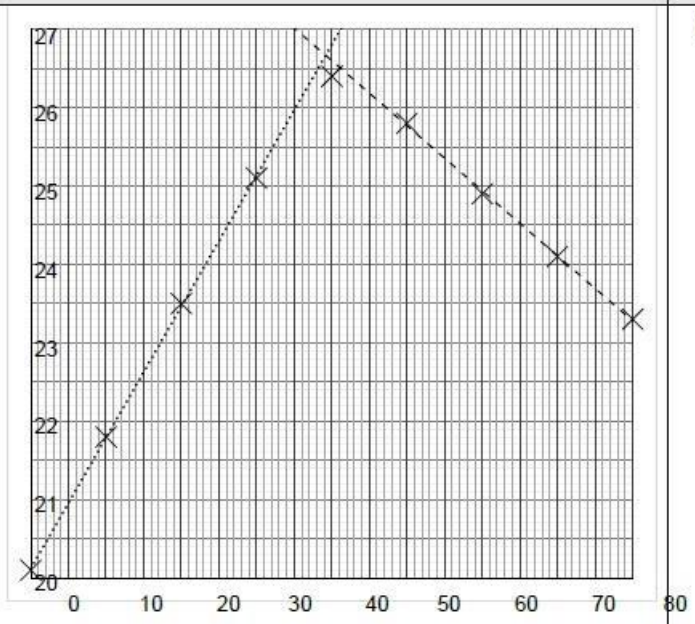
Mark Scheme

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 plotted correctly **(1)** • two suitable straight lines of best fit drawn **(1)**	 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 = $\frac{39}{1000}$ x 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 x c x ΔT (1) • calculation of energy change per mole (1) • final answer with correct sign and units (1)	Example of calculation (30 + 39) x 4.18 x 6.6 = 1 903.6 / 1.9036 x 10^3 (J) = $\frac{1\,903.6}{0.0429}$ = 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)** • (+) 42.5 **(1)**	Do not award MP1 for "1.6" (must be to 2 D.P.) Do not award MP2 for "42.50" (must be to 1 D.P.) Penalise D.P. error once only	(2)

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

Question Number	Acceptable Answers	Additional Guidance	Mark
(c)	• Calculation of energy change **(1)** • Calculation of moles of CH_3OH **(1)** • Calculation of energy ÷ moles CH_3OH **(1)** • ΔH final answer in kJ mol^{-1} **and** negative sign included **and** ΔH final answer to 2 or 3 S.F. **(1)**	Example of calculation (= $mc\Delta T$ = 150 x 4.18 x 42.5 =) 26647.5 (J) Moles CH_3OH = 1.60/32 (= 0.05(00)) $\frac{26647.5}{0.05(00)}$ = 532950 (J mol^{-1}) Ignore any signs at this stage −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	(4)

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)(i)	(±)0.7 (%)	Allow from 1 SF up to calculator value correctly rounded where (% uncertainty =) (±) $\frac{1}{150}$ x 100 = 0.66666...7 (%) 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 cm^3 measuring cylinder **(1)** **Then any two from:** • % uncertainty with use of 25 cm^3 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 cm^3 six times is greater than using 250 cm^3 measuring cylinder once only Award MP1 EITHER if multiplies errors: 100 x (0.2 /25) x 6 = 4.8% OR If adds errors 100 x (1.2 /150) = 0.8% Do not award (0.2 / 25) x 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 $\frac{-1652}{4} = -413$ (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_3H_8 **(1)** • calculation of mean C-C bond enthalpy **(1)**	Example of calculation 8 x -413 = -3304 (kJ mol^{-1}) $\frac{-3998 - -3304}{2} = \frac{-694}{2} = -347$ (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)

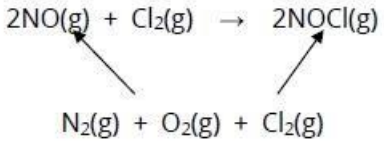
Question Number	Answer	Additional Guidance	Mark
(ii)	• bond breaking requires energy or by convention bond enthalpies refer to dissociation and so are endothermic	ALLOW bond breaking is endothermic ALLOW bond making is exothermic Ignore just 'bonds are broken' / 'it is endothermic'	(1)

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  	**(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 $-\frac{75.6}{2} = -37.8$ (kJ) $2\Delta_f H^{\ominus}_{298}$NOCl $= \frac{180.6-75.6}{2} = 52.5$ (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 $\Delta_c H$ (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** $K_c = \frac{[NH_3]^2}{[N_2][H_2]^3}$ **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 ÷ 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 ÷ 1.00 = 1.86 cm^3 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 ΔT = 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 ÷ 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)** • calculation of energy released when bonds are made **(1)** • calculation of mean bond enthalpy of C—O **(1)**	<u>Example of calculation</u> Energy to break bonds: (C—C) + (C—H) + (C—O) = 347 + 413 + (C—O) = (C—O) + 760 (kJ) Energy released in forming bonds: (C=C) + (O—H) = 612 + 464 = (−)1076 (kJ) (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	**(3)**

Q11.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	• calculation of Q **(1)** • mass of hydrocarbon burnt and value of $\Delta_c H$ **(1)** • sign and significant figures **(1)**	example of calculation use of Q= m c ΔT Q = 250 x 4.18 x 8.2 = 8569 (J) / 8.569 **kJ** ignore any sign at this stage = 112.990 – 112.732 = 0.258 g $\Delta_c H$ = (-) 8569 x 84/0.258 = (-) 2789907 (J mol^{-1}) /(-) 2789.907 (kJ mol^{-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	**(3)**

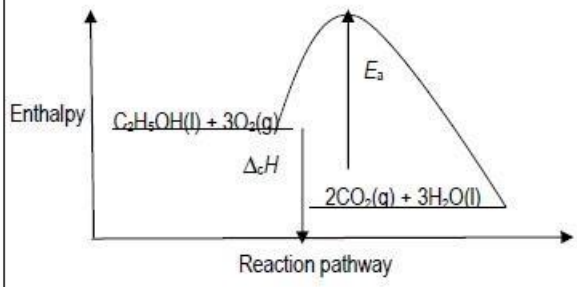
Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	an answer that makes reference to the following point: improved/better (thermal/heat) conduction	Allow copper is a good conductor (of heat) Allow reverse argument in terms of (thermal) insulators Ignore references to heat capacity/ heat 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)** • calculation of energy for that number of moles **(1)** • calculation of temperature change **and** gives answer to 2 SF (because a school thermometer cannot measure to 3 SF) **(1)**	Example of calculation moles used = 25.0 x 1.00/1000 = 0.0250 energy released = 0.025 x 53.4 = 1.335 (kJ) / 1335 (J) TE on moles used Ignore sign 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)	**(3)**

Q13.

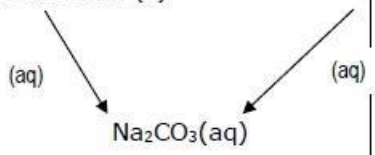
Question Number	Acceptable Answers	Additional Guidance	Mark
(i)	• calculation or working of energy needed to break bonds **(1)** • calculation or working of energy released when bonds made **(1)** • calculation of enthalpy change of combustion with sign **(1)**	Example of calculation energy to break 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 and at a lower enthalpy and arrow labelled Δ_cH **(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 and 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.

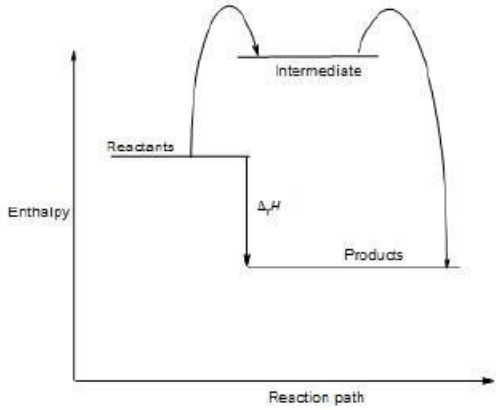
Question Number	Acceptable Answers	Additional Guidance	Mark
(a)	• calculation or working of heat evolved during reaction **(1)** • calculation or working of mol Na_2CO_3 used **(1)** • calculation of enthalpy change of solution **(1)** • negative sign and answer to 2 or 3 SF **(1)**	Example of calculation heat evolved = 50 x 4.18 x 5.4 = 1128.6 J or 1.1286 kJ Ignore any sign mol Na_2CO_3 used = 5.09/106 = 0.04802 enthalpy of solution = 1.1286/0.04802 = 23.5 TE on heat evolved and mol Na_2CO_3 −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)	**(4)**

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)**	$Na_2CO_3(s) + 10H_2O(l) \rightarrow Na_2CO_3.10H_2O(s)$  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)** • 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)**	Allow smaller / requires less energy Allow more exothermic / negative 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	(2)

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 $NaHCO_3$ used / g: 5.62 Temperature fall / °C: (−)6.6	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	• calculation of amount of $NaHCO_3$ **and** calculation of amount of hydrochloric acid (1) • 0.0669 mol $NaHCO_3$ needs 0.0699 mol HCl for reaction so HCl is in excess (1)	Example of calculation amount $NaHCO_3$ = 5.62 / (23 + 1 + 12 + (3 x 16)) = 0.0669 (mol) TE on mass of $NaHCO_3$ in (a)(i) **and** amount HCl = 50 x 2.00 / 1000 = 0.10 (mol) Ignore SF including 1SF 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)	(2)

Question Number	Answer	Additional Guidance	Mark
(iii)	• calculation of heat absorbed (1) • calculation of enthalpy change (1) • positive sign **and** units (1)	Example of calculation heat absorbed = 50.0 x 4.18 x 6.6 = 1379.4 (J) / 1.3794 (kJ) Ignore sign enthalpy change = $\frac{1379.4}{0.0669}$ = 20619 (J mol^{-1}) **or** = $\frac{1.3794}{0.0669}$ = 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.

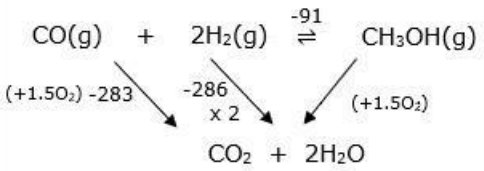
Question Number	Answer	Mark
	The only correct answer is D (endothermic, dehydration) **A** *is not correct because hydration involves adding water* **B** *is not correct because a reaction that requires heat is unlikely to be exothermic and hydration involves adding water* **C** *is not correct because 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: • gives an equation linking the three values or processes together / constructs a Hess's Law cycle **(1)**	Example of calculation $\Delta_c H$ (CH_3OH) = $-\Delta H$ (Step 2) + $\Delta_c H(CO)$ + $2\Delta_c H(H_2)$ or  	**(3)**
	• uses of numerical values in equation or on cycle, including use of 2 x $\Delta_c H(H_2)$ **(1)** • calculation of final value with correct sign **(1)**	Do not penalise lack of 2 in $2H_2O$ in cycle or in $2\Delta_c H(H_2)$ if M2 not scored. $\Delta_c H$ (CH_3OH) = 91 + −283 + 2(−286) = −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) $= \frac{2.08}{32.0}$ = 0.0650 / 0.065 / 6.50×10^{-2} (mol) $= \frac{20\,691}{0.0650} = 318323$ (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 $\sum\Delta_f H$(products) **(1)** • $\sum\Delta_f H$(products) - $\Delta_r H$ **(1)** • calculates $\Delta_f H_{(NH3)}$ for 1 mol ammonia **(1)**	Example of calculation (+90.4 x 4) + (-241.8 x 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 $\frac{4NO}{4NO + 6H_2O}$ OR $\frac{4NO}{4NH_3 + 5O_2}$ may be shown as numbers only $\frac{4(14+16)}{4(14+16)+6(16+2)} \times 100$ OR $\frac{4(14+16)}{4(14+3)+5(16\times 2)} \times 100$ = 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)**

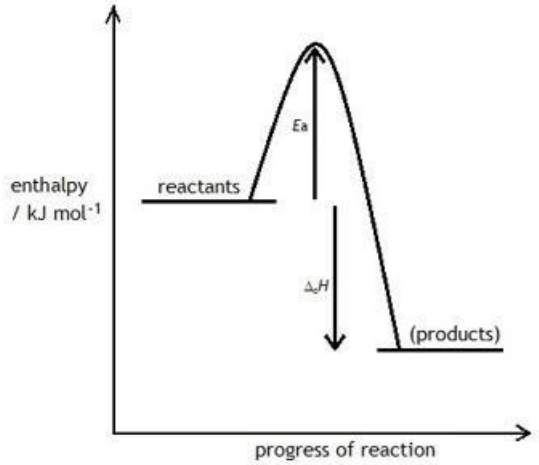
Q23.

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 = $\frac{1421.2}{0.025}$ = 56848 ($J\ mol^{-1}$) **or** = $\frac{1.4212}{0.025}$ = 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:		(2)
	• (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)**	Accept energy released Ignore air Do not award one mole of atoms burns.... Do not award energy required / needed	
	• under standard conditions of 100 kPa and a stated temperature **(1)**	e.g 25°C / 298 K / 273 K / 293 K Allow 101 kPa / 1 atm Do not award just 'under standard conditions' / rtp	

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	$C_8H_{18}(l) + 12½O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l)$ • 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 $2Al(s) + 1½O_2(g) \rightarrow Al_2O_3(s)$ 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 x 10^5 Pa / 101 kPa / 1.01 x 10^5 Pa for pressure Allow a value for the temperature of 298K / 25^{0}C Ignore 273K Ignore other standard conditions e.g. 1 mol dm^{-3} Do not allow ^{o}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)**

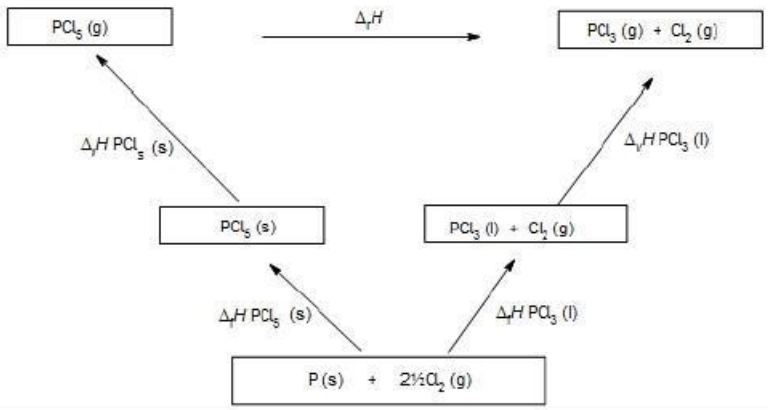
Q27.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• species and balanced **(1)** • arrows pointing downwards **(1)** • calculation of $\Delta_c H$ of reactants and show $\Delta_c H$ of product **(1)** • calculation of $\Delta_r H$ **(1)**	Ignore state symbols even if incorrect Ignore absence of oxygen alongside arrows Example of calculation $\Delta_c H_{reactants}$ = −394 + (2 x −286) (kJ mol^{-1}) = −966 (kJ mol^{-1}) $\Delta_c H_{products}$ = −890 (kJ mol^{-1}) $\Delta_r H$ = −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.

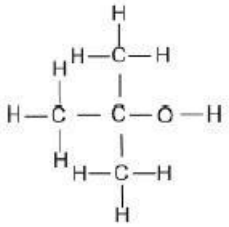
Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: • correct elements in the lower box (P(s), $Cl_2(g)$) (1) • correct moles of each element, P(s) **and** $2½Cl_2(g)$ (1) • arrows correctly labelled ($\Delta_f H$ [PCl_5], $\Delta_f H$ [PCl_3]) (1)	Penalise missing states only once (M1) States are required Allow $P_4(s)$ Ignore balancing numbers for M1 Allow $¼P_4(s)$ Ignore state symbols (if given) Ignore state symbols (if given) on arrows	(3)

Example of cycle

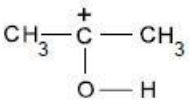


Question Number	Answer	Additional Guidance	Mark
(ii)	• use of $\sum(\Delta_f H$[products] - $\sum(\Delta_f H$[reactants] (1) • correct answer with sign and units (1)	Example of calculation (-319.7 + 30.5) - (-443.5 + 64.9) Allow correct sums (−289.2 and −378.6) but must be negative = +89.4 kJ mol^{-1} 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)

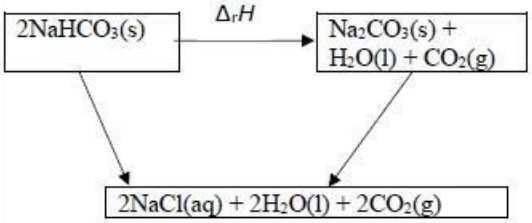
Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)		allow + charge on any part of the ion/outside the structure but + must be shown allow displayed/structural/skeletal/ molecular formulae or any combination of these.	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(c)(i)	• calculation for bonds broken in the alcohol (*) **(1)** • calculation for bonds broken in oxygen **and** total energy for bonds broken(**) **(1)** • calculation for bonds made(***) **(1)** • calculation of $\Delta_c H$ (2-methylpropan-2-ol) with sign **(1)**	Example of calculation 3(C-C) + 9(C-H) + (C-O) + (O-H) =(3x347) + (9x413) + 358 + 464 = (+)5580 (kJ mol^{-1}) 6(O=O) = (6 x 498) = (+)2988 (kJ mol^{-1}) total = + 5580 + 2988 = (+)8568 (kJ mol^{-1}) TE from ans * M1 + 2988 = 8(C=O) + 10(O-H) = (8x805) + (10x464) = -11080 (kJ mol^{-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)** • $\Delta_c H$ (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 and 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)

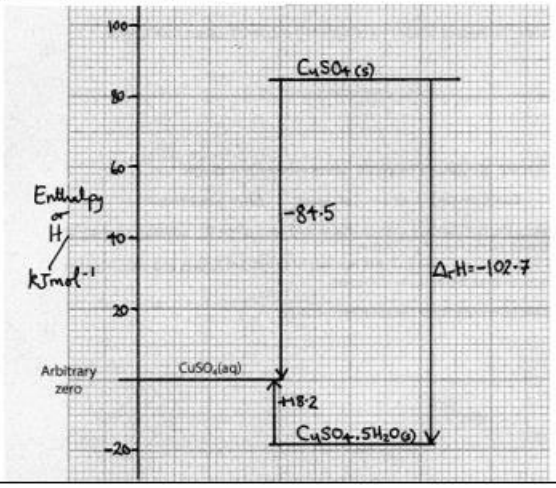
Q30.

Question Number	Answer	Additional Guidance	Mark
(i)	 • correct species and balancing numbers in lower box (1) • both arrows pointing in correct directions (1)	Example of Hess cycle Ignore missing state symbols Stand alone mark Ignore labels on arrows and inclusion of HCl	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	• expression for $\Delta_r H$ (1) • substitution of values into expression with both values in same units (1) • calculation of $\Delta_r H$ **and** sign **and** units (1)	Example of calculation $\Delta_r H = 2x\Delta H_1 - \Delta H_2$ $\Delta_r H = 2 \times 20.619 - (-29.4)$ **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 $\Delta_r H = +70.638$ 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)	(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
	• calculation of energy required for breaking the bond in Cl_2 and I_2 **(1)** • calculation of energy in 2 moles of I-Cl bonds and divides by 2. **(1)**	Example of calculation = 151 + 243 = 394 (kJ mol^{-1}) = $\frac{394 + 30}{2}$ = (+)212 (kJ mol^{-1})	**(2)**

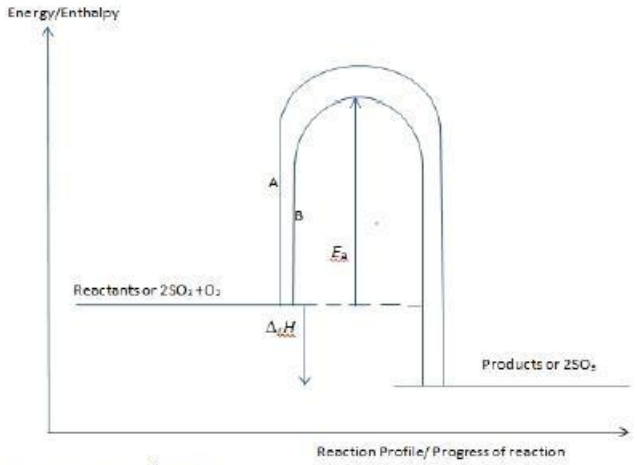
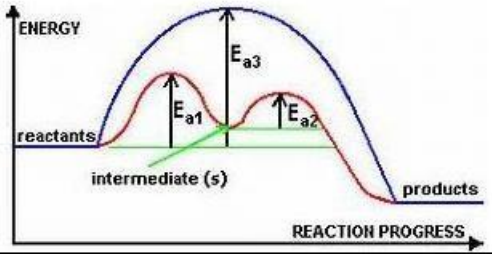
Q33.

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)** activation energy, E_a, shown correctly (upper diagram) **(1)**	Ignore presence/absence of arrowheads Allow a degree of imprecision in the start/finish points of the lines for ΔH and E_a Ea shown on double hump profile - shown in this diagram as Ea_1 Ignore Ea2 if also shown	**(2)**

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)	calculation of Q **(1)** calculation of enthalpy change **(1)** answer to nearest whole number **and** with negative sign **(1)**	Example of calculation Q=(100 x 4.18 x 6.5=) = 2717 (J) / 2.717 kJ ΔH= 2.717 ÷ 0.05= (–)54.340 = –54 (kJ mol^{-1}) Allow TE at each stage Correct answer with no working scores (3)	**(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)**	$2C(s, \text{graphite}) + 3H_2(g) + \frac{1}{2}O_2(g) \rightarrow C_2H_5OH(l)$ Allow C_2H_6O Do not allow multiples Conditional on all species correct Allow C(s) / C(graphite)	(2)