $CH_3OH(l)$, is measured. Include state symbols.

(2)

(c) Use Student 1's result to calculate the enthalpy change of combustion of methanol in kJ mol^{-1}.
Give your answer to an appropriate number of significant figures.

Specific heat capacity of water = 4.18 J g^{-1} $°C^{-1}$
Density of water = 1.00 g cm^{-3}

(4)

(d) Student 1 compared the experimental value for the enthalpy change of combustion of methanol obtained in part (c) with the standard value given on the internet.
The student's value was **less exothermic** than the standard value.

Student 1 decided to evaluate the uncertainty in the measurements made in this experiment.

(i) Student 1 used a 250 cm^3 measuring cylinder to measure the volume of 150 cm^3 distilled water. The uncertainty in this volume measurement is ±1 cm^3.
Calculate the percentage uncertainty in the volume of distilled water that Student 1 measured in the experiment.

(1)

(ii) Compare and contrast the use of a 250 cm^3 measuring cylinder to measure out the 150 cm^3 distilled water with the use of a 25 cm^3 measuring cylinder (uncertainty ±0.2 cm^3 for each volume measurement) six times to measure the same volume.

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(iii) Student 1 calculated the uncertainties in the remaining measurements. However, Student 1 realised that the measurement uncertainties did **not** explain the difference between the experimental value for the enthalpy change of combustion of methanol calculated in part (c) and the value obtained from the internet.
Other than human error, give **three** reasons for the difference in the values.

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(e) Student 1 decided to repeat the experiment.

Student 1 used the copper calorimeter and water from the first experiment and recorded the initial temperature as 60.0°C.
Student 1 burned **exactly** the same mass of methanol as in the first experiment.
Explain, with a reason, how the value for the enthalpy change of combustion of methanol from this experiment would differ, if at all, from the value obtained in the first experiment.

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(f) Student 2 followed the **original** instructions provided, but extinguished the flame after **four** minutes rather than after three minutes.

Explain how the value calculated by Student 2 for the enthalpy change of combustion of methanol compared with that obtained in Student 1's first experiment.

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(g) Another student, Student 3, used the results from Student 1's first experiment to find the enthalpy change of combustion of methanol. Student 3 incorrectly used a value of 46.0 g mol^{-1} for the molar mass of methanol.

State and justify how this mistake would affect the calculated value for the enthalpy change of combustion of methanol.

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(Total for question = 21 marks)

Q4.

This question is about enthalpy changes.

The equations for the combination of gaseous atoms of carbon and hydrogen to form methane, CH_4, and propane, C_3H_8, are

$$C(g) + 4H(g) \rightarrow CH_4(g) \quad \Delta H = -1652\,kJ\,mol^{-1}$$

$$3C(g) + 8H(g) \rightarrow C_3H_8(g) \quad \Delta H = -3998\,kJ\,mol^{-1}$$

Calculate:

(i) the mean bond enthalpy of a C−−H bond.

(1)

(ii) the mean bond enthalpy of a C−−C bond.

(2)

(Total for question = 3 marks)

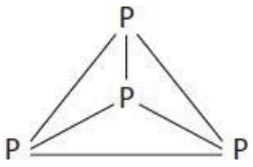
Q5.

The halogens are elements in Group 7 of the Periodic Table.

Chlorine compounds have many uses, including water treatment.

(i) Chlorine and phosphorus (P_4) can react to form phosphorus(V) chloride.

The structure of a molecule of phosphorus is



Some mean bond enthalpy values are shown in the table.

Bond	Mean bond enthalpy / kJ mol^{-1}
P—P	+198
Cl—Cl	+243
P—Cl	+326

Calculate the enthalpy change for the reaction between chlorine and phosphorus to form phosphorus(V) chloride.

$$10Cl_2 + P_4 \rightarrow 4PCl_5$$

(3)

(ii) Give a reason why bond enthalpy values are always positive.

(1)

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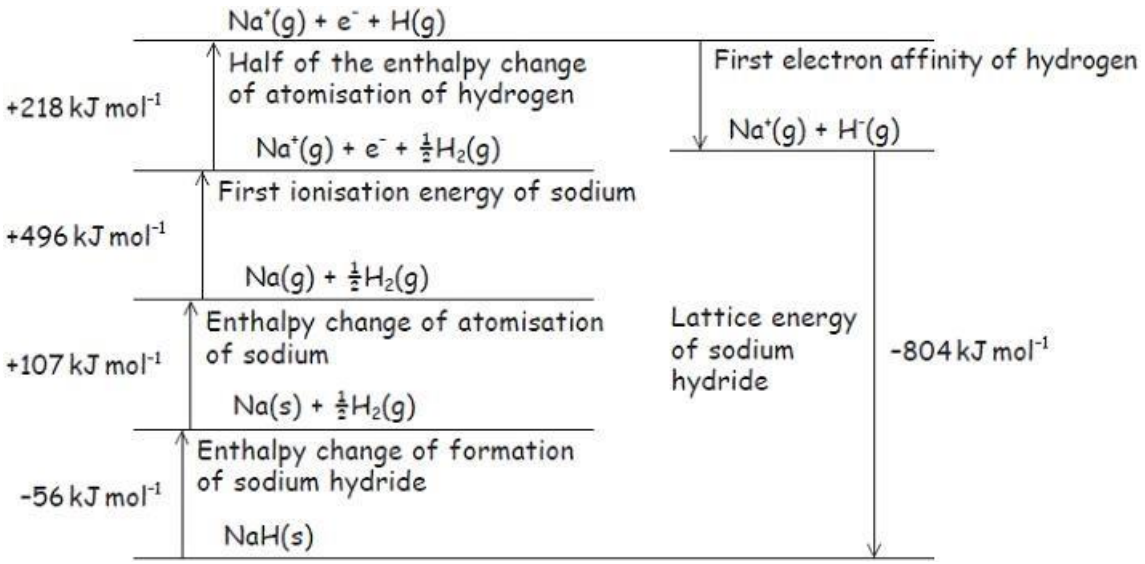
(Total for question = 4 marks)

Q6.

Sodium hydride, NaH, can be used to generate hydrogen for fuel cells.

In order to calculate the first electron affinity of hydrogen, a student was asked to draw a Born-Haber cycle for sodium hydride.

The cycle had **two** errors but the numerical data were correct.



(i) Identify and correct the **two** errors in this Born-Haber cycle.

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(ii) Calculate the first electron affinity, in kJ mol^{-1}, of hydrogen, using the values given in the cycle.

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(Total for question = 3 marks)

Q7.

Nitrogen monoxide and chlorine gases react together to form a single product, nitrosyl chloride, NOCl.

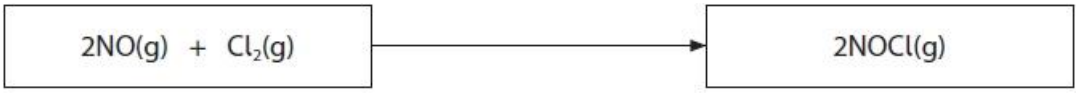
Below 100 °C the yield of NOCl is almost 100 %, but as the temperature rises the yield of NOCl decreases as the equilibrium position shifts to the left.

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g) \qquad \Delta_r H^{\ominus} = -75.6\ kJ\ mol^{-1}$$

(i) Complete the Hess cycle to enable you to calculate the enthalpy change of formation, $\Delta_f H^{\ominus}_{298}$, of NOCl.

Include state symbols.

(2)



(ii) Calculate the enthalpy change of formation, $\Delta_f H^{\ominus}_{298}$, of NOCl given the data

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g) \qquad \Delta_r H^{\ominus}_{298} = -75.6\ kJ\ mol^{-1}$$

enthalpy change of formation of NO, $\Delta_f H^{\ominus}_{298}$, $= +90.3\ kJ\ mol^{-1}$

(2)

(Total for question = 4 marks)

Q8.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

An equation for the formation of ammonia using the Haber process is shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(i) Calculate the enthalpy change for the forward reaction shown in the equation, selecting from the bond enthalpies in the table.
Include a sign in your answer.

(3)

Bond	Mean bond enthalpy / kJ mol^{-1}
N—N	158
N═N	410
N≡N	945
N—H	391
H—H	436

(ii) A data book gives the standard enthalpy change of formation of ammonia as –46.1 kJ mol^{-1}.

Give two reasons for the difference between this value and the value that you calculated in (a)(i).

(2)

Reason 1

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Reason 2

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(iii) What is the percentage atom economy, by mass, for ammonia in the forward reaction?

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

(1)

- ☒ **A** 17.6 %
- ☒ **B** 50.0 %
- ☒ **C** 82.4 %
- ☒ **D** 100 %

(iv) What is the equilibrium expression for K_c?

(1)

- ☒ **A** $K_c = \frac{[N_2][3H_2]}{[2NH_3]}$
- ☒ **B** $K_c = \frac{[2NH_3]}{[N_2][3H_2]}$
- ☒ **C** $K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$
- ☒ **D** $K_c = \frac{[N_2][H_2]^3}{[NH_3]^2}$

(Total for question = 7 marks)

Q9.

When solid calcium sulfate dihydrate, $CaSO_4 \cdot 2H_2O$, is heated in a crucible, it forms solid calcium sulfate hemihydrate, $CaSO_4 \cdot \frac{1}{2}H_2O$.

When water is added to calcium sulfate hemihydrate, there is a rise in temperature.

A student decided to investigate this reaction using the following procedure:

Step **1** 10 cm^3 of distilled water is measured using a measuring cylinder having an uncertainty of ±0.5 cm^3, and is placed in an insulated cup with a lid.

Step **2** A thermometer with an uncertainty of ±0.5 °C is placed in the water.

Step **3** Exactly 10.00 g of calcium sulfate hemihydrate is weighed out using a balance with an uncertainty of ±0.005 g.

Step **4** The weighed quantity of calcium sulfate hemihydrate is added to the water in the insulated cup.

Step **5** The mixture in the insulated cup is stirred until no further temperature change is observed.

Results

Temperature of the water before adding the solid	= 23.5 °C
Maximum temperature of the mixture after adding the solid	= 26.3 °C

Other data

Molar mass of calcium sulfate hemihydrate, $CaSO_4 \cdot \frac{1}{2}H_2O$	= 145.2 g mol^{-1}
Density of water	= 1.00 g cm^{-3}

(i) Calculate the minimum volume of water needed to convert 10.00 g of $CaSO_4 \cdot \frac{1}{2}H_2O$ into $CaSO_4 \cdot 2H_2O$.

(2)

(ii) Calculate the enthalpy change, in kJ mol^{-1}, for this reaction.
Include a sign in your answer and give your answer to an appropriate number of significant figures.

Assume that the liquid has a mass of 10.00 g and a specific heat capacity of 4.18 J g^{-1} $°C^{-1}$.

(4)

(iii) Deduce which measurement has the greatest uncertainty in this experiment. Justify your answer by calculating the percentage uncertainty of this piece of apparatus.

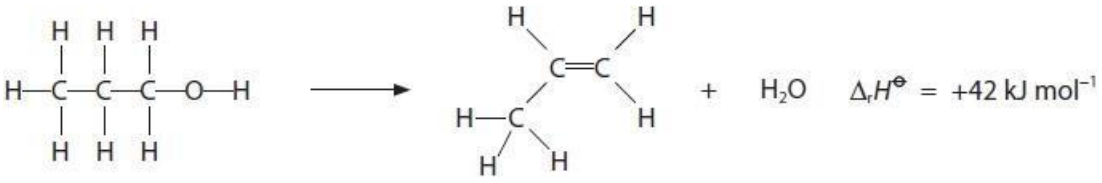
(2)

(Total for question = 8 marks)

Q10.

This question is about enthalpy changes and entropy changes.

Propan-1-ol is dehydrated to form propene.



The relevant mean bond enthalpies are given in the table.

Bond	Mean bond enthalpy / kJ mol^{-1}
C—C	347
C=C	612
C—H	413
O—H	464

Calculate the C—O mean bond enthalpy, using the mean bond enthalpies given in the table and the enthalpy change of reaction.

(3)

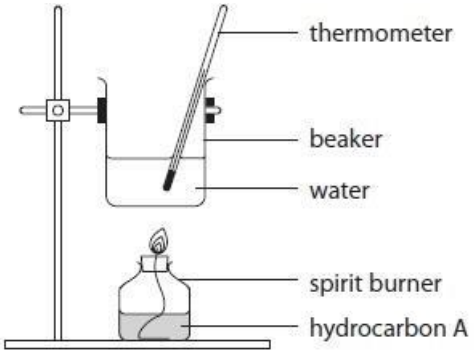
(Total for question = 3 marks)

Q11.

In an experiment, 1.000 g of a hydrocarbon, **A**, was burned completely in oxygen to produce 3.143 g of carbon dioxide and 1.284 g of water.

In a different experiment, the molar mass of the hydrocarbon, **A**, was found to be 84.0 g mol^{-1}.

A spirit burner was filled with the liquid hydrocarbon, **A**. The burner was weighed, lit and then used to raise the temperature of a quantity of water in a beaker, as shown in the diagram. The burner was then reweighed.



Results	
Mass of spirit burner + hydrocarbon **A** before use	112.990 g
Mass of spirit burner + hydrocarbon **A** after use	112.732 g
Volume of water in the beaker	250 cm^3
Temperature of water before heating	21.3 °C
Temperature of water after heating	29.5 °C
Other data	
Density of water	1.00 g cm^{-3}
Specific heat capacity of water	4.18 J g^{-1} $°C^{-1}$
Molar mass of hydrocarbon **A**	84.0 g mol^{-1}

(i) Use these results to calculate the enthalpy change of combustion of hydrocarbon **A** in kJ mol^{-1}.

Give your answer to an appropriate number of significant figures and include a sign.

(3)

(ii) The beaker used in this experiment was made of copper rather than glass. Give a reason for this.

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(Total for question = 4 marks)

Q12.

In acid-base neutralisation reactions, there is a temperature change.

The enthalpy change when hydrochloric acid reacts with aqueous ammonia is –53.4 kJ mol^{-1}.

$$HCl(aq) + NH_3(aq) \rightarrow NH_4Cl(aq)$$

Calculate the temperature change you would expect when
25.0 cm^3 of 1.00 mol dm^{-3} hydrochloric acid is mixed with
25.0 cm^3 of 1.00 mol dm^{-3} aqueous ammonia.

Give your answer to an appropriate number of significant figures.

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

(3)

(Total for question = 3 marks)

Q13.

Ethanol burns completely in excess oxygen.

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

(i) The table shows some mean bond enthalpy data.

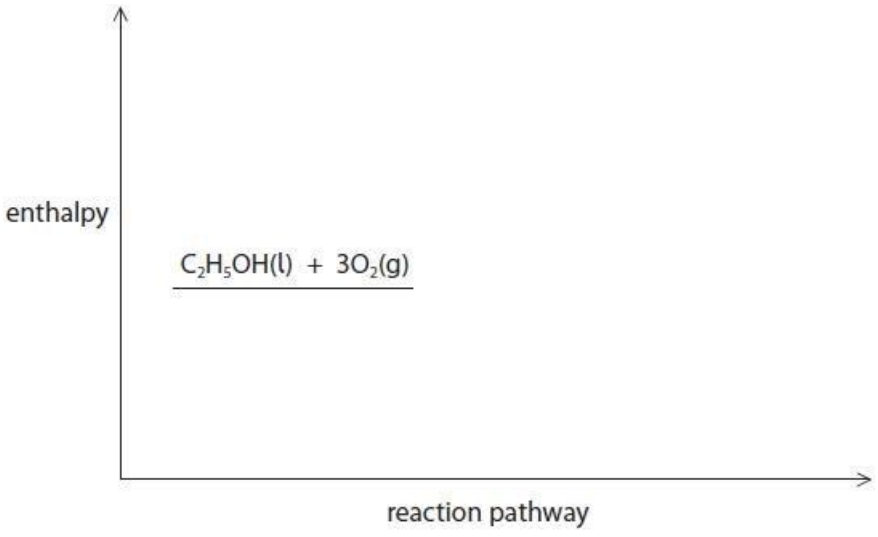
Bond	C—C	C—H	C—O	O—H	O=O	C=O
Mean bond enthalpy / kJ mol^{-1}	347	413	358	464	498	805

Calculate the enthalpy change, in kJ mol^{-1}, for the complete combustion of 1 mol of ethanol.

(3)

(ii) Complete the reaction profile diagram for the combustion of ethanol and fully label the diagram.

(2)



(iii) A data book value for the standard enthalpy change of combustion of ethanol is −1367.3 kJ mol^{-1}.

Give the **main** reason why the value you calculated in (i) is different from this data book value.

(1)

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(Total for question = 6 marks)

Q14.

A student carries out two experiments to determine the enthalpy change that occurs when anhydrous sodium carbonate reacts to form hydrated sodium carbonate.

$$Na_2CO_3(s) + 10H_2O(l) \rightarrow Na_2CO_3.10H_2O(s)$$

(a) In the first experiment, the student determines the enthalpy change of solution for anhydrous sodium carbonate.

50.0g of distilled water is placed in a polystyrene cup and the temperature is recorded.
A sample of anhydrous sodium carbonate is added to the water, the mixture is stirred and the final temperature recorded.
The results for this experiment are shown in the table.

mass used / g	5.09
initial temperature / °C	27.0
final temperature / °C	32.4

Calculate the enthalpy change of solution, in kJ mol^{-1}, for anhydrous sodium carbonate.
Give your answer to an appropriate number of significant figures and include a sign.
[Use 4.18 J g^{-1} $°C^{-1}$ as the specific heat capacity of water]

$$Na_2CO_3(s) + aq \rightarrow Na_2CO_3(aq)$$

(4)

(b) In the second experiment, the student determines the enthalpy change of solution for hydrated sodium carbonate.

$$Na_2CO_3.10H_2O(s) + aq \rightarrow Na_2CO_3(aq) \qquad \Delta H = +53.7\,kJ\,mol^{-1}$$

Complete the Hess cycle and, together with your answer to (a) calculate the enthalpy change when anhydrous sodium carbonate reacts to form hydrated sodium carbonate. Include a sign in your answer.

(2)

(c) Hydrated sodium carbonate slowly loses some water of crystallisation when left in air.

Explain how the enthalpy change in the second experiment would compare with the data book value if an old sample of hydrated sodium carbonate had been used.

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(Total for question = 8 marks)

Q15.

An equation for the formation of ammonia using the Haber process is shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

Ammonia is stable in air but can be oxidised on the surface of a copper catalyst.

An equation for this reaction is

$$4NH_3(g) + 5O_2(g) \rightarrow 6H_2O(g) + 4NO(g) \qquad \Delta_r H = -905.2 \text{ kJ mol}^{-1}$$

The catalyst is usually warmed to approximately 300 °C to start the reaction, but after a short reaction time the copper catalyst often melts.

(i) Give a reason why the catalyst is warmed and a reason why the catalyst may melt.

(2)

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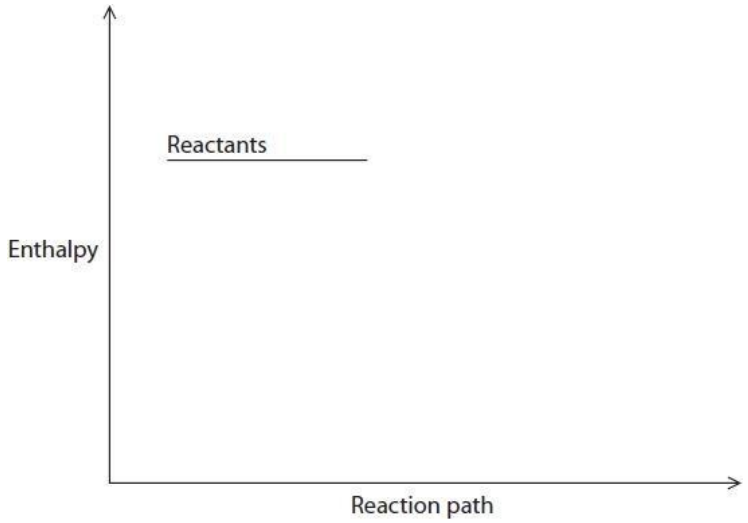
(ii) Complete the reaction profile for this catalysed oxidation of ammonia, showing the enthalpy change, $\Delta_r H$.

(2)



(iii) Describe the processes that occur on the surface of a heterogeneous catalyst during the oxidation of ammonia in air.

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(Total for question = 7 marks)

Q16.

The enthalpy change for the decomposition of sodium hydrogencarbonate can be determined indirectly using Hess's Law.

$$2NaHCO_3(s) \xrightarrow{\Delta_r H} Na_2CO_3(s) + H_2O(l) + CO_2(g)$$

A student carried out two experiments.

Experiment 1 involved the reaction between sodium hydrogencarbonate and hydrochloric acid.

The student used the following procedure:

- use a measuring cylinder to measure 50 cm^3 of 2.00 mol dm^{-3} hydrochloric acid and pour it into a polystyrene cup
- measure the initial temperature of the acid
- weigh the test tube containing sodium hydrogencarbonate
- tip the sodium hydrogencarbonate into the hydrochloric acid in the polystyrene cup, stir the mixture and record the lowest temperature reached
- weigh the empty test tube.

Results

Measurement	Value
Mass of test tube + $NaHCO_3$ / g	21.23
Mass of empty test tube / g	15.61
Mass of $NaHCO_3$ used / g	
Initial temperature / °C	21.0
Final temperature / °C	14.4
Temperature fall / °C	

(i) Complete the table.

(1)

(ii) Show, by calculation, that the hydrochloric acid is in excess.
You must show your working.

$$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$$

(2)

(iii) Calculate the enthalpy change for the reaction between sodium hydrogencarbonate and hydrochloric acid, using the results of the experiment.
Include a sign and units in your answer.

[Assume: mass of reaction mixture = 50.0 g
specific heat capacity of the reaction mixture = 4.18 J g^{-1} $°C^{-1}$]

(3)

(Total for question = 6 marks)

Q17.

Answer the question with a cross in the box you think is correct ☒ . If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒ .

When solid calcium sulfate dihydrate, $CaSO_4 \cdot 2H_2O$, is heated in a crucible, it forms solid calcium sulfate hemihydrate, $CaSO_4 \cdot \frac{1}{2}H_2O$.

Which two terms could be used to describe this reaction?

(1)

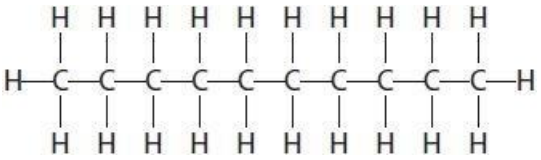
		Enthalpy change	Type of process
☒	**A**	endothermic	hydration
☒	**B**	exothermic	hydration
☒	**C**	exothermic	dehydration
☒	**D**	endothermic	dehydration

(Total for question = 1 mark)

Q18.

Decane, $C_{10}H_{22}$, is an alkane present in petrol and kerosene.

It has the displayed formula



The enthalpy change of combustion, $\Delta_c H^{\ominus}$, of decane can be estimated using mean bond enthalpy values and the equation shown.

$$C_{10}H_{22}(l) + 15.5O_2(g) \rightarrow 10CO_2(g) + 11H_2O(l)$$

(i) Calculate the enthalpy change of combustion of decane, using the mean bond enthalpy values in the table.

(3)

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

(ii) A data book value for the enthalpy change of combustion of decane is −6 778 kJ mol^{-1}.

Give two reasons for the difference between your answer to (i) and this value.

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(Total for question = 5 marks)

Q19.

Methanol, CH_3OH, is a liquid fuel.

Methanol can be synthesised from methane and steam by a process that occurs in two steps.

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

Step **2** $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H = -91\,kJ\,mol^{-1}$

Calculate a value for the standard enthalpy change of combustion of gaseous methanol using the enthalpy change for Step **2** and the standard enthalpy change of combustion of gaseous carbon monoxide and of hydrogen.

Substance	Standard enthalpy change of combustion / kJ mol^{-1}
CO	−283
H_2	−286

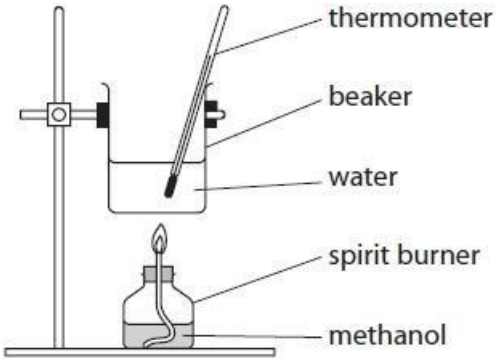
(3)

(Total for question = 3 marks)

Q20.

Methanol, CH_3OH, is a liquid fuel.

An experiment was carried out to determine the enthalpy change of combustion of liquid methanol.



The energy obtained from burning 2.08 g of methanol was used to heat 75.0 g of water.

The temperature of the water rose from 25.0 °C to 91.0 °C.

[Specific heat capacity of water = 4.18 J g^{-1} $°C^{-1}$]

Use the data to calculate a value for the enthalpy change of combustion of one mole of methanol.

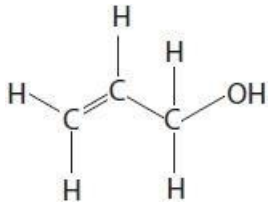
Give your answer to an appropriate number of significant figures and include a sign and units.

(4)

(Total for question = 4 marks)

Q21.

Prop-2-en-1-ol is an unsaturated alcohol with the structure shown.



A student planned to use bond enthalpy data to calculate a value for the enthalpy change of combustion of prop-2-en-1-ol.

(i) When researching the bond enthalpy data, the student claimed that it was not necessary to find the value for the C=C bond as they could use the value for a C–C bond and multiply it by two.

Explain why the student is **incorrect**.

(2)

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(ii) Calculate a value for the enthalpy of combustion of prop-2-en-1-ol using the data shown.

$$C_3H_6O(g) + 4O_2(g) \rightarrow 3CO_2(g) + 3H_2O(g)$$

Bond	C–C	C=C	C–O	C=O	O–H	C–H	O=O
Bond enthalpy / kJ mol^{-1}	347	612	358	805	464	413	498

(3)

(iii) Explain, in terms of entropy, why the combustion of prop-2-en-1-ol is always feasible in the gaseous state.

(2)

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(Total for question = 7 marks)

Q22.

This question is about the oxidation of ammonia.

Nitric acid is made from ammonia. One of the stages in nitric acid production involves the oxidation of ammonia to produce nitrogen(II) oxide, NO. In this process, a mixture of ammonia and oxygen is passed over a platinum-rhodium catalyst. One manufacturer uses a pressure of 5 atm and a temperature of 850 °C.

$$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g) \qquad \Delta_r H = -904.8\,kJ\,mol^{-1}$$

(i) Use this equation, and the enthalpy changes of formation of nitrogen(II) oxide and water, to calculate the enthalpy change of formation of ammonia in kJ mol^{-1}.

You may find it helpful to draw a Hess cycle first. You must show your working.

$\Delta_f H$ (NO(g)) = +90.4 kJ mol^{-1}

$\Delta_f H$ (H_2O(g)) = −241.8 kJ mol^{-1}

(3)

(ii) Calculate the atom economy by mass for the formation of NO in this reaction.

Give your answer to an appropriate number of significant figures.

(2)

(Total for question = 5 marks)

Q23.

Nitric acid reacts with sodium hydroxide solution in a neutralisation reaction.

$$HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(l)$$

In an experiment to determine the enthalpy change of neutralisation, the following results were obtained.

Volume of 1.00 mol dm^{-3} HNO_3 = 25.0 cm^3

Volume of 1.05 mol dm^{-3} NaOH = 25.0 cm^3

Temperature rise = 6.8 °C

Calculate the enthalpy change of neutralisation for the reaction between nitric acid and sodium hydroxide solution, using the results of the experiment.

Give your answer to an appropriate number of significant figures.

[Assume: density of the reaction mixture = 1.0 g cm^{-3}
specific heat capacity of the reaction mixture = 4.18 J g^{-1} $°C^{-1}$]

(4)

(Total for question = 4 marks)

Q24.

This question is about enthalpy changes.

(i) State what is meant by the term 'standard enthalpy change of combustion'.

(2)

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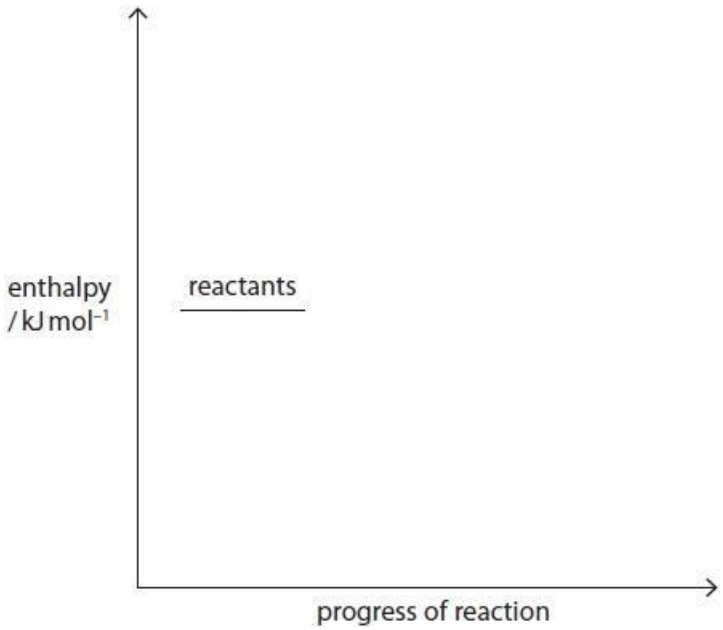
(ii) Write the equation, including state symbols, for the reaction that occurs when the standard enthalpy change of combustion of octane, $C_8H_{18}(l)$, is measured.

(2)

(iii) The standard enthalpy change of combustion of octane is –5 470 kJ mol^{-1}.

Complete the reaction profile diagram for the combustion of octane.
Include labels showing the standard enthalpy change of combustion, $\Delta_c H^{\theta}$, and the activation energy, E_a.

(2)



(Total for question = 6 marks)

Q25.

This question is about enthalpy changes and energy changes.

State what is meant by the standard enthalpy change of formation of aluminium oxide, $Al_2O_3(s)$. Include standard conditions.

(3)

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(Total for question = 3 marks)

Q26.

This question is about enthalpy changes and energy changes.

Magnesium carbonate reacts with dilute hydrochloric acid at room temperature.

$$MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + CO_2(g) + H_2O(l)$$

When the reaction is carried out in a sealed container with a constant volume, the heat energy change is not the same as the enthalpy change for this reaction.

Give a reason why this is so.

(1)

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(Total for question = 1 mark)

Q27.

This question is about enthalpy changes.

Enthalpy changes of reactions which cannot be measured directly can be calculated using standard enthalpy changes of combustion.
The table shows some of these values.

Substance	$\Delta_c H^{\ominus}$ / kJ mol^{-1}
C(s)	–394
$H_2(g)$	–286
$CH_4(g)$	–890

Complete the Hess cycle and use it to calculate the standard enthalpy change for the following reaction.

(4)

(Total for question = 4 marks)

Q28.

Phosphorus(V) chloride, PCl_5, can be thermally decomposed to phosphorus(III) chloride, PCl_3, and chlorine, Cl_2 . The equation for this reaction is

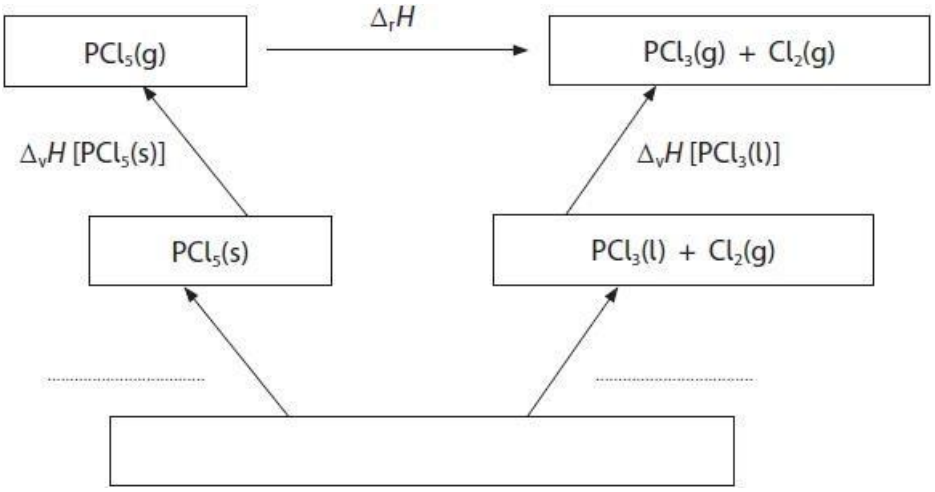
$$PCl_5(g) \rightarrow PCl_3(g) + Cl_2(g)$$

The enthalpy change for this reaction cannot be measured directly.

(i) Complete the Hess's Law cycle to include the enthalpy change of formation of both phosphorus chlorides.

Include the labels of the missing enthalpy changes.
$\Delta_v H$ is the enthalpy change for the vaporisation of the substance from the state shown to the gaseous state.

(3)



(ii) Calculate the enthalpy change for the thermal decomposition of $PCl_5(g)$ to $PCl_3(g)$ and $Cl_2(g)$, using the data given in the table.
Include a sign and units in your answer.

(2)

	Enthalpy change / kJ mol^{-1}
$\Delta_f H$ [$PCl_5(s)$]	–443.5
$\Delta_f H$ [$PCl_3(l)$]	–319.7
$\Delta_v H$ [$PCl_5(s)$]	+64.9
$\Delta_v H$ [$PCl_3(l)$]	+30.5

(Total for question = 5 marks)

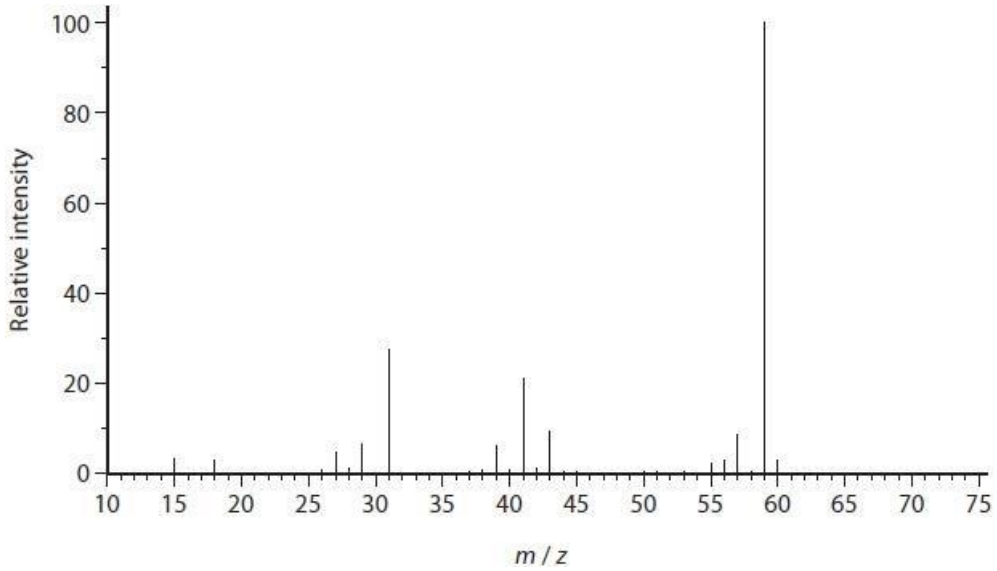
Q29.

This question is about 2-methylpropan-2-ol.

(a) Draw the fully **displayed** formula of 2-methylpropan-2-ol.

(1)

(b) The mass spectrum of 2-methylpropan-2-ol is shown.



(i) The relative molecular mass of 2-methylpropan-2-ol is 74.
Give a possible reason why there is no molecular ion peak in the mass spectrum of 2-methylpropan-2-ol.

(1)

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(ii) Write the formula for a species that could be responsible for the peak at $m / z = 59$.

(1)

(c) The equation for the complete combustion of 2-methylpropan-2-ol is

$$C_4H_{10}O(l) + 6O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$$

(i) Using the bond enthalpies shown in the table, calculate a value for the enthalpy change, in kJ mol^{-1}, for the complete combustion of 2-methylpropan-2-ol.

(4)

Bond	Mean bond enthalpy / kJ mol^{-1}
C—C	347
C—H	413
C—O	358
O—H	464
O═O	498
C═O	805

(ii) 2-methylpropan-2-ol burns in air with a smoky flame.
Explain how burning with a smoky flame affects the value of the experimentally determined enthalpy change of combustion.

(2)

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(iii) A Data Book value for the enthalpy change of combustion of 2-methylpropan-2-ol is −2643.8 kJ mol^{-1}.
Give the main reason for the difference between this value and your answer to part (c)(i).

(1)

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(Total for question = 10 marks)

Q30.

The enthalpy change for the decomposition of sodium hydrogencarbonate can be determined indirectly using Hess's Law.

$$2NaHCO_3(s) \xrightarrow{\Delta_r H} Na_2CO_3(s) + H_2O(l) + CO_2(g)$$

A student carried out two experiments.

Experiment 2 involved the reaction between sodium carbonate and hydrochloric acid.

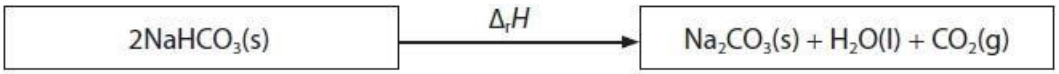
The student repeated the procedure for **Experiment 1** but used sodium carbonate instead of sodium hydrogencarbonate and measured the maximum temperature rise.

$$Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g)$$

The student calculated the enthalpy change for this reaction as −29.4 kJ mol^{-1}.

(i) Complete the Hess cycle with appropriate formulae and labelled arrows.

(2)



(ii) Calculate the enthalpy change for the decomposition of sodium hydrogencarbonate. Include a sign and units in your answer.

$$2NaHCO_3(s) \xrightarrow{\Delta_r H} Na_2CO_3(s) + H_2O(l) + CO_2(g)$$

(3)

(Total for question = 5 marks)

Q31.

Hess's law can be used to determine enthalpy changes for reactions which cannot be obtained directly.
An example is the reaction of anhydrous copper(II) sulfate with water to form hydrated copper(II) sulfate, $CuSO_4.5H_2O$.

The following outline procedure was carried out.

Step **1** 42.75 g of deionised water was weighed out in a polystyrene cup and the temperature measured.

Step **2** 0.0250 mol of hydrated copper(II) sulfate was added to the water in the polystyrene cup with stirring, making a total of 45.00 g of water.

Step **3** The temperature change was recorded.

Step **4** Steps **1** to **3** were repeated using 45.00 g of deionised water and 0.0250 mol of anhydrous copper(II) sulfate.

The reaction of hydrated copper(II) sulfate with water is shown.

$$CuSO_4.5H_2O(s) + aq \rightarrow CuSO_4(aq) \qquad \Delta H_1 = +18.2 \text{ kJ mol}^{-1}$$

(a) Calculate the temperature change that would have given this enthalpy change for the stated experimental procedure.
Give your answer to a measurable number of significant figures and state whether the temperature increases or decreases.

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

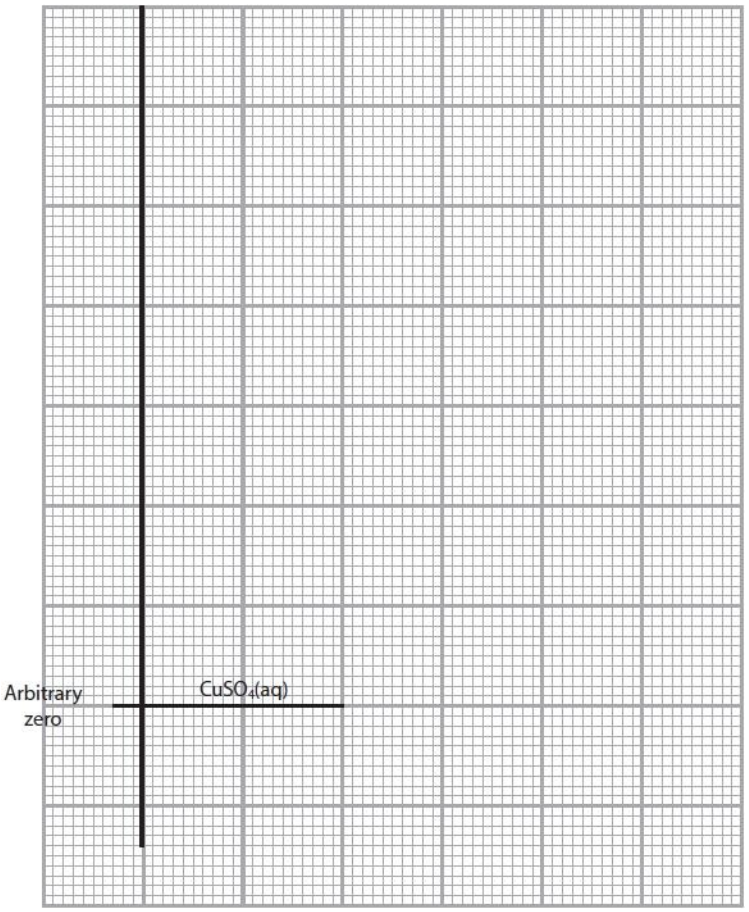
(3)

The reaction of anhydrous copper(II) sulfate with water is shown.((

$$CuSO_4(s) + aq \rightarrow CuSO_4(aq) \qquad \Delta H_2 = -84.5 \text{ kJ mol}^{-1}$$

(b) (i) Draw to scale, on the graph paper, a labelled enthalpy level diagram which shows the enthalpy changes for the reactions of water with hydrated copper(II) sulfate (ΔH_1) and anhydrous copper(II) sulfate (ΔH_2) .

(3)



(b) (ii) Use your enthalpy level diagram in (i) to determine the enthalpy change, $\Delta_r H$, for the reaction

$$CuSO_4(s) + 5H_2O(l) \rightarrow CuSO_4.5H_2O(s)$$

You **must** show your working on the diagram.

(1)

$\Delta_r H$ .....

(c) State why the enthalpy change for the reaction of one mole of anhydrous copper(II) sulfate with five moles of water to form hydrated copper(II) sulfate, $CuSO_4.5H_2O$, cannot be measured directly.

(1)

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(Total for question = 8 marks)

Q32.

This question concerns iodine monochloride, ICl, a red-brown solid which melts at 27 °C to form a red-brown liquid.

Iodine monochloride is used in measuring unsaturation in organic compounds.

Iodine monochloride gas can be produced by the reaction between iodine vapour and chlorine gas. The reaction is exothermic.

$$I_2(g) + Cl_2(g) \rightarrow 2ICl(g) \quad \Delta_r H = -30 \text{ kJ mol}^{-1}$$

The table shows bond energy values for the bonds in iodine and chlorine.

Calculate the value of the bond energy of the I—Cl bond using these data and the equation.

Bond	Energy / kJ mol^{-1}
I—I	151
Cl—Cl	243

(2)

(Total for question = 2 marks)

Q33.

Nitric acid reacts with sodium hydroxide solution in a neutralisation reaction.

$$HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(l)$$

In an experiment to determine the enthalpy change of neutralisation, the following results were obtained.

Volume of 1.00 mol dm^{-3} HNO_3 = 25.0 cm^3

Volume of 1.05 mol dm^{-3} NaOH = 25.0 cm^3

Temperature rise = 6.8 °C

Give a reason why excess sodium hydroxide was used.

(1)

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(Total for question = 1 mark)

Q34.

This question is about enthalpy changes and entropy changes.

Which is the equation for the standard enthalpy change of formation, $\Delta_f H^{\ominus}$, of aluminium oxide?

(1)

☒ **A** $4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$

☒ **B** $4Al(s) + 6O(g) \rightarrow 2Al_2O_3(s)$

☒ **C** $2Al(s) + 1½O_2(g) \rightarrow Al_2O_3(s)$

☒ **D** $2Al(s) + 3O(g) \rightarrow Al_2O_3(s)$

(Total for question = 1 mark)

Q35.

One of the stages in the production of sulfuric acid from sulfide ores involves the oxidation of sulfur dioxide to sulfur trioxide. The equation for the reaction is

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta rH = -197 \text{ kJ mol}^{-1}$

The conditions used in one industrial process are: 420°C and a pressure of 1.7 atm together with a vanadium(V) oxide catalyst.

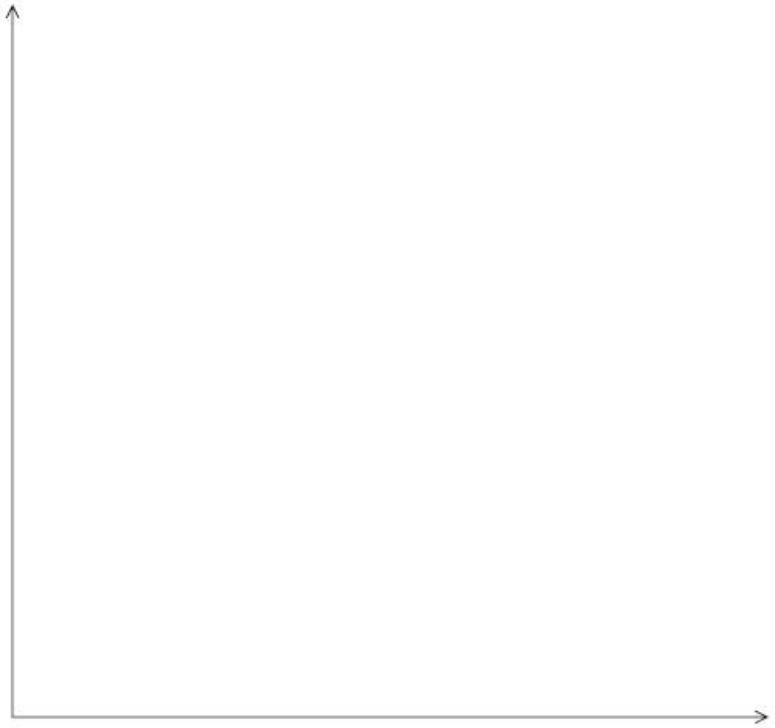
It is proposed to change the conditions to 600°C and 10 atm pressure, while still using the same catalyst.

(i) On the axes provided, sketch the reaction profiles for the uncatalysed and catalysed reaction.

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta rH = -197 \text{ kJ mol}^{-1}$

Label the uncatalysed reaction, **A**, and the reaction catalysed by vanadium(V) oxide, **B**.

(3)



(ii) On your reaction profile, identify and label both the enthalpy change and the activation energy for the catalysed reaction.

(2)

(Total for question = 5 marks)

Q36.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The standard molar enthalpy change of neutralisation is the enthalpy change when an acid and an alkali react under standard conditions to form one mole of water.

An experiment was carried out to determine the enthalpy change of neutralisation for the reaction between propanoic acid and sodium hydroxide.

The equation for this reaction is

$$CH_3CH_2COOH(aq) + NaOH(aq) \rightarrow CH_3CH_2COO^-Na^+(aq) + H_2O(l)$$

50.0 cm^3 of sodium hydroxide solution, of concentration 1.00 mol dm^{-3}, was placed in a polystyrene cup. The initial temperature was measured.

(i) Which piece of equipment has the **smallest** measurement uncertainty for the measurement of 50.0 cm^3 of sodium hydroxide solution?

(1)

		Equipment	Measurement uncertainty for **each** reading
☐	**A**	burette	±0.05 cm^3
☐	**B**	50 cm^3 measuring cylinder	±1 cm^3
☐	**C**	25 cm^3 pipette	±0.06 cm^3
☐	**D**	50 cm^3 pipette	±0.08 cm^3

(ii) 50.0 cm^3 of propanoic acid solution, of concentration 1.00 mol dm^{-3}, was added and thoroughly mixed with the sodium hydroxide solution in the polystyrene cup.

The maximum temperature rise was 6.5 °C.

Calculate the enthalpy change of neutralisation for propanoic acid, in kJ mol^{-1}, giving your answer to the **nearest whole number**.

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

(3)

(Total for question = 4 marks)

Q37.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

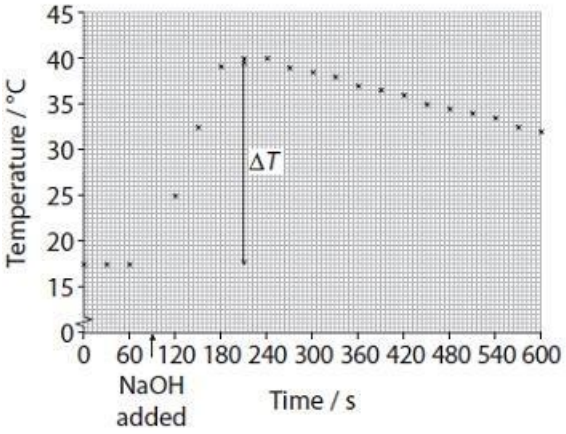
The standard molar enthalpy change of neutralisation is the enthalpy change when an acid and an alkali react under standard conditions to form one mole of water.

An experiment was carried out with a solution of ethanoic acid and sodium hydroxide solution of the same concentration.

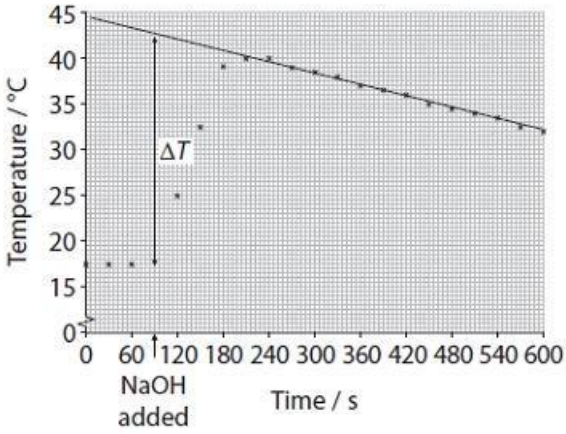
(i) Which graph shows the correct way that the maximum temperature rise should be determined?

(1)

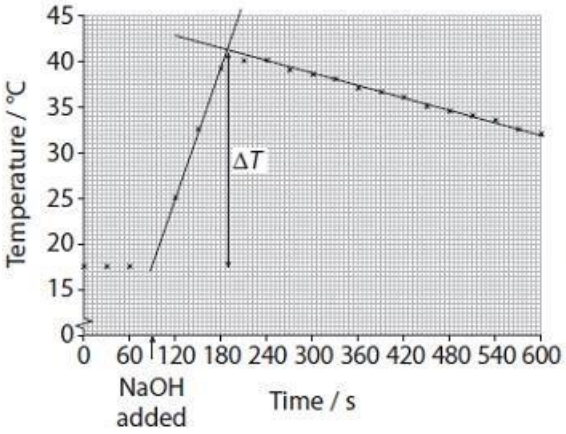
☒ **A**



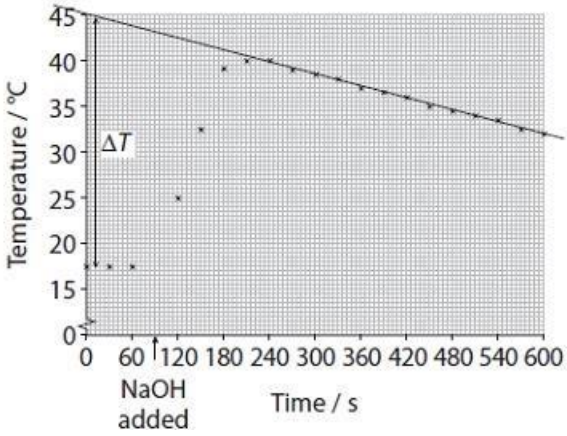
☒ **B**



☒ **C**



☒ **D**



(ii) Explain why the data book value for the standard enthalpy change of neutralisation of ethanoic acid with sodium hydroxide is –55.2 kJ mol^{-1} but the value for hydrochloric acid is –57.1 kJ mol^{-1}.

(2)

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(Total for question = 3 marks)

Q38.

Write the equation to represent the standard enthalpy change of formation of ethanol.
Include state symbols.

(2)

(Total for question = 2 marks)