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.

(1)

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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.
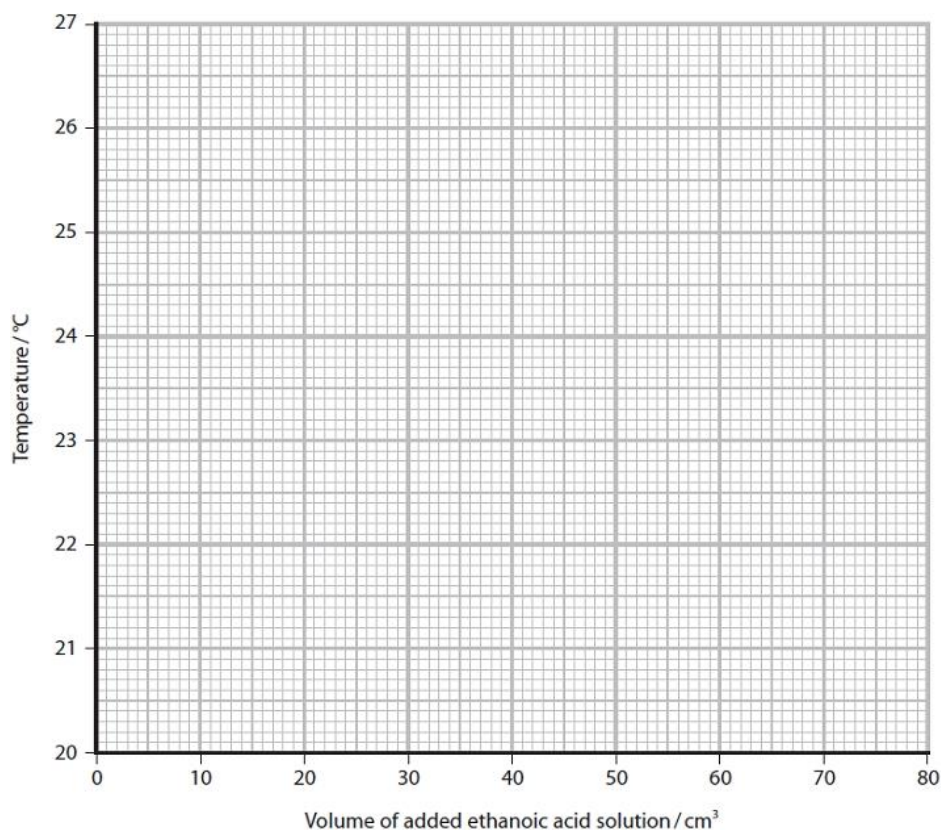
Results for this experiment are shown in the table.

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.

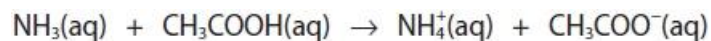   Include two straight lines of best fit, extrapolated until they meet.

(2)

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

(1)

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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 cm³ of distilled water, using a 250 cm³ 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**.
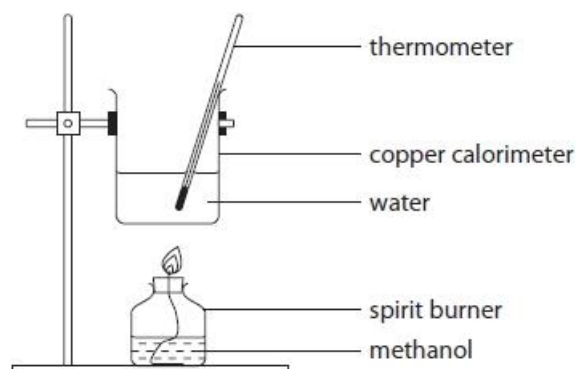
The results of Student 1 are recorded in **Table 1**.

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.

(2)

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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.

(2)

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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.
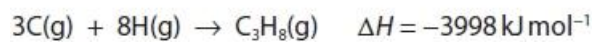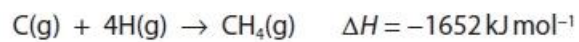
(2)

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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.
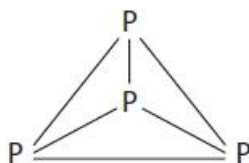
(2)

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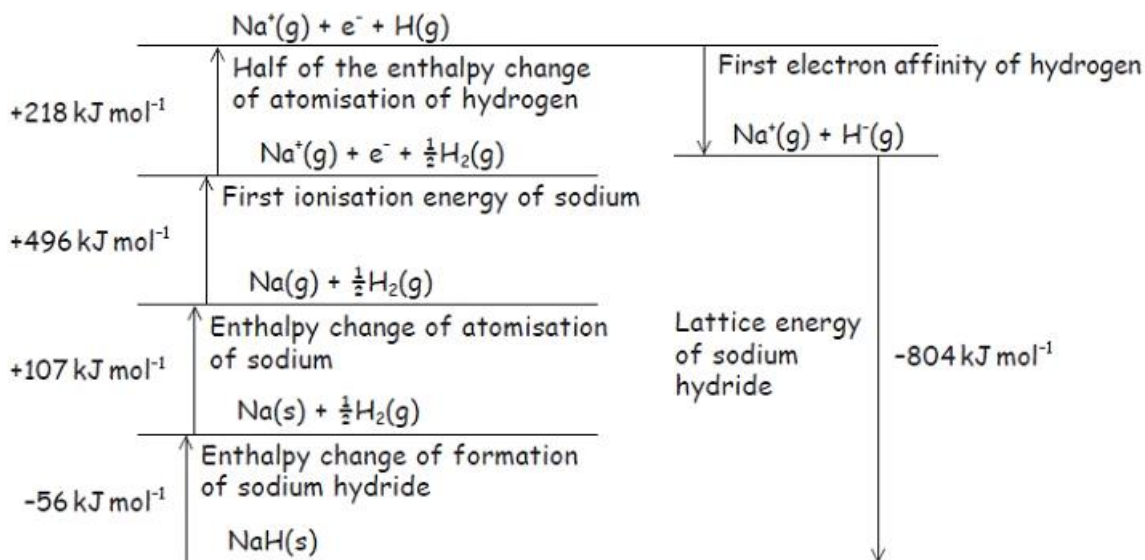
(i) Identify and correct the **two** errors in this Born-Haber cycle.

(2)

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

(1)

(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.

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g) \qquad \Delta_r H^{\ominus} = -75.6 \text{ kJ mol}^{-1}$$
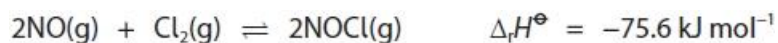
(i) Complete the Hess cycle to enable you to calculate the enthalpy change of formation, $\Delta_f H^{\ominus}_{298}$, of NOCl.

   Include state symbols.

(2)

| $2NO(g) + Cl_2(g)$ | $\longrightarrow$ | $2NOCl(g)$ |

| |

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

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

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

(2)
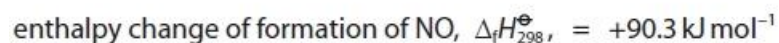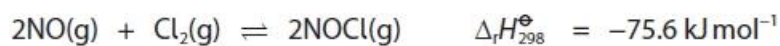
(Total for question = 4 marks)

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.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$
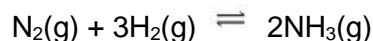
(i) Calculate the enthalpy change for the forward reaction shown in the equation, selecting from the bond enthalpies in the table.
    Include a sign in your answer.

(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?

$$N_2(g) + 3H_2(g) \rightleftharpoons 3(g)$$
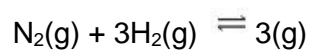
(1)

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

(iv) What is the equilibrium expression for K_c?

(1)

☒   **A** $K_c = \dfrac{[N_2][3H_2]}{[2NH_3]}$

☒   **B** $K_c = \dfrac{[2NH_3]}{[N_2][3H_2]}$

☒   **C** $K_c = \dfrac{[NH_3]^2}{[N_2][H_2]^3}$

☒   **D** $K_c = \dfrac{[N_2][H_2]^3}{[NH_3]^2}$

(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 $\pm 0.5 \, cm^3$, and is placed in an insulated cup with a lid.

Step 2 A thermometer with an uncertainty of $\pm 0.5 \, °C$ 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 $\pm 0.005 \, g$.

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.
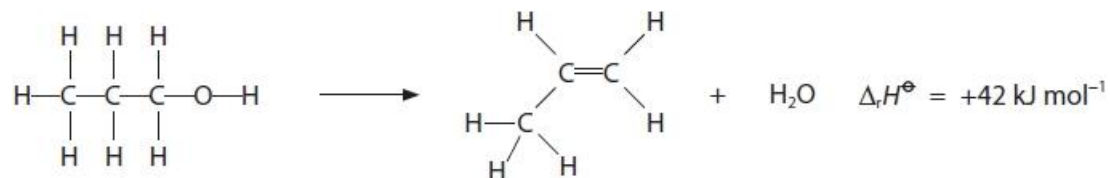
The relevant mean bond enthalpies are given in the table.

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.
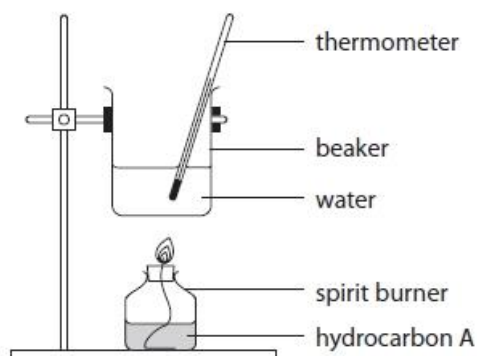
Results

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 cm³
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.

(1)

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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}.

$$HCl(aq) + NH_3(aq) \rightarrow NH_4Cl(aq)$$
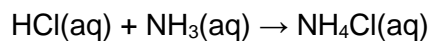
Calculate the temperature change you would expect when
25.0 cm^3 of 1.00 mol dm^{-3} hydrochloric acid is mixed with
25.0 cm^3 of 1.00 mol dm^{-3} aqueous ammonia.

Give your answer to an appropriate number of significant figures.

$$\left[\begin{array}{l} \text{Assume: the density of the solution is 1.00 g cm}^{-3} \\ \qquad\quad \text{the specific heat capacity of the solution is 4.18 J g}^{-1}\,{}^{\circ}\text{C}^{-1} \end{array} \right]$$

(3)

(Total for question = 3 marks)

Q13.

Ethanol burns completely in excess oxygen.

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$
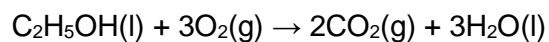
(i)   The table shows some mean bond enthalpy data.

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)

enthalpy

$C_2H_5OH(l) + 3O_2(g)$

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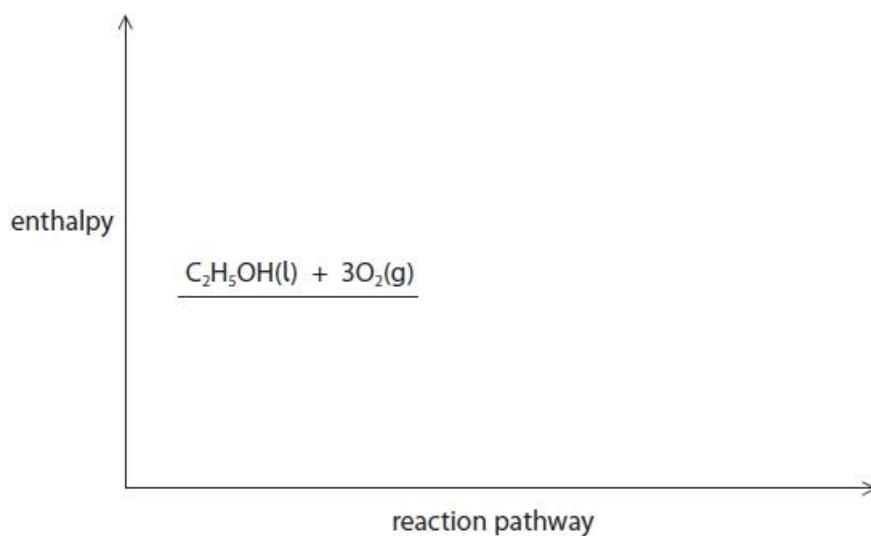
(iii) A data book value for the standard enthalpy change of combustion of ethanol is −1367.3 kJ mol^{-1}.

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.

$$Na_2CO_3(s) + 10H_2O(l) \rightarrow Na_2CO_3.10H_2O(s)$$
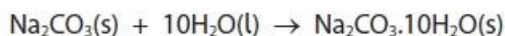
(a)   In the first experiment, the student determines the enthalpy change of solution for anhydrous sodium carbonate.

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]

$$Na_2CO_3(s) + aq \rightarrow Na_2CO_3(aq)$$
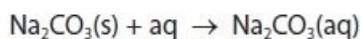
(4)

(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)

| $Na_2CO_3(s) + 10H_2O(l)$ | $\longrightarrow$ | $Na_2CO_3.10H_2O(s)$ |

(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.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$
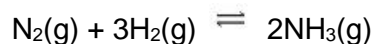
Ammonia is stable in air but can be oxidised on the surface of a copper catalyst.

An equation for this reaction is

$$4NH_3(g) + 5O_2(g) \rightarrow 6H_2O(g) + 4NO(g) \qquad \Delta_rH = -905.2 \text{ kJ mol}^{-1}$$
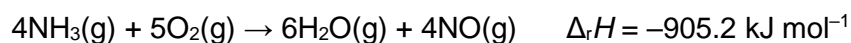
The catalyst is usually warmed to approximately 300 °C to start the reaction, but after a short reaction time the copper catalyst often melts.

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

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(ii) Complete the reaction profile for this catalysed oxidation of ammonia, showing the enthalpy change, Δ_rH.

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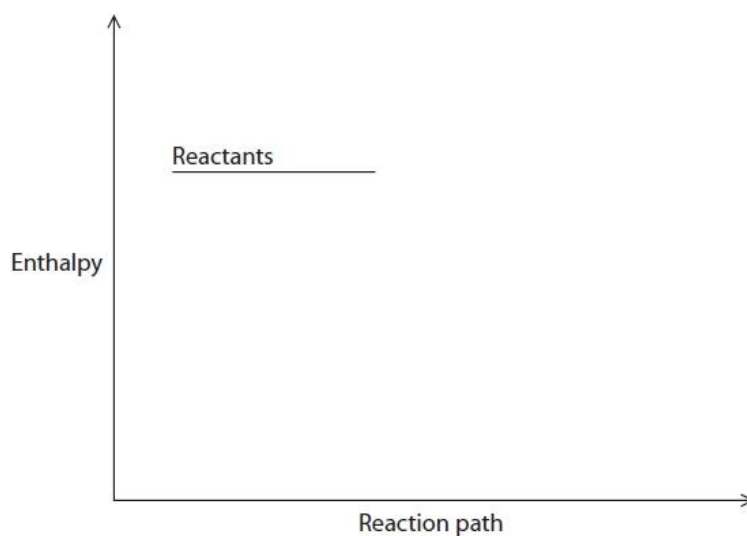
(iii) Describe the processes that occur on the surface of a heterogeneous catalyst during the oxidation of ammonia in air.

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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.

$$2NaHCO_3(s) \xrightarrow{\Delta_r H} Na_2CO_3(s) + H_2O(l) + CO_2(g)$$
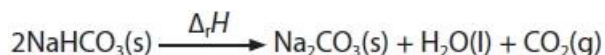
A student carried out two experiments.

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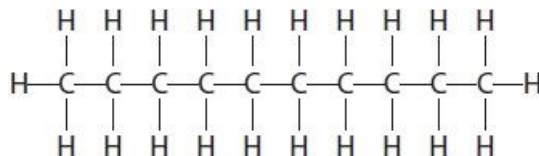
The enthalpy change of combustion, $\Delta_c H^{\ominus}$, of decane can be estimated using mean bond enthalpy values and the equation shown.

$$C_{10}H_{22}(l) + 15.5O_2(g) \rightarrow 10CO_2(g) + 11H_2O(l)$$
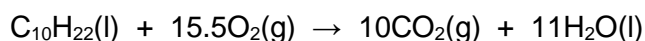
(i) Calculate the enthalpy change of combustion of decane, using the mean bond enthalpy values in the table.

(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.

(2)

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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 $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H = -91 \, kJ \, mol^{-1}$
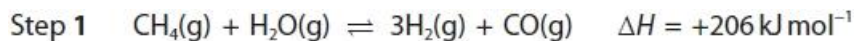
Calculate a value for the standard enthalpy change of combustion of gaseous methanol using the enthalpy change for Step **2** and the standard enthalpy change of combustion of gaseous carbon monoxide and of hydrogen.

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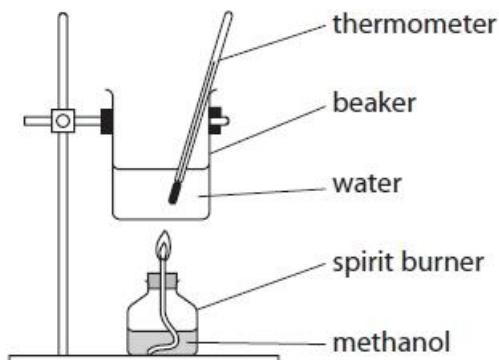
The energy obtained from burning 2.08 g of methanol was used to heat 75.0 g of water.

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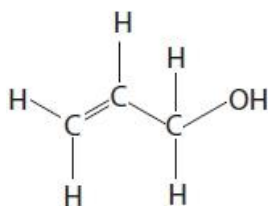
A student planned to use bond enthalpy data to calculate a value for the enthalpy change of combustion of prop-2-en-1-ol.

(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.

$$C_3H_6O(g) + 4O_2(g) \rightarrow 3CO_2(g) + 3H_2O(g)$$
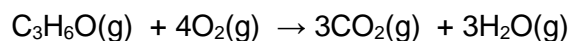
Bond	C–C	C=C	C–O	C=O	O–H	C–H	O=O
Bond enthalpy / kJ mol^{-1}	347	612	358	805	464	413	498

(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.

$$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g) \qquad \Delta_rH = -904.8 \, kJ \, mol^{-1}$$
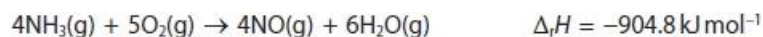
(i) Use this equation, and the enthalpy changes of formation of nitrogen(II) oxide and water, to calculate the enthalpy change of formation of ammonia in kJ mol^{-1}.

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

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

$\Delta_fH \, (H_2O(g)) = -241.8 \, kJ \, mol^{-1}$

(3)

(ii) Calculate the atom economy by mass for the formation of NO in this reaction.
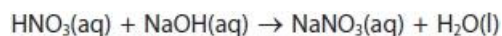
Give your answer to an appropriate number of significant figures.

(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.

$$\left[\begin{array}{ll} \text{Assume:} & \text{density of the reaction mixture} = 1.0\,g\,cm^{-3} \\ & \text{specific heat capacity of the reaction mixture} = 4.18\,J\,g^{-1}\,°C^{-1} \end{array}\right]$$

(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, Δ_cH^θ, and the activation energy, E_a.

(2)
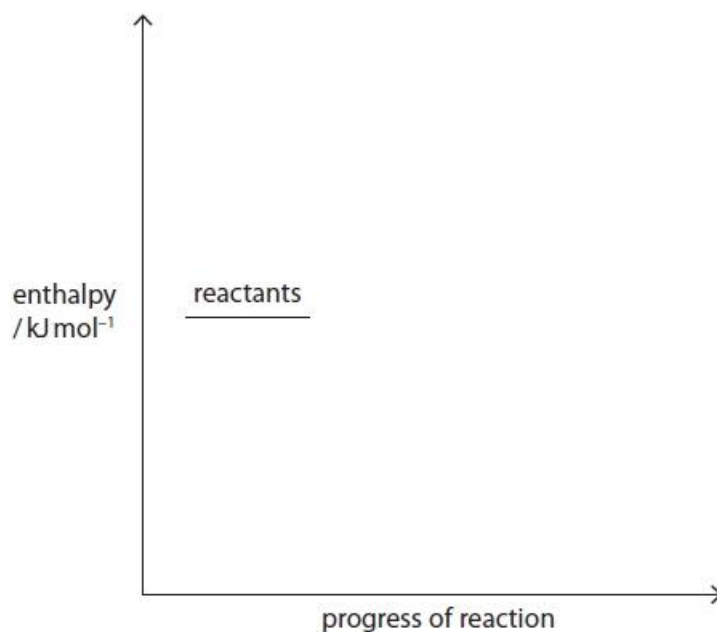
(Total for question = 6 marks)

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)

$C(s) + 2H_2(g)$	$\rightarrow$	$CH_4(g)$

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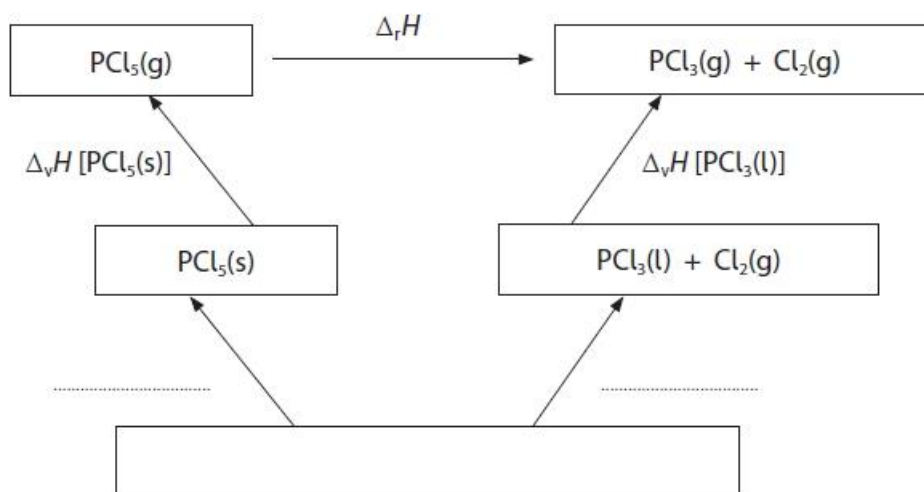
(ii) Calculate the enthalpy change for the thermal decomposition of PCl_5(g) to PCl_3(g) and Cl_2(g), using the data given in the table.
    Include a sign and units in your answer.

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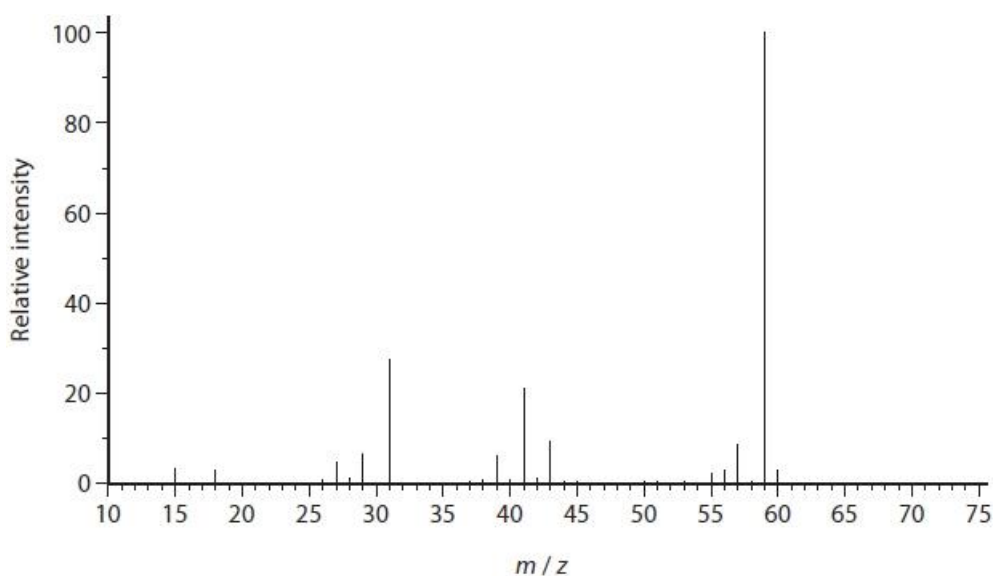
(i) The relative molecular mass of 2-methylpropan-2-ol is 74.
Give a possible reason why there is no molecular ion peak in the mass spectrum of 2-methylpropan-2-ol.

(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

$$C_4H_{10}O(l) + 6O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$$
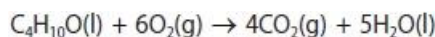
(i) Using the bond enthalpies shown in the table, calculate a value for the enthalpy change, in kJ mol^{-1}, for the complete combustion of 2-methylpropan-2-ol.

(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)

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

$$2NaHCO_3(s) \xrightarrow{\Delta_r H} Na_2CO_3(s) + H_2O(l) + CO_2(g)$$
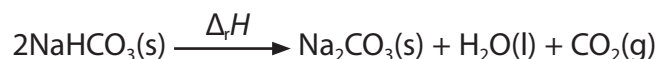
A student carried out two experiments.

(a) **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)

(b) **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)

| 2NaHCO$_3$(s) | $\xrightarrow{\Delta_r H}$ | Na$_2$CO$_3$(s) + H$_2$O(l) + CO$_2$(g) |
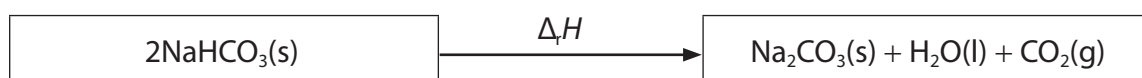
(ii) Calculate the enthalpy change for the decomposition of sodium hydrogencarbonate.
Include a sign and units in your answer.

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

(3)
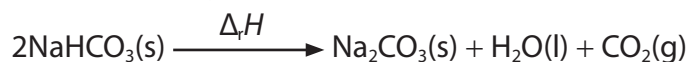
(Total for question = 11 marks)

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.

$$CuSO_4.5H_2O(s) + aq \rightarrow CuSO_4(aq) \qquad \Delta H_1 = +18.2 \text{ kJ mol}^{-1}$$
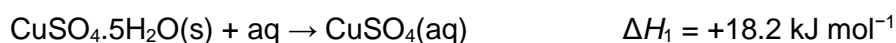
(a) Calculate the temperature change that would have given this enthalpy change for the stated experimental procedure.
Give your answer to a measurable number of significant figures and state whether the temperature increases or decreases.

[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.((

$$CuSO_4(s) + aq \rightarrow CuSO_4(aq) \qquad \Delta H_2 = -84.5 \text{ kJ mol}^{-1}$$
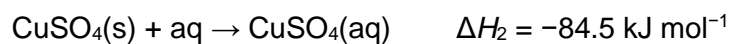
(b) (i) Draw to scale, on the graph paper, a labelled enthalpy level diagram which shows the enthalpy changes for the reactions of water with hydrated copper(II) sulfate (ΔH_1) and anhydrous copper(II) sulfate (ΔH_2) .

(3)

Arbitrary zero   CuSO$_4$(aq)
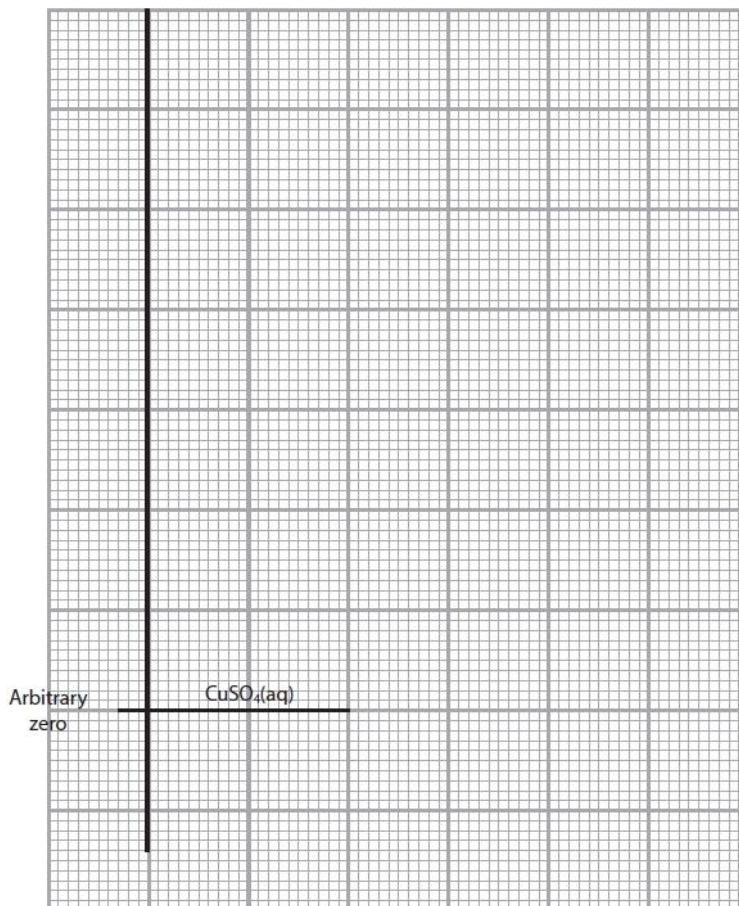
(b) (ii) Use your enthalpy level diagram in (i) to determine the enthalpy change, $\Delta_r H$, for the reaction

$$CuSO_4(s) + 5H_2O(l) \rightarrow CuSO_4.5H_2O(s)$$
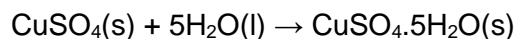
You **must** show your working on the diagram.

(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.

$$I_2(g) \ + \ Cl_2(g) \ \rightarrow \ 2ICl(g) \ \ \Delta_rH = -30 \ kJ \ mol^{-1}$$
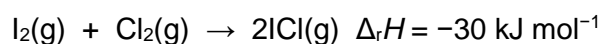
The table shows bond energy values for the bonds in iodine and chlorine.

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** $2Al(s) + 1\frac{1}{2}O_2(g) \rightarrow Al_2O_3(s)$

☐ **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

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta rH = -197$ kJ mol^{-1}
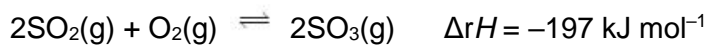
The conditions used in one industrial process are: 420°C and a pressure of 1.7 atm together with a vanadium(V) oxide catalyst.

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.

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta rH = -197$ kJ mol^{-1}
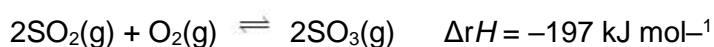
     Label the uncatalysed reaction, **A**, and the reaction catalysed by vanadium(V) oxide, **B**.

(3)
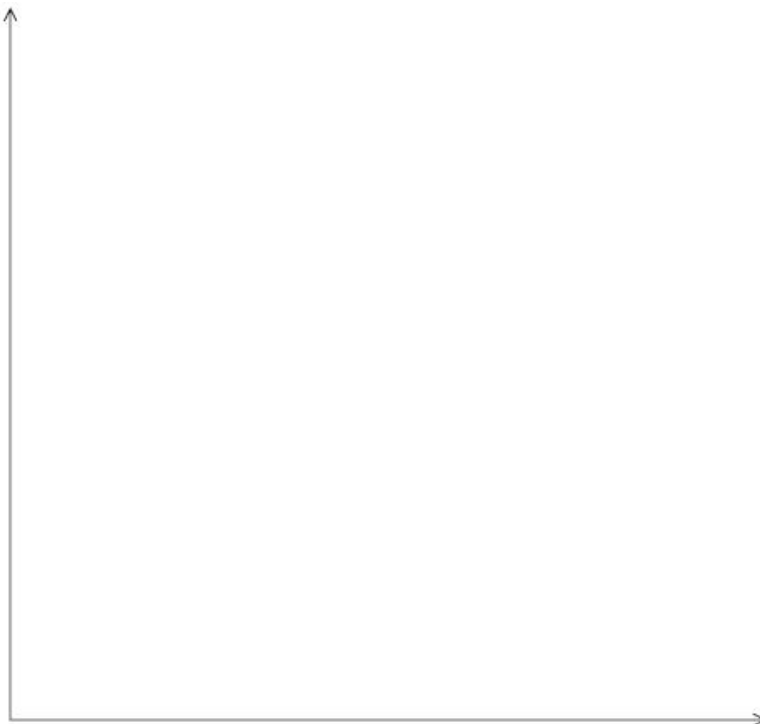
(ii) On your reaction profile, identify and label both the enthalpy change and the activation energy for the catalysed reaction.

(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

$$CH_3CH_2COOH(aq) + NaOH(aq) \rightarrow CH_3CH_2COO^-Na^+(aq) + H_2O(l)$$
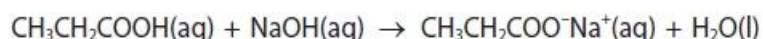
50.0 cm^3 of sodium hydroxide solution, of concentration 1.00 mol dm^{-3}, was placed in a polystyrene cup. The initial temperature was measured.

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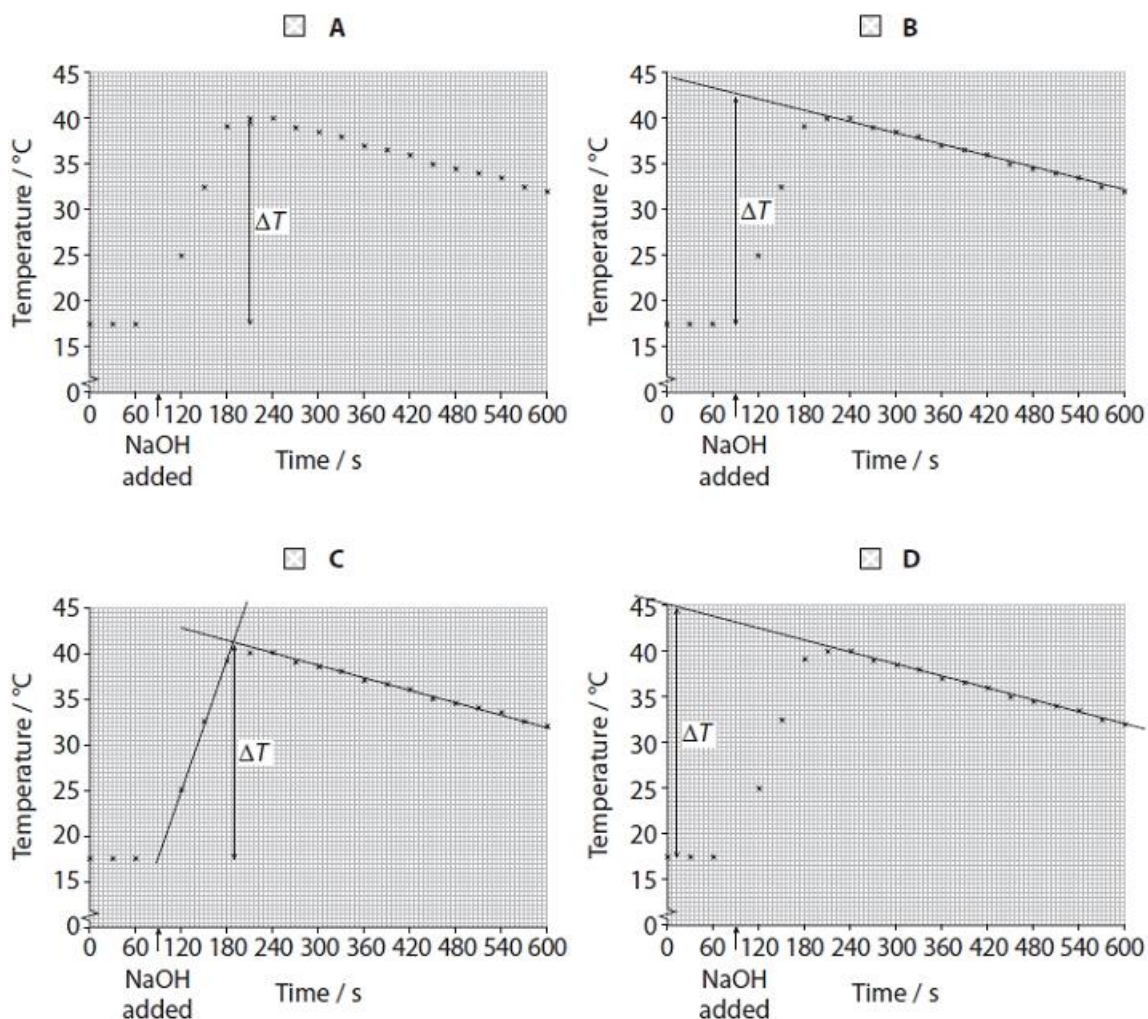
(ii) Explain why the data book value for the standard enthalpy change of neutralisation of ethanoic acid with sodium hydroxide is –55.2 kJ mol^{-1} but the value for hydrochloric acid is –57.1 kJ mol^{-1}.

(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)

Mark Scheme

Q1.

Question Number	Answer	Mark
(i)	The only correct answer is **C** (exothermic so energy is absorbed by the water) *A is not correct because the reaction is exothermic not endothermic* *B is not correct because the reaction is exothermic not endothermic and energy is absorbed not released by the water* *D is not correct because energy is absorbed not released by the water*	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	An answer that makes reference to the following point: • (no further release of energy so colder) solution being added cools the reaction mixture OR Added ethanoic acid is at a lower temperature than the reaction mixture	Allow the heat energy is shared over a larger volume Ignore the reaction has stopped so no more energy is released Ignore heat loss	(1)

Q2.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: • points **(1)** plotted correctly • two **(1)** suitable straight lines of best fit drawn	 Do not award dot to dot lines	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	• temperature rise read from graph	26.7 – 20.1 = 6.6 (°C) Allow maximum temperature shown by graph – 20.1 or temperature from line of best fit at 0 cm^3 added when these are not the same BUT do not award temperature rises which include subtraction of 20.0 unless the lines of best fit indicate this. Ignore SF except 1SF	(1)

Question Number	Answer	Additional Guidance	Mark
(iii)	• gives correct volume added at end-point from the graph (accurate to half a square) **(1)** • finds moles of acid added **(1)**	Example of calculation $= 39$ cm^3 Do not award 40 cm^3 unless the lines of best fit indicate this value $= \dfrac{39}{1000} \times 1.10 =$ 0.0429 / 4.29 x 10^{-2} (mol) Ignore units, even if incorrect Allow TE on first volume given, e.g. Use of 80cm^3 as volume giving 0.088 moles scores (1)	**(2)**

Question Number	Answer	Additional Guidance	Mark
(iv)	• use of energy change $= m \times c \times \Delta T$ **(1)** • calculation of energy change per mole **(1)** • final answer with correct sign and units **(1)**	Example of calculation $(30 + 39) \times 4.18 \times 6.6 = 1\,903.6 / 1.9036 \times 10^3$ (J) $= \dfrac{1\,903.6}{0.0429} = 44\,372$ (J mol^{-1}) $- 44\,372$ J mol^{-1} / $- 44\,400$ J mol^{-1} $/ - 44.372$ kJ mol^{-1} / $- 44.4$ kJ mol^{-1} Allow TE throughout from the graph in (a)(i) and calculations in (a)(ii) and (a)(iii) Ignore SF except 1 SF	**(3)**

Q3.

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)	• 1.60 **(1)**	Do not award MP1 for "1.6" (must be to 2 D.P.)	**(2)**
	• (+) 42.5 **(1)**	Do not award MP2 for "42.50" (must be to 1 D.P.) Penalise D.P. error once only	

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)	$CH_3OH(l) + 1.5O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$		**(2)**
	• Balanced equation **(1)**	Do not award multiples (enthalpy change is for the complete combustion of one mole) for MP1	
	• State symbols all correct **(1)**	MP2 depends on the award of MP1 or correct species	

Question Number	Acceptable Answers	Additional Guidance	Mark
(c)		Example of calculation	**(4)**
	• Calculation of energy change **(1)**	$(= mc\Delta T = 150 \times 4.18 \times 42.5 =)$ 26647.5 (J)	
	• Calculation of moles of CH_3OH **(1)**	Moles CH_3OH = 1.60/32 (= 0.05(00))	
	• Calculation of energy ÷ moles CH_3OH **(1)**	$\frac{26647.5}{0.05(00)}$ = 532950 (J mol⁻¹) Ignore any signs at this stage	
	• ΔH final answer in kJ mol⁻¹ **and** negative sign included **and** ΔH final answer to 2 or 3 S.F. **(1)**	−533 (kJ mol⁻¹) **Or** −530 (kJ mol⁻¹) Correct answer with no working gains full marks Penalise incorrect units for MP4 only Allow TE at each stage Allow correct rounding to 2SF or more at each stage	

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)(i)	$(\pm)0.7$ (%)	Allow from 1 SF up to calculator value correctly rounded where $$(\% \text{ uncertainty} =) (\pm) \frac{1}{150} \times 100 = 0.66666...7 \text{ (\%)}$$ Allow 0.6 or $\frac{2}{3}$ Do not award 0.66/0.6	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)(ii)	An answer that makes reference to the following points: • Calculation of the % uncertainty using the 25 cm³ measuring cylinder **(1)** **Then any two from:** • % uncertainty with use of 25 cm³ measuring cylinder is greater **(1)** • Repeated use of the small measuring cylinder will lead to greater transfer losses **(1)** • Repeated use will take more time **(1)**	Needs to show combined error in using the 25 cm³ six times is greater than using 250 cm³ measuring cylinder once only Award MP1 EITHER if multiplies errors: $100 \times (0.2/25) \times 6 = 4.8\%$ OR If adds errors $100 \times (1.2/150) = 0.8\%$ Do not award $(0.2/25) \times 100 = 0.8\%$ Do not award 'easier' to use larger measuring cylinder	(3)

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)(iii)	An answer that makes reference to any **three** of the following points: • heat/energy loss (to the surroundings) **(1)** • evaporation of methanol / water from the calorimeter **(1)** • incomplete combustion (of methanol) **(1)** • (specific) heat capacity of the calorimeter/apparatus has been ignored **(1)**	Ignore experiment carried out under non-standard conditions Ignore just 'no lid' Allow calorimeter has not been calibrated	(3)

Question Number	Acceptable Answers	Additional Guidance	Mark
(e)	An explanation that makes reference to the following points: • The second value will be less exothermic / less negative **(1)** • Some energy will be used to boil the water/boiling water is endothermic Water can only be heated to 100°C/ Temperature rise (measured) can only be (a maximum) of 40°C Greater heat losses in the 60°C to 100°C range **(1)**	Allow 'more positive' or 'smaller in magnitude' Do not accept 'greater' or 'smaller' for 'less negative' Do not award **just** "the water boils" Mark points M1 and M2 independently	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(f)	An explanation that makes reference to the following points: Either • student 2's value will be similar / the same **(1)** • (As) both the energy change **and** moles/mass (of methanol) burned will be higher/ Ratio of energy change to moles/mass (of methanol) burned will be the same/ The energy change is proportional to the moles/mass (of methanol) burned **(1)** Or • student 2's value will be less negative/ less exothermic **(1)** • greater heat loss because higher temperature/heated for longer **(1)**	Allow 'temperature change' for 'energy change' Allow 'more positive' or 'smaller in magnitude' or 'smaller' for 'less negative' Mark points MP1 and MP2 independently within each route	**(2)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(g)	An answer that makes reference to the following points: • (Calculated) value of moles (of methanol) burned will be less / too small **(1)** • The calculated value will be more exothermic / more negative **(1)**	Allow **both** marks for a calculation using M_r of 46.0 (instead of 32.0), giving a final ΔH value (approx.) of -766 (kJ mol^{-1}) Allow 'increase' or 'greater' for 'more negative' MP2 depends on MP1	**(2)**

Q4.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	calculation of mean C-H bond enthalpy	Example of calculation $\dfrac{-1652}{4}$ = -413 (kJ mol^{-1}) Therefore bond enthalpy is (+)413 (kJ mol^{-1}) Correct answer with no working scores 1	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	• calculation of energy released when 8(C-H) bonds are formed in the formation of C$_3$H$_8$ **(1)** • calculation of mean C-C bond enthalpy **(1)**	Example of calculation 8 x -413 = -3304 (kJ mol^{-1}) $\dfrac{-3998 - -3304}{2}$ = $\dfrac{-694}{2}$ = -347 (kJ mol^{-1}) Therefore bond enthalpy is +347 (kJ mol^{-1}) Allow -347 (kJ mol^{-1}) if -413 given as answer in (i) for 2 marks Allow TE from (c)(i)	(2)

Q5.

Question Number	Answer	Additional Guidance	Mark
(i)	• sum of bonds broken **(1)** • and sum of bonds made **(1)** • answer and with negative sign **(1)**	Example of calculation bonds broken = (6 x 198) + (10 x 243) = 3618 (kJ mol^{-1}) bonds made = (20 x 326) = (−)6520 (kJ mol^{-1}) enthalpy change = Bonds broken − bonds made = (3618 − 6520) =−2902 (kJ mol^{-1}) Correct answer with no working scores (3) TE on bonds broken and made	(3)

Question Number	Answer	Additional Guidance	Mark
(ii)	• bond breaking requires energy or by convention bond enthalpies refer to dissociation and so are endothermic	ALLOW bond breaking is endothermic ALLOW bond making is exothermic Ignore just 'bonds are broken' / 'it is endothermic'	(1)

Q6.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: • identification and correction of the first error **(1)** • identification and correction of the second error **(1)**	Allow corrections to be made on the diagram Error 1 – arrow for enthalpy change of formation should go down/be reversed Error 2 – the word 'half' should be deleted from the enthalpy change of atomisation of hydrogen	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	• calculation of first electron affinity of hydrogen	Example of calculation 1st EA= –(218+496+107)–56 +804 = –73 (kJ mol⁻¹) Allow a TE 1st EA = +39(kJ mol⁻¹) if the first arrow reversed direction is not identified	(1)

Q7.

Question Number	Answer	Additional Guidance	Mark
(i)	• correct species with state symbols in bottom box **(1)** • arrows in correct direction **(1)**	Example of Hess cycle $2NO(g) + Cl_2(g) \rightarrow 2NOCl(g)$ $N_2(g) + O_2(g) + Cl_2(g)$	**(2)**

Question Number	Answer	Additional Guidance	Mark
(ii)	• multiplies enthalpy change of formation of NO, $\Delta_f H^{\ominus}_{298}$(NO) by 2 or divides $\Delta_r H^{\ominus}_{298}$ by 2 **(1)** • calculates enthalpy of formation of NOCl **(1)**	Example of calculation $(2 x + 90.3) = 180.6 / 181$ (kJ) or $\dfrac{-75.6}{2} = -37.8$ (kJ) $2\Delta_f H^{\ominus}_{298}NOCl = \dfrac{180.6 - 75.6}{2} = 52.5$ (kJ mol^{-1}) or $\Delta_f H^{\ominus}_{298}NOCl = 90.3 - 37.8 = 52.5$ (kJ mol^{-1}) Unit, if given, must be correct. Correct answer with no working scores (2) −52.5 (kJ mol^{-1}) scores (1) 14.7 (kJ mol^{-1}) scores (1) +7.35 (kJ mol^{-1}) scores (1) −14.7 (kJ mol^{-1}) scores (0) Ignore presence of absence of 298 Ignore SF except 1 SF M2 no TE other than the answers above No TE on an incorrect cycle	**(2)**

Q8.

Question Number	Answer	Additional Guidance	Mark
(i)	• sum of bond energies of all reactants (1) • sum of bond energies of all products (1) • calculation of $\Delta_r H$ (1)	Example of calculation $945 + (3 \times 436) = (+)2253$ (kJ mol^{-1}) $6(N-H) = 6 \times 391 = (-)2346$ (kJ mol^{-1}) $-2346 + 2253 = -93$ (kJ mol^{-1}) TE from either/both M1 and M2 Correct answer with no working scores 3	(3)

Question Number	Answer	Additional Guidance	Mark
(ii)	An answer that makes reference to the following points: • the equation in 9(a)(i) is for the formation of two moles of ammonia (1) • the bond energies in the table are mean / not specific to ammonia (1)	Ignore any references to differing conditions for the Haber process Ignore heat losses	(2)

Question Number	Answer	Mark
(iii)	The only correct answer is D (100 %) A *is not correct because this is the percentage of hydrogen* B *is not correct because this is half the atom economy for making ammonia* C *is not correct because this is the percentage of nitrogen*	(1)

Question Number	Answer	Mark
(iv)	The only correct answer is C $\qquad K_c = \dfrac{[NH_3]^2}{[N_2][H_2]^3}$ A *is not correct because this expression shows molar quantities, not powers and is inverted* B *is not correct because this expression shows molar quantities, not powers* D *is not correct because this expression is for the reverse equation*	(1)

Q9.

Question Number	Answer	Additional Guidance	Mark
(i)	• calculation of moles of $CaSO_4 \cdot \frac{1}{2}H_2O$ **(1)** • calculation of volume (or mass) of water required **(1)**	Example of calculation 10.00 g $CaSO_4 \cdot \frac{1}{2}H_2O = 10.00 \div 145.2$ mol $= 0.06887$ mol Allow 0.069 (moles of water required $= 0.06887$ x 1.5 $= 0.1033$ mol) volume of water required $= 0.1033$ x 18 $\div 1.00 = 1.86$ cm³ Allow 1.86 g Ignore SF except 1 SF Correct answer with no working scores (2) Allow calculation using multiples of these moles (still gets same final answer scores 2) Allow alternative correct calculations: e.g. comparison of moles of $CaSO_4 \cdot \frac{1}{2}H_2O$ with moles of water in 10.00 g.	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	• calculation of ΔT **(1)** • use of $mc\Delta T$ to find Q **(1)** • calculation of $\Delta_r H$ **(1)** • correct final answer, with sign and 2 or 3 SF **(1)**	Example of calculation $\Delta T = 2.8$ °C $m = 10.00$ g, $c = 4.18$ J g⁻¹ °C⁻¹ $Q = mc\Delta T = 117.04$ J / 0.11704 kJ Allow M1 and M2 if figure of 117.04 J is seen Ignore units unless converted to kJ $117.04 \div 0.06887 = -1699.4$ (J mol⁻¹) $-1.70 / -1.7$ (kJ mol⁻¹) Correct answer with no working scores (4) Allow TE throughout and from 4ci (for moles $CaSO_4 \cdot \frac{1}{2}H_2O$)	(4)

Question Number	Answer	Additional Guidance	Mark
(iii)	• selection of thermometer **(1)** • calculation of percentage uncertainty **(1)**	Example of calculation $\frac{2 \times 0.5 \times 100}{2.8} = 35.7 / 36 / 40$ (%) Allow selection of measuring cylinder and percentage uncertainty is 5%, scores (1) mark Do not award selection of balance Ignore SF	(2)

Q10.

Question Number	Answer	Additional Guidance	Mark
	• calculation of energy needed to break bonds **(1)**	Example of calculation Energy to break bonds: (C—C) + (C—H) + (C—O) = 347 + 413 + (C—O) = (C—O) + 760 (kJ)	**(3)**
	• calculation of energy released when bonds are made **(1)**	Energy released in forming bonds: (C=C) + (O—H) = 612 + 464 = (−)1076 (kJ)	
	• calculation of mean bond enthalpy of C—O **(1)**	(C—O) + 760 − 1076 = 42 (C—O) = (+)358 (kJ mol⁻¹) TE on M1 and M2 If all bonds broken: Energy to break bonds = (C—O) + 4049 (kJ) Energy released in forming bonds = (−)4365 (kJ) Ignore units Correct answer with no working scores (3) Allow correct working in M1 and M2 if answers not evaluated	

Q11.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)		example of calculation use of $Q = m\,c\,\Delta T$ $Q = 250 \times 4.18 \times 8.2$ $= 8569$ (J) / 8.569 **kJ** ignore any sign at this stage	(3)
	• calculation of Q (1)		
	• mass of hydrocarbon burnt and value of Δ_cH (1)	$= 112.990 - 112.732$ $= 0.258$ g $\Delta_cH = (-)\,8569 \times 84/0.258$ $= (-)\,2789907$ (J mol^{-1}) /$(-)\,2789.907$ (kJ mol^{-1})	
	• sign and significant figures (1)	TE on incorrect value from M1 $= -2790/-2800$ (kJ mol^{-1}) allow -2790000/-2800000 **J mol^{-1}** final answer to 2 or 3 sig figs only Do not award M3 for incorrect method used in M2 correct final answer without working scores 3	
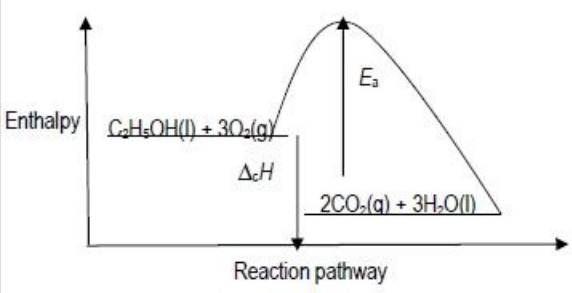
Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	an answer that makes reference to the following point: improved/better (thermal/heat) conduction	Allow copper is a good conductor (of heat) Allow reverse argument in terms of (thermal) insulators Ignore references to heat capacity/ heat lost to surroundings/ heat absorbed by container. Ignore any mention of glass breakage	(1)

Q12.

Question Number	Answer	Additional Guidance	Mark
	• calculation of moles used **(1)**	<u>Example of calculation</u> moles used = 25.0 x 1.00/1000 = 0.0250	**(3)**
	• calculation of energy for that number of moles **(1)**	energy released = 0.025 x 53.4 = 1.335 (kJ) / 1335 (J) TE on moles used Ignore sign	

	• calculation of temperature change **and**
	gives answer to 2 SF (because a school thermometer cannot measure to 3 SF) **(1)**
		temperature change = 1335/(50.0 x 4.18)
		         = 6.3876
		         = 6.4 (°C / K)
		TE on moles and energy
		
		Allow final answer to 3 SF 6.39 (°C / K)
		
		Ignore units
		
		Correct answer with no working scores (3)	

Q13.

Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	• calculation or working of energy needed to break bonds **(1)** • calculation or working of energy released when bonds made **(1)** • calculation of enthalpy change of combustion with sign **(1)**	<u>Example of calculation</u> energy to break bonds = 347 + (5 x 413) + 358 + 464 + (3 x 498) = 4728 (kJ) energy released in making bonds = (4 x 805) + (6 x 464) = 6004 (kJ) enthalpy change of combustion = 4728 – 6004 = –1276 (kJ mol⁻¹) **or** energy to break bonds = 347 + (5 x 413) + 358 + (3 x 498) = 4264 (kJ) energy released in making bonds = (4 x 805) + (5 x 464) = 5540 (kJ) enthalpy change of combustion = 4464 – 5540 = –1276 (kJ mol⁻¹) TE on energies calculated to break and form bonds Correct answer with sign but no working scores 3 Ignore SF except 1SF Ignore missing units but do not allow incorrect units in M3 e.g. kJ mol⁻	**(3)**

Question Number	Acceptable Answers	Additional Guidance	Mark
(ii)	products to the right of reactants <u>and</u> at a lower enthalpy <u>and</u> arrow labelled $\Delta_c H$ (1) • curve and arrow labelled E_a (1)	M1 is conditional on exothermic or endothermic value calculated in (c)(i) but if no value is calculated, award mark for exothermic reaction only Allow double headed arrows / lines, but penalise arrows pointing in wrong direction once only Allow 'products'/ unbalanced formulae / missing state symbols as labels for product line Allow $(-)\Delta H/(-)\Delta H_c$/enthalpy change or value calculated in (c)(i) Allow value calculated for energy needed to break bonds in (c)(i) Ignore any transition state	(2)
		Do not allow straight lines instead of Ea curve If no other marks awarded, allow 1 mark for the correct labelled product line <u>and</u> activation energy curve if both arrows missing	

Question Number	Acceptable Answers	Additional Guidance	Mark
(iii)	• standard enthalpy change of combustion refers to ethanol / water as liquid(s) but bond energies are calculated for gases **or** change of state data is not included **or** ethanol / water are not in standard states for bond enthalpy calculation	Ignore bond energies are mean values and the actual values in these compounds/ethanol may be different Ignore any reference to heat loss Ignore any reference to incomplete combustion	(1)

Q14.
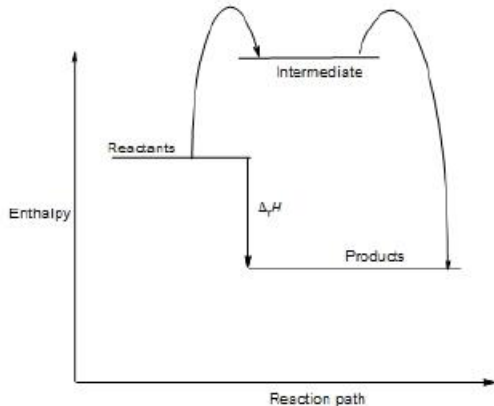
Question Number	Acceptable Answers	Additional Guidance	Mark
(a)	• calculation or working of heat evolved during reaction **(1)**	Example of calculation heat evolved = 50 x 4.18 x 5.4 $\qquad$ = 1128.6 J or 1.1286 kJ Ignore any sign	**(4)**
	• calculation or working of mol Na_2CO_3 used **(1)**	mol Na_2CO_3 used = 5.09/106 $\qquad$ = 0.04802	
	• calculation of enthalpy change of solution **(1)**	enthalpy of solution = $\quad$ 1.1286/0.04802 $\qquad$ = 23.5 TE on heat evolved and mol Na_2CO_3	
	• negative sign and answer to 2 or 3 SF **(1)**	$-23.5/-24$ (kJ mol^{-1}) TE on enthalpy change in M3 Correct answer with $-$ sign but no working scores 4 Ignore missing units but penalise incorrect units once only in (a) or (b)	

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)	• both arrows in correct direction and $Na_2CO_3(aq)$ (+ $10H_2O(l)$) / $2Na^+(aq) + CO_3^{2-}(aq)$ (+ $10H_2O(l)$) **(1)**	$Na_2CO_3(s) + 10H_2O(l) \rightarrow$ $Na_2CO_3.10H_2O(s)$ (aq) (aq) $Na_2CO_3(aq)$ Allow aq omitted from arrows Allow both arrows pointing upwards provided labelled as opposite signs	**(2)**
	• answer to (a) − 53.7 with correct sign **(1)**	Example of calculation $-23.5 - 53.7$ $= -77.2$ (kJ mol^{-1}) TE on answers to (a) but not on incorrect cycle Allow **−77200 J mol⁻¹** Ignore SF except 1SF Ignore missing units but penalise incorrect units	

Question Number	Acceptable Answers	Additional Guidance	Mark
(c)	An explanation that makes reference to the following points: • enthalpy change of solution will be lower/ less endothermic / less positive (than data book value) **(1)**	Allow smaller / requires less energy Allow more exothermic / negative	**(2)**
	• because anhydrous sodium carbonate releases energy/reacts exothermically with water **or** because less energy is needed to separate the (fewer) water molecules from the ions (in the crystal structure) **(1)**	Conditional on M1 Allow because there is (less water so) more Na_2CO_3 (in the sample) Allow because less energy is needed to break the bonds between water and sodium carbonate	

Q15.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: • provide / overcome the activation energy or (is slow at room temperature but) accelerates as temperature rises **(1)** • (sufficiently / very) exothermic enough to melt the copper / break bonds in copper **(1)**	Do not allow 'to lower the activation energy' Allow answers that link rise in temperature to rising rate	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	 • intermediate energy level/transition state **(1)** • product line below level of reactant line **and** $\Delta_r H$ / ΔH shown on down/ vertical arrow **(1)**	Allow transition state for intermediate Ignore type of arrows to and from intermediate Allow any diagram with a hump shown, with / without intermediate / transition state label Do not penalise missing 'Products' label Allow use of $\Delta_r H$ / - 905.2 (kJ mol^{-1})	(2)

Question Number	Answer	Additional Guidance	Mark
(iii)	An answer that makes reference to any **three** of the following points: • reactants **adsorb** onto catalyst/surface (1) • (there are) active sites on catalyst (surface) (1) • bonds in reactants weakened / broken **or** reaction takes place (1) • products **desorb** from the catalyst/active site (1)	Do not allow absorb	(3)

Q16.

Question Number	Answer	Additional Guidance		Mark
(i)	• mass and temperature fall correct	Mass of NaHCO₃ used / g	5.62	(1)
		Temperature fall / °C	(−)6.6	

Question Number	Answer		Additional Guidance	Mark
(ii)	• calculation of amount of NaHCO₃ **and** calculation of amount of hydrochloric acid	(1)	Example of calculation amount NaHCO₃ = $\frac{5.62}{23 + 1 + 12 + (3 \times 16)}$ = 0.0669 (mol) TE on mass of NaHCO₃ in (a)(i) **and** amount HCl = $\frac{50 \times 2.00}{1000}$ = 0.10 (mol) Ignore SF including 1SF	(2)
	• 0.0669 mol NaHCO₃ needs 0.0699 mol HCl for reaction so HCl is in excess	(1)	Allow mol ratio = 1 : 1 so HCl is in excess Allow just more moles of HCl used Allow 0.10 > 0.0669 (mol) Allow HCl is in excess by 0.033 (mol)	

Question Number	Answer	Additional Guidance	Mark

(iii)	• calculation of heat absorbed (1)
	
	• calculation of enthalpy change (1)
	
	• positive sign **and** units (1)
		<u>Example of calculation</u>
		
		heat absorbed = 50.0 x 4.18 x 6.6
		  = 1379.4 (J) / 1.3794 (kJ)
		Ignore sign
		
		enthalpy change = $\dfrac{1379.4}{0.0669}$
		  = 20619 (J mol^{-1})
		or = $\dfrac{1.3794}{0.0669}$
		  = 20.619 (kJ mol^{-1})
		TE on heat absorbed and amount $NaHCO_3$ in (a)(ii)
		
		Final answer +20.6(19) kJ mol^{-1} or +20619 J mol^{-1}
		TE on enthalpy change
		Allow +19.7(06) kJ mol^{-1} from 0.07 mol in (a)(ii)
		Allow kJ mol$^-$ / J mol$^-$
		
		Ignore SF except 1 SF
		Ignore incorrect / missing units in M1 and M2
		
		Correct answer with sign and units scores (3)
			(3)

Q17.
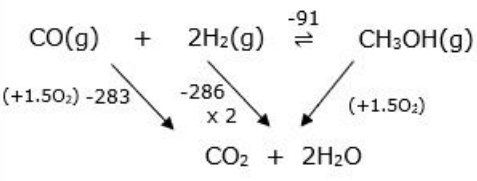
Question Number	Answer	Mark
	The only correct answer is D (endothermic, dehydration) *A is not correct because hydration involves adding water* *B is not correct because a reaction that requires heat is unlikely to be exothermic and hydration involves adding water* *C is not correct because a reaction that requires heat is unlikely to be exothermic*	(1)

Q18.

Question Number	Answer	Additional Guidance	Mark
(i)	• calculation of energy associated with bond breaking **(1)** • calculation of energy associated with bond formation **(1)** • calculation of the enthalpy change of combustion by subtraction and a negative sign **(1)**	Example of calculation = (22 x 413) + (9 x 347) + (15.5 x 498) = 19928 (kJ) (ans 1) = (20 x 805) + (22 x 464) = 26308 (kJ) (ans 2) Ignore minus sign = (ans 1) – (ans 2) = 19928 – 26308 = –6380 (kJ mol⁻¹) Ignore units even if incorrect Allow TE throughout but for M3 do not award positive values Ignore SF except 1 SF Correct answer with no working scores (3) (+)6380 (kJ mol⁻¹) with no working scores (2)	(3)

Question Number	Answer	Additional Guidance	Mark
(ii)	An answer that makes reference to the following points: • use of mean bond enthalpy values rather than actual values for the molecules involved **(1)** • substances in the wrong state for bond energy calculations **(1)**	 Ignore just 'mean bond enthalpies are not accurate' without qualification Allow water / decane is a liquid / not a gas	(2)

Q19.

Question Number	Answer	Additional Guidance	Mark
	An answer that makes reference to the following points:	Example of calculation	(3)
	• gives an equation linking the three values or processes together / constructs a Hess's Law cycle **(1)**	$\Delta_c H$ (CH$_3$OH) = $-\Delta H$ (Step 2) + $\Delta_c H$(CO) + $2\Delta_c H$(H$_2$) or $$CO(g) \quad + \quad 2H_2(g) \overset{-91}{\rightleftharpoons} CH_3OH(g)$$ (+1.5O$_2$) -283 $\searrow$ $\underset{\times 2}{-286}$ $\searrow$ $\swarrow$ (+1.5O$_2$) $$CO_2 \; + \; 2H_2O$$	
	• uses of numerical values in equation or on cycle, including use of $2 \times \Delta_c H$(H$_2$) **(1)**	Do not penalise lack of 2 in 2H$_2$O in cycle or in $2\Delta_c H$(H$_2$) if M2 not scored. $\Delta_c H$ (CH$_3$OH) = 91 + -283 + 2(-286)	
	• calculation of final value with correct sign **(1)**	= -764 (kJ mol^{-1}) Correct answer with no working scores (3) Possible incorrect answers include: Award 2 marks for -478, -1424, (+)946, -855, (+)764 Award 1 mark for -946, (+)478, -946, (+)1424	

Q20.

Question Number	Answer	Additional Guidance	Mark
	An answer that makes reference to the following points: • calculation of the energy absorbed by water **(1)** • calculation of the number of moles of methanol **(1)** • calculation of the energy absorbed per mole of methanol **(1)** • gives enthalpy change of combustion to 2 or 3 SF and correct sign and units (either J mol⁻¹ or kJ mol⁻¹) **(1)**	Example of calculation $Q = m \times c \times \Delta T$ $= 75.0 \times 4.18 \times 66.0$ $= 20\,691$ (J) $= \dfrac{2.08}{32.0} = 0.0650 / 0.065 / 6.50 \times 10^{-2}$ (mol) $= \dfrac{20\,691}{0.0650} = 318323$ (J mol⁻¹) $= -320 / -318$ kJ mol⁻¹ $-320\,000 / -318\,000$ J mol⁻¹ Do not award J/mol⁻¹ Ignore sign until final answer when must be negative Ignore significant figures until final answer Allow TE throughout Correct answer with units and no working scores (4)	**(4)**

Q21.

Question Number	Answer	Additional guidance	Mark
(i)	An explanation that makes reference to the following points • C=C bond is weaker than 2 x C-C bond **(1)** • as it consists of a pi and a sigma bond (rather than 2 sigma bonds) **(1)**	Ignore pi bond formed by sideways / less effective orbital overlap	(2)

Question number	Answer	Additional guidance	Mark
(ii)	- calculation of energy required to break reactant bonds **(1)** - calculation of energy release when product bonds form **(1)** - calculation of enthalpy change **(1)**	Example of calculation: 5(C-H) + (C=C)+(C- C)+(C-O)+(O-H)+4(O=O) 5(413) + (612) + (347) + (358) + (464) + (4x498) = 5838 (kJ mol^{-1}) 6(C=O) + 6(O-H) (6x805) + (6x464) = 7614 (kJ mol^{-1}) 5838 – 7614 = –1776 (kJ mol^{-1}) Ignore SF except 1 SF Allow TE from M1 and M2 Correct answer no working scores 3	(3)

Question Number	Answer	Additional Guidance	Mark
(iii)	An explanation that makes reference to one of the following points EITHER ΔS_{total} is always positive (1) **(1)** - As both $\Delta S_{surroundings}$ and ΔS_{system} are positive **(1)** - OR ΔG is always negative **(1)** - as ΔH is negative and $\Delta S_{(system)}$ is positive **(1)**	If no marking points awarded allow 1 mark for idea that ΔS_{system} / $\Delta S_{surroundings}$ / entropy increases with correct explanation	(2)

Q22.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• calculates $\sum\Delta_f H(\text{products})$ **(1)** • $\sum\Delta_f H(\text{products}) - \Delta_r H$ **(1)** • calculates $\Delta_f H_{(NH3)}$ for 1 mol ammonia **(1)**	Example of calculation $(+90.4 \times 4) + (-241.8 \times 6)$ $= -1089.2$ $-1089.2 - (-904.8) = -184.4$ $-184.4/4 = -46.1$ (kJ mol^{-1}) TE from M1 to M2 M3 can be awarded for an incorrect answer to M2 divided by 4 correct answer with no working scores 3 marks	**(3)**

Question Number	Answer Acceptable	Additional Guidance	Mark
(ii)	• correct expression **(1)** • correct evaluation of atom economy **(1)**	Example of calculation $\dfrac{4NO}{4NO + 6H_2O}$ OR $\dfrac{4NO}{4NH_3 + 5O_2}$ may be shown as numbers only $\dfrac{4(14 + 16)}{4(14 + 16) + 6(16 + 2)} \times 100$ OR $\dfrac{4(14 + 16)}{4(14 + 3) + 5(16 \times 2)} \times 100$ $= 53/52.6(316)(\%)$ allow answer to 2 or 3 SF only correct answer with no working scores 2 marks 0.53/0.526 scores M1 only	**(2)**
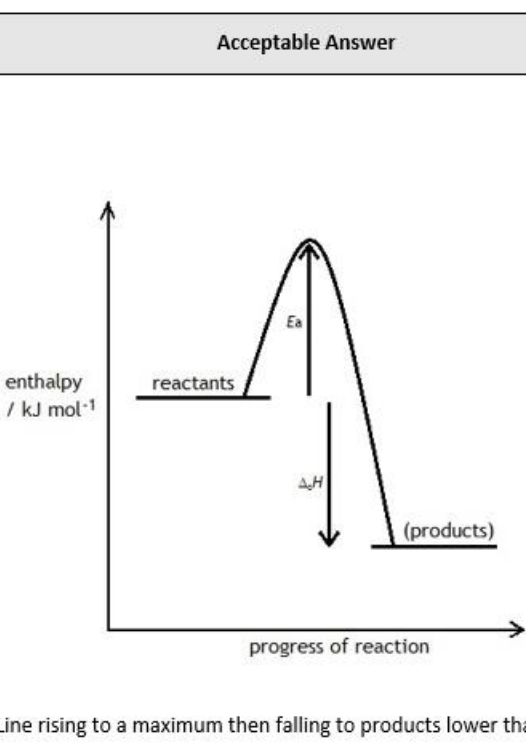
Q23.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• calculation of heat produced **(1)**	Example of calculation heat produced = 50.0 x 4.18 x 6.8 = 1421.2(J) / 1.4212 (kJ)	**(4)**
	• calculation of amount (mol) of HNO_3 **(1)**	amount HNO_3 used = 25.0 x 1.00/1000 = 0.025 / 2.5 x 10^{-2} (mol) Ignore moles NaOH and total moles calculated	
	• calculation of enthalpy change **(1)**	enthalpy change = $\dfrac{1421.2}{0.025}$ = 56848 (J mol^{-1}) or $= \dfrac{1.4212}{0.025}$ = 56.848 (kJ mol^{-1}) TE on heat produced and amount HNO_3	
	• negative sign **and** units **and** answer to 2 / 1 SF **(1)**	final answer −57 / −60 kJ mol^{-1} **or** −57 000 / −60 000 J mol^{-1} TE on enthalpy change Do not award 3 SF Correct final answer with sign, units and 2 or 1 SF but no working scores (4) Ignore units and sign of enthalpy change in M1 and M3	

Q24.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: • (standard enthalpy change of combustion is the enthalpy change when) one mole of a substance burns completely (in oxygen) / burns in excess oxygen / fully combusts **(1)** • under standard conditions of 100 kPa and a stated temperature **(1)**	Accept energy released Ignore air Do not award one mole of atoms burns.... Do not award energy required / needed e.g 25°C / 298 K / 273 K / 293 K Allow 101 kPa / 1 atm Do not award just 'under standard conditions' / rtp	**(2)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	$C_8H_{18}(l) + 12\frac{1}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$ • correct species **(1)** • balancing and state symbols **(1)**	Allow multiples only if one mole is not stated in (a)(i)	**(2)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(iii)	 Line rising to a maximum then falling to products lower than reactants **(1)** Labelled arrows for E_a and $\Delta_cH^\ominus$ /-5 470 which touch or almost touch the maximum and be level or almost level with the product and reactant lines **(1)**	Do not award double headed arrows Do not award $-\Delta_cH^\ominus$ Do not award lines with no arrow heads Allow TE on an endothermic diagram	**(2)**

Q25.

Question Number	Answer	Additional Guidance	Mark
	An answer that makes reference to the following points: • (the enthalpy/energy change when) 1 mol of aluminium oxide **(1)** • is formed from its elements in their standard states **(1)** • at 100 kPa and a 'specified' / 'stated' temperature **(1)**	Allow $2Al(s) + 1\frac{1}{2}O_2(g) \rightarrow Al_2O_3(s)$ for M1 and M2 If state symbols are missing or incorrect only M1 can be awarded Allow M2 for multiples in equation provided state symbols for the elements are correct Allow 1 atm / 1×10^5 Pa / 101 kPa / 1.01×10^5 Pa for pressure Allow a value for the temperature of 298K / 25°C Ignore 273K Ignore other standard conditions e.g. 1 mol dm⁻³ Do not allow °K	(3)

Q26.

Question Number	Answer	Additional Guidance	Mark
	An answer that makes reference to the following point: • (the system / it) is not at constant pressure **or** enthalpy change is the heat change at a constant pressure	Allow a gas / carbon dioxide is produced and this increases the pressure Allow the pressure is increased / increases Ignore reference to temperature	(1)

Q27.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• species and balanced **(1)** • arrows pointing downwards **(1)** • calculation of Δ_cH of reactants and show Δ_cH of product **(1)** • calculation of Δ_rH **(1)**	Ignore state symbols even if incorrect Ignore absence of oxygen alongside arrows <u>Example of calculation</u> $\Delta_cH_{reactants}$ = −394 + (2 x −286) (kJ mol^{-1}) = −966 (kJ mol^{-1}) $\Delta_cH_{products}$ = −890 (kJ mol^{-1}) Δ_rH = −394 + (2 x -286) − −890 = -76 (kJ mol^{-1}) Correct answer with no working scores final 2 Units not required, but if given must be correct Ignore SF Do not award kJ / mol^{-1} Allow TE on incorrect enthalpy of combustion calculation	**(4)**

Q28.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: • correct elements in the lower box (P(s), Cl_2(g)) (1) • correct moles of each element, P(s) **and** $2\frac{1}{2}Cl_2$(g) (1) • arrows correctly labelled ($\Delta_f H$ [PCl_5], $\Delta_f H$ [PCl_3]) (1)	Penalise missing states only once (M1) States are required Allow P_4(s) Ignore balancing numbers for M1 Allow $\frac{1}{4}P_4$(s) Ignore state symbols (if given) Ignore state symbols (if given) on arrows	(3)

Example of cycle

Question Number	Answer	Additional Guidance	Mark
(ii)	• use of $\sum(\Delta_f H$[products]) - $\sum(\Delta_f H$[reactants]) (1) • correct answer with sign and units (1)	Example of calculation (-319.7 + 30.5) - (-443.5 + 64.9) Allow correct sums (−289.2 and −378.6) but must be negative = +89.4 kJ mol^{-1} Sign and units must be shown Allow TE from M1(for omission of $\Delta_v H$ data (+123.8 kJ mol^{-1}) Correct answer with no working scores (2)	(2)

Q29.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)		display all three methyl groups allow –OH do not award C-H-O	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(i)	An answer that makes reference to one of the following: molecular ion/molecule fragments/is unstable		(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)		allow + charge on any part of the ion/outside the structure but + must be shown allow displayed/structural/skeletal/molecular formulae or any combination of these.	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(c)(i)		Example of calculation	
	• calculation for bonds broken in the alcohol (*) **(1)**	3(C-C) + 9(C-H) + (C-O) + (O-H) =(3x347) + (9x413) + 358 + 464 = (+)5580 (kJ mol^{-1})	
	• calculation for bonds broken in oxygen **and** total energy for bonds broken(**) **(1)**	6(O=O) = (6 x 498) = (+)2988 (kJ mol^{-1}) total = + 5580 + 2988 = (+)8568 (kJ mol^{-1}) TE from ans * M1 + 2988	
	• calculation for bonds made(***) **(1)**	= 8(C=O) + 10(O-H) = (8x805) + (10x464) = -11080 (kJ mol^{-1})	
	• calculation of Δ_cH (2-methylpropan-2-ol) with sign **(1)**	= +8568 − 11080 = -2512 (kJ mol^{-1}) allow TE for answer(**) + answer(***) units not required but if given they must be correct correct final answer with no working scores 4 marks	**(4)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points: • incomplete combustion **(1)** • Δ_cH (2-methylpropan-2-ol) will be less negative /less exothermic than data book value **(1)**	mark independently do not award just lower/smaller/decreases/ more positive allow reduce the magnitude (of the value)	**(2)**
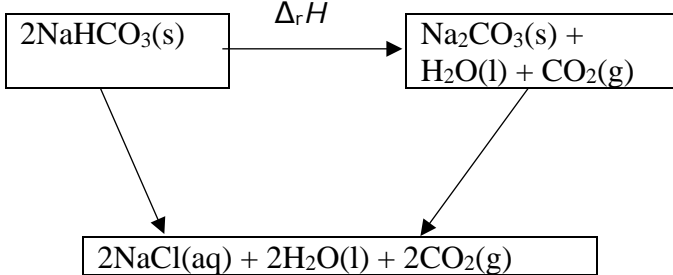
Question Number	Acceptable Answer	Additional Guidance	Mark
(iii)	An answer that makes reference to the following points: $\Delta_c H$ figures are at 298 K /data book bond energies refer to gaseous state <u>and</u> water and/or 2-methylpropan-2-ol are/is (both) liquid(s) (at 298 K)	allow just liquid involved do not award data book bond energies are mean (values)/not specific to 2-methylpropan-2-ol	(1)

Q30

Question Number	Answer	Additional Guidance	Mark
30(a)(i)	• mass **and** temperature fall correct	<table><tr><td>Mass of NaHCO₃ used / g</td><td>5.62</td></tr><tr><td>Temperature fall / °C</td><td>(−)6.6</td></tr></table>	**(1)**

Question Number	Answer	Additional Guidance	Mark
30(a)(ii)	• calculation of amount of NaHCO₃ **and** calculation of amount of hydrochloric acid **(1)**	Example of calculation amount NaHCO₃ = $\dfrac{5.62}{23 + 1 + 12 + (3 \times 16)}$ = 0.0669 (mol) TE on mass of NaHCO₃ in (a)(i) **and** amount HCl = $\dfrac{50 \times 2.00}{1000}$ = 0.10 (mol) Ignore SF including 1SF	**(2)**
	• 0.0669 mol NaHCO₃ needs 0.0699 mol HCl for reaction so HCl is in excess **(1)**	Allow mol ratio = 1 : 1 so HCl is in excess Allow just more moles of HCl used Allow 0.10 > 0.0669 (mol) Allow HCl is in excess by 0.033 (mol)	

Question Number	Answer	Additional Guidance	Mark
30(a)(iii)		Example of calculation	**(3)**
	• calculation of heat absorbed **(1)**	heat absorbed = 50.0 x 4.18 x 6.6 = 1379.4 (J) / 1.3794 (kJ) Ignore sign	
	• calculation of enthalpy change **(1)**	enthalpy change = $\dfrac{1379.4}{0.0669}$ = 20619 (J mol^{-1}) **or** = $\dfrac{1.3794}{0.0669}$ = 20.619 (kJ mol^{-1}) TE on heat absorbed and amount NaHCO$_3$ in (a)(ii)	
	• positive sign **and** units **(1)**	Final answer +20.6(19) kJ mol^{-1} **or** +20619 J mol^{-1} TE on enthalpy change Allow +19.7(06) kJ mol^{-1} from 0.07 mol in (a)(ii) Allow kJ mol$^-$ / J mol$^-$ Ignore SF except 1 SF Ignore incorrect / missing units in M1 and M2 Correct answer with sign and units scores (3)	

Question Number	Answer	Additional Guidance	Mark
30(b)(i)		Example of Hess cycle	**(2)**
		$2NaHCO_3(s)$ $\xrightarrow{\Delta_r H}$ $Na_2CO_3(s) + H_2O(l) + CO_2(g)$ $\searrow$ $\swarrow$ $2NaCl(aq) + 2H_2O(l) + 2CO_2(g)$	
	• correct species and balancing numbers in lower box **(1)**	Ignore missing state symbols	
	• both arrows pointing in correct directions **(1)**	Stand alone mark Ignore labels on arrows and inclusion of HCl	

Question Number	Answer		Additional Guidance	Mark
30(b)(ii)	• expression for $\Delta_r H$	**(1)**	Example of calculation $\Delta_r H = 2x\Delta H_1 - \Delta H_2$	**(3)**
	• substitution of values into expression with both values in same units	**(1)**	$\Delta_r H = 2 \times 20.619 - (-29.4)$ **or** $\Delta_r H = 2 \times 20619 - (-29\ 400)$ M1 can be scored from values substituted into correct expression in M2 TE on ΔH_1 in (a)(iii) and expression in M1 No TE on incorrect arrows in cycle	
	• calculation of $\Delta_r H$ **and** sign **and** units	**(1)**	$\Delta_r H = +70.638$ kJ mol^{-1} **or** $\Delta_r H = +70638$ J mol^{-1} TE on ΔH_1 in (a)(iii) and expression in M1 provided it is a +ve answer Ignore SF except 1 SF Correct answer with sign and units scores (3)	

Q31.

Question Number	Answer	Additional Guidance	Mark
(a)	• evaluation of Q **(1)** • rearrangement to give ΔT **(1)** • Answer to 1 or 2SF and temperature change **(1)**	Example of calculation Q =(ΔH x n)=18.2 x 0.025 = 0.455(kJ) or 455 **J** ΔT=Q ÷(m x c) = 455 ÷ (45.00 x 4.18) = 2.4189...(°C) ΔT = 2/2.4 °C/ K **and** decrease Allow -2/2.4 °C/ K Correct final answer without working scores (3) TE throughout	**(3)**

Question Number	Answer	Additional Guidance	Mark
(b)(i)	• labelled y axis, including units, with appropriate scale **(1)** • direction and placement of enthalpy changes, +18.2 and −84.5 **(1)** • Entities with state symbols **(1)**	Allow energy for 'enthalpy' Ignore horizontal axis Do not award enthalpy change/ΔH for y axis Allow ΔH_1 and ΔH_2 for respective values Arrows must be shown and in the correct direction Ignore activation energy 'curves' Do not award double-headed arrows Ignore inclusion of '+ aq' Example of diagram 	**(3)**

Question Number	Answer	Additional Guidance	Mark
(b)(ii)	• Use of Hess's law to calculate $\Delta_r H$ shown on the diagram	Value from diagram = −102.7 (kJ mol⁻¹) Allow $\Delta_r H = \Delta H_2 - \Delta H_1 = -84.5 - (+18.2) = -102.7$ (kJ mol⁻¹) Allow −103 (kJ mol⁻¹) Do not award if no working shown on the diagram	**(1)**

Question Number	Answer	Additional Guidance	Mark
(c)	An answer that makes reference to • Cannot react exactly 5 mol of water with 1 mol of anhydrous copper(II) sulfate	Cannot measure the temperature (change) for a **solid** Description that states more (than 5) water molecules will attach to some $CuSO_4$ while less (than 5) water molecules will attach to other $CuSO_4$ ACCEPT reasonable ideas such as some water may evaporate (due to exothermic reaction) Ignore heat loss to surroundings if given as an alternative reason Do not award heat is needed to start the reaction	(1)

Q32.

Question Number	Answer	Additional Guidance	Mark
		Example of calculation	(2)
	• calculation of energy required for breaking the bond in Cl_2 and I_2 **(1)**	$= 151 + 243 = 394$ (kJ mol^{-1})	
	• calculation of energy in 2 moles of I-Cl bonds and divides by 2. **(1)**	$= \dfrac{394 + 30}{2} = (+)212$ (kJ mol^{-1})	
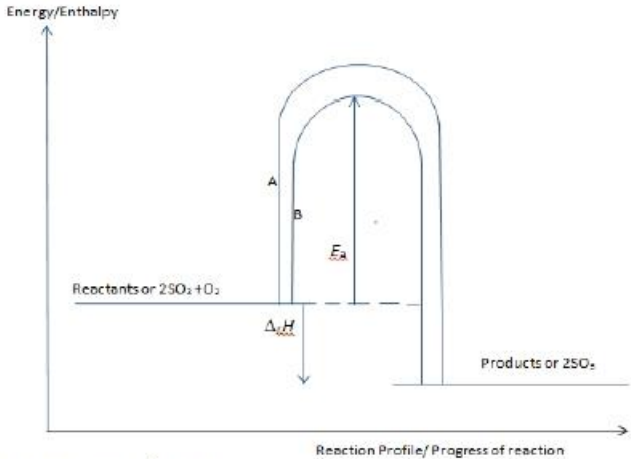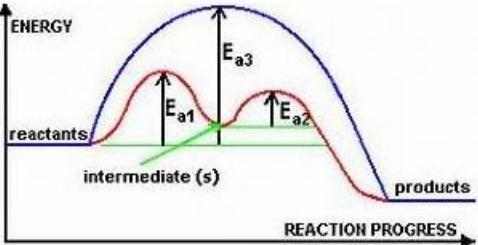
Q33.

Question Number	Acceptable Answer	Additional Guidance	Mark
	An answer that makes reference to the following point: • to make sure that (all) the (nitric) acid / HNO_3 / H^+ has reacted / been neutralised / is used up	Allow (nitric acid) / HNO_3 is the limiting reagent Allow so that 0.025 mol of water / H_2O forms Ignore to make sure that 1 mol of water / H_2O forms Ignore just 'to ensure that reaction is complete'	(1)

Q34.

Question Number	Answer	Mark
	The only correct answer is C **A** is not correct because standard enthalpy of formation is for making 1 moles of a compound **B** is not correct because standard enthalpy of formation is for making 1 moles of a compound **D** is not correct because oxygen must be O_2	(1)

Q35.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)			(3)
	• vertical axis labelled: H/enthalpy/energy/E **(1)**	Do not award ΔH Ignore horizontal axis label Ignore units if given	
	• level of reactants / $2SO_2 + O_2$ above level of products / $2SO_3$ **(1)**	ignore state symbols even if incorrect	
	• correct profile for uncatalysed reaction labelled A **and** peak lower for catalysed reaction labelled B **(1)**	allow vertical lines for catalysed and uncatalysed reactions to run together allow double hump profile 	

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	enthalpy change, $\Delta_r H / \Delta H / (-)197$ (kJ mol⁻¹), shown correctly **(1)**	Ignore presence/absence of arrowheads Allow a degree of imprecision in the start/finish points of the lines for ΔH and E_a	**(2)**
	activation energy, E_a, shown correctly (upper diagram) **(1)**	E_a shown on double hump profile - shown in this diagram as E_{a1} Ignore E_{a2} if also shown	

Q36.

Question Number	Answer	Mark
(i)	The only correct answer is D *A is not correct because the measurement uncertainty is doubled as there are two burette readings* *B is not correct because this gives the largest measurement uncertainty* *C is not correct because the measurement uncertainty is doubled as the pipette is used twice*	**(1)**

Question Number	Answer	Additional Guidance	Mark
(ii)		Example of calculation	**(3)**
	calculation of Q **(1)**	$Q=(100 \times 4.18 \times 6.5=)$ $= 2717$ (J) / 2.717 kJ	
	calculation of enthalpy change **(1)**	$\Delta H= 2.717 \div 0.05= (-)54.340$	
	answer to nearest whole number **and** with negative sign **(1)**	$= -54$ (kJ mol⁻¹) Allow TE at each stage Correct answer with no working scores (3)	

Q37.

Question Number	Answer	Mark
(i)	The only correct answer is B *A is not correct because there is no extrapolation to the largest temperature increase carried out* *C is not correct because the extrapolation is at the wrong time* *D is not correct because the extrapolation extends beyond the time of addition of alkali*	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to • ethanoic acid is a weak(er) acid / only partially ionised/dissociated **(1)** • (some) **energy** is used to fully/completely ionise the ethanoic acid **(1)**	Allow hydrochloric acid is a strong(er) acid/fully ionised Do not award 'more NaOH will react so more energy given off'	(2)

Q38.

Question Number	Acceptable Answers	Additional Guidance	Mark
	• balanced equation **(1)** • all state symbols **(1)**	$2C(s, graphite) + 3H_2(g) + \frac{1}{2}O_2(g) \rightarrow C_2H_5OH(l)$ Allow C_2H_6O Do not allow multiples Conditional on all species correct Allow $C(s)$ / $C(graphite)$	(2)