



Mark Scheme

Q1.

Question Number	Answer	Additional guidance	Mark
(i)	<p>An explanation that makes reference to the following points</p> <ul style="list-style-type: none"> 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)	<ul style="list-style-type: none"> calculation of energy required to break reactant bonds (1) calculation of energy release when product bonds form (1) calculation of enthalpy change (1) 	<p><u>Example of calculation:</u></p> $5(\text{C-H}) + (\text{C=C}) + (\text{C-C}) + (\text{C-O}) + (\text{O-H}) + 4(\text{O=O})$ $5(413) + (612) + (347) + (358) + (464) + (4 \times 498)$ $= 5838 \text{ (kJ mol}^{-1}\text{)}$ $6(\text{C=O}) + 6(\text{O-H})$ $(6 \times 805) + (6 \times 464)$ $= 7614 \text{ (kJ mol}^{-1}\text{)}$ $5838 - 7614 = -1776 \text{ (kJ mol}^{-1}\text{)}$ <p>Ignore SF except 1 SF Allow TE from M1 and M2</p> <p>Correct answer no working scores 3</p>	(3)
Question Number	Answer	Additional Guidance	Mark
(iii)	<p>An explanation that makes reference to one of the following points</p> <p>EITHER</p> <ul style="list-style-type: none"> ΔS_{total} is always positive (1) (1) As both $\Delta S_{\text{surroundings}}$ and ΔS_{system} are positive (1) OR ΔG is always negative (1) as ΔH is negative and $\Delta S_{(\text{system})}$ is positive (1) 	If no marking points awarded allow 1 mark for idea that $\Delta S_{\text{system}} / \Delta S_{\text{surroundings}}$ / entropy increases with correct explanation	(2)



Q2.

Question Number	Answer	Additional Guidance	Mark
(i)	An answer that makes reference to the following points: <ul style="list-style-type: none">• there is an increase of number of moles (1)• change of state as gas / liquid / solution are produced from solids (1)	Allow particles for moles 3 to 13 moles Do not award 11 to 13 moles Do not award reference to 'more types' of products than reactants Ignore references to ΔH	(2)

Question Number	Answer	Additional Guidance	Mark
(ii)	An explanation that makes reference to the following points: <ul style="list-style-type: none">• the reaction is endothermic (1)• (and so) freezes the water (which attaches the wooden block to the flask) (1)	Allow description of endothermic	(2)



Q3.

	Answer	Additional Guidance	Mark
(i)	<ul style="list-style-type: none"> oxygen lone pair and curly arrow to the H^+ (1) curly arrow from oxygen lone pair on the ethanol to the carbon of the $C=O$ (1) curly arrow from $C-O$ bond to oxygen of water molecule (1) curly arrow from $O-H$ bond back to the O^+ oxygen (1) 		(4)
	<p>Example of reaction mechanism</p> <p>Penalise additional curly arrows for each marking point</p> <p>Penalise missing lone pair on oxygen once only in M1 and M2</p>		

Question Number	Answer	Additional Guidance	Mark
(ii)	<ul style="list-style-type: none"> correct oxygen identified (1) <p>or</p> <ul style="list-style-type: none"> the single bond $C-O$ in the carboxylic acid breaks rather than the one in ethanol (1) 	<p>Allow 'loss of OH from the carboxylic acid'</p>	(2)



Question Number	Answer	Additional Guidance	Mark
(iii)	<ul style="list-style-type: none"> (M1) calculation of ΔG (1) (M2) correct equation (1) (M3) rearrangement of equation (1) (M4) calculation of ΔS_{system} (1) (M5) rearrangement of equation so $S_{(ethyl\ ethanoate)} =$ (1) (M6) calculation of $S_{(ethyl\ ethanoate)}$ with sign and units (1) 	<p><u>Example of calculation</u></p> $\Delta G = -RT \ln K = -8.31 \times 298 \times \ln 4.0$ $= -3433 \text{ (J mol}^{-1}\text{)}$ $\Delta G = \Delta H - T\Delta S_{system}$ $\Delta S_{system} = (\Delta H - \Delta G) \div T$ $\Delta S_{system} = (-6.0 \times 10^3 - (-3433)) \div 298$ $= -8.614\dots \text{ (J mol}^{-1}\text{ K}^{-1}\text{)}$ $(\Delta S_{system} = \sum S_{(products)} - \sum S_{(reactants)})$ $S_{(ethyl\ ethanoate)} = \Delta S + \sum S_{(reactants)} - S_{(water)}$ $S_{(ethyl\ ethanoate)} = (-8.614 + (159.8 + 160.7) - 69.9)$ $= +242/240 \text{ J mol}^{-1}\text{ K}^{-1}$ <p>Ignore SF except 1SF</p> <p>Correct final answer without working scores (6)</p> <p>TE throughout</p>	(6)



Q4.

Question Number	Answer	Additional Guidance	Mark
	<ul style="list-style-type: none"> calculation of ΔG (1) ΔG is positive / >0 so reaction is not feasible (1) calculation of T (1) 	<p>Penalise incorrect units in M1 or M3 once only</p> <p>Working is not required for the calculations</p> <p><u>Example of calculation</u> $\Delta G = 178 - \frac{(298 \times 165)}{1000}$ $= (+)128.83 / 129 \text{ (kJ mol}^{-1}\text{)}$ or $\Delta G = 178000 - (298 \times 165)$ $= (+)128830 / 129000 \text{ (J mol}^{-1}\text{)}$</p> <p>Stand alone mark Allow ΔG must be negative for a reaction to be feasible Ignore 'so reaction is not feasible' without a reason No TE on a calculated negative value</p> <p><u>Example of calculation</u> $\Delta G = 0$, so $\Delta H = T\Delta S_{(sys)}$ or $T = \Delta H/\Delta S_{(sys)}$ or $\Delta S_{total} = \Delta S_{sys} - \Delta H/T = 0$, so $T = \Delta H/\Delta S_{(sys)}$</p> <p>$T = 178/0.165 = 1078.8 / 1079 / 1080 \text{ (K)}$ or $T = 178000/165 = 1078.8 / 1079 / 1080 \text{ (K)}$ or $T = 806 \text{ (}^\circ\text{C)}$</p> <p>Ignore SF except 1 SF</p>	(3)

Q5.

Question Number	Answer	Additional Guidance	Mark
Penalise incorrect or missing units in (b)(i) and (b)(ii) once only			
(i)	<ul style="list-style-type: none"> calculation of ΔG (1) ΔG is negative/ <0 and so reaction is feasible (1) 	<p><u>Example of calculation</u> $\Delta G = -56 - \frac{(298 \times -76.5)}{1000}$ $= -33.203 \text{ (kJ mol}^{-1}\text{)}$ or $\Delta G = -56000 - (298 \times -76.5)$ $= -33203 \text{ (J mol}^{-1}\text{)}$</p> <p>Ignore SF except 1</p> <p>Allow ≤ 0 and so reaction is feasible Standalone mark Allow TE on own ΔG calculated value</p>	(2)



Question Number	Answer	Additional Guidance	Mark
(ii)	<ul style="list-style-type: none"> calculation of T 	<p>Example of calculation</p> $\Delta G = 0, \text{ so } \Delta H = T\Delta S_{(\text{system})} \text{ Or } T = \Delta H/\Delta S_{(\text{system})}$ $T = 56/0.0765 = 732 \text{ K}$ <p>or</p> $T = 56000/76.5 = 732 \text{ K or}$ $T = 459^\circ\text{C}$ <p>Ignore SF except 1 SF</p> <p>Do not award -732K TE on incorrect values penalised already in (b)(i)</p>	(1)

Q6.

Question Number	Answer	Additional Guidance	Mark
	<ul style="list-style-type: none"> expression for ΔS_{system} (1) calculation of ΔS_{system} (1) expression for $\Delta S_{\text{surroundings}}$ (1) calculation of $\Delta S_{\text{surroundings}}$ (1) calculation of ΔS_{total}, correct units and comment on feasibility (1) 	<p>Example of calculation</p> $\Delta S_{\text{system}} = [(6 \times 205) + (219.5) + (160.7)] - [(4 \times 213.6) + (5 \times 69.9)]$ $= 1610.2 - 1203.9 = (+) 406.3 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$ $\Delta S_{\text{surroundings}} = -\Delta H/T = -2778 \times 10^3 / 298$ $= -9322.14765 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$ $\Delta S_{\text{total}} = 406.3 - 9322.14765$ $= -8915.85 \text{ J K}^{-1} \text{ mol}^{-1}, \text{ (negative) so not feasible}$ <p>Ignore SF except 1 SF. Allow TE and KJ throughout</p>	(5)

Q7.

Question Number	Acceptable Answer	Additional Guidance	Mark								
	<ul style="list-style-type: none"> all 3 correct (2) any 2 correct (1) 	<p>Example of table</p> <table border="1"> <thead> <tr> <th>Reaction</th> <th>Sign of ΔS_{system}</th> </tr> </thead> <tbody> <tr> <td>$\text{CO}_2(\text{s}) \rightarrow \text{CO}_2(\text{g})$</td> <td>positive / + / +ve / plus</td> </tr> <tr> <td>$\text{NaCl}(\text{s}) + \text{aq} \rightarrow \text{NaCl}(\text{aq})$</td> <td>positive / + / +ve / plus</td> </tr> <tr> <td>$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$</td> <td>negative / - / -ve / minus</td> </tr> </tbody> </table>	Reaction	Sign of ΔS_{system}	$\text{CO}_2(\text{s}) \rightarrow \text{CO}_2(\text{g})$	positive / + / +ve / plus	$\text{NaCl}(\text{s}) + \text{aq} \rightarrow \text{NaCl}(\text{aq})$	positive / + / +ve / plus	$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$	negative / - / -ve / minus	(2)
Reaction	Sign of ΔS_{system}										
$\text{CO}_2(\text{s}) \rightarrow \text{CO}_2(\text{g})$	positive / + / +ve / plus										
$\text{NaCl}(\text{s}) + \text{aq} \rightarrow \text{NaCl}(\text{aq})$	positive / + / +ve / plus										
$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$	negative / - / -ve / minus										



Q8.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	<ul style="list-style-type: none"> correct working (1) correct answer and sign (1) 	<p>Example of calculation</p> $(2 \times 95.6) - ((2 \times 248.1) + 205.0) / (2 \times 95.6) - (2 \times 248.1) - 205.0$ <p>-510(.0) (J K⁻¹ mol⁻¹) or -0.510 (kJ K⁻¹ mol⁻¹)</p> <p>TE on working</p> <p>Ignore SF except 1SF</p> <p>Correct answer with sign and working scores both marks</p>	(2)

Question Number	Acceptable Answer	Additional Guidance	Mark
(ii)	<ul style="list-style-type: none"> use of $\Delta G = \Delta H - T\Delta S_{\text{system}}$ (1) calculation of ΔG and sign and units (1) ΔG is negative / less than 0 / <0 and so the reaction is feasible (1) 	<p>Example of calculation</p> <p>The equation may be stated or numbers substituted directly e.g. $-288.4 - (298 \times -0.510) / -288400 - (298 \times -510)$</p> <p>$-136(.42) \text{ kJ mol}^{-1} / -136420 \text{ J mol}^{-1}$</p> <p>TE on ΔS_{system} in (i) Ignore SF except 1SF</p> <p>Correct answer with sign and units without working scores both marks</p> <p>Conditional on a stated number TE on sign of ΔG: ΔG is positive / greater than 0 / >0 so the reaction is not feasible</p>	(3)



Question Number	Acceptable Answer	Additional Guidance	Mark
(iii)	<ul style="list-style-type: none"> • use of $\Delta G = -RT \ln K$ (1) • rearrangement of equation and substitution of correct values (1) • calculation of K (1) 	<p><u>Example of calculation</u> $-60000 = -$ 8.31×700 $\ln K$</p> <p>$(\ln K = -\Delta G/RT)$ $\ln K = \frac{-(-60000)}{(8.31 \times 700)}$</p> <p>Allow $\ln K = \frac{60000}{8.31 \times 700}$</p> <p>Allow $\ln K = 10.3146 / 10.315 / 10.32 / 10.3 / 10$</p> <p>TE on equation, provided equation involves all of ΔG, K, R and T and no others e.g. S</p> <p>$K = e^{10.315} = 3.016975 \times 10^4 / 30169.75$ TE on $\ln K$ expression / value</p> <p>Allow answers based on earlier correct rounding Ignore SF including 1SF</p> <p>Ignore units</p> <p>Correct answer without working scores 3 marks</p>	(3)



Question Number	Acceptable Answer	Additional Guidance	Mark
(iv)	<p>An explanation that makes reference to any two of the following points:</p> <ul style="list-style-type: none"> • Yield - even though the (percentage) yield / amount of SO₃ is higher at 298 K / lower temperature (1) • Rate - the rate of reaction is slower at 298 K / lower temperature (1) • Compromise - so 700 K is a compromise between a (high) yield and (high) rate (1) 	<p>Allow reverse argument for M1 and M2 Ignore reference to changing the pressure</p> <p>Allow the unused reactants can be recycled to increase the yield / products are removed to increase the yield</p> <p>Allow the reaction does not reach equilibrium in industry so there is no effect on the yield</p> <p>Ignore just a reference to 'equilibrium shifting'</p> <p>Ignore references to activation energy</p> <p>Allow at 700K the amount of product per unit time is larger</p> <p>Ignore just '700 K is more economically viable'</p> <p>Note If three points are made related to yield, rate and compromise and one of these is incorrect, maximum mark is (1) for 1 correct point</p>	(2)



Q9.

Question Number	Answer	Additional Guidance	Mark
(i)	<ul style="list-style-type: none"> calculation of ΔS_{system} (1) calculation of $\Delta S_{\text{surroundings}}$ (1) conversion of ΔS_{system} or $\Delta S_{\text{surroundings}}$ for consistent units (1) calculation of ΔS_{total} and corresponding units (1) comment on thermal stability at 298 K (1) <p>Alternative method on next page</p>	<p>Marks should be awarded for method 1 or method 2 but not via mixed methods. If both methods used, then award higher mark.</p> <p><u>Example of calculation</u> $(213.6 + 70.4) - 112.1 = 171.9 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$</p> <p>$-169.3 / 298 = -0.56812 \text{ (kJ K}^{-1} \text{ mol}^{-1}\text{)}$ or $(-169.3 \times 1000) / 298 = -568.12 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$</p> <p>$\Delta S_{\text{surroundings}}$ converted to $\text{J K}^{-1} \text{ mol}^{-1}$ or ΔS_{system} converted to $\text{kJ K}^{-1} \text{ mol}^{-1}$</p> <p>M3 could be subsumed as part of either M1 or M2</p> <p>$171.9 + (-568.12) = -396.22$ $\text{J K}^{-1} \text{ mol}^{-1}$ or $0.1719 + (-0.56812) = -0.39622 \text{ kJ K}^{-1} \text{ mol}^{-1}$</p> <p>Allow units to be missing here if correct units given for ΔS_{system} and $\Delta S_{\text{surroundings}}$</p> <p>Correct answer with units with some or no working scores (4) Ignore SF except 1 SF Allow TE throughout calculation</p> <p>Stand alone mark on any negative value for ΔS_{total} Negative value / <0 and so reaction is not feasible / it is thermodynamically stable (at 298 K)/ Ignore just 'so the reaction is not feasible'</p> <p>No TE for positive values for ΔS_{total}</p>	(5)



(i) continued	Alternative method using ΔG	<u>Example of calculation</u>	(5)
	<ul style="list-style-type: none"> • calculation of ΔS_{system} (1) • calculation of $T\Delta S_{\text{system}}$ (1) • conversion of $T\Delta S_{\text{system}}$ or ΔS_{system} or ΔH for consistent units (1) • calculation of ΔG_{total} and corresponding units (1) • comment on thermal stability at 298 K (1) 	<p>$(213.6 + 70.4) - 112.1 = 171.9 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$</p> <p>$298 \times 171.9 = 51226 \text{ (J mol}^{-1}\text{)}$ M2 could be subsumed as part of M3</p> <p>ΔH converted to J mol⁻¹ or ΔS_{system} converted to kJ K⁻¹ mol⁻¹ or $T\Delta S_{\text{system}}$ converted to kJ mol⁻¹ M3 could be subsumed as part of M4</p> <p>$169300 - 51226 = (+) 118074 \text{ J mol}^{-1}$ or $(+) 118.074 \text{ kJ mol}^{-1}$ Correct answer with units with some or no working scores (4)</p> <p>Ignore SF except 1 SF Allow TE from M1 to M4</p> <p>Stand alone mark on any positive value for ΔG Positive value / >0 and so reaction is not feasible (at 298 K) Ignore just 'so reaction is not feasible' No TE on negative values for ΔG</p>	



Question Number	Answer	Additional Guidance	Mark
(ii)	<p>recognition that $\Delta S_{\text{surroundings}} \geq -171.9 \text{ J K}^{-1} \text{ mol}^{-1}$</p> <ul style="list-style-type: none"> • for decomposition to be feasible <p>(1) substitution and rearrangement to find T</p> <ul style="list-style-type: none"> • (1) • <p>calculation of T and conversion to $^{\circ}\text{C}$ and answer given to 3 SF (1)</p>	<p><u>Example of calculation</u></p> $\Delta S_{\text{total}} = \Delta S_{\text{system}} - \frac{\Delta H}{T} = 0$ <p>Or</p> $\Delta S_{\text{system}} = \frac{\Delta H}{T}$ <p>Allow this equation rearranged This may be subsumed in M2</p> $-171.9 = (-169.3 \times 1000) / T$ $T = (-169.3 \times 1000) / -171.9$ <p>TE on ΔS_{system} from 4(a)(i)</p> <p>(= 984.87 K) (= 711.87$^{\circ}\text{C}$) = 712$^{\circ}\text{C}$</p> <p>TE on M1 and M2 but do not award any temperature below 0$^{\circ}\text{C}$ Correct answer to 3 SF and in $^{\circ}\text{C}$ scores (3)</p> <p>Alternative method for M1 and M2</p> $\Delta G = \Delta H - T\Delta S = 0 \text{ or } \Delta H = T\Delta S$ <p>This may be subsumed in M2 (1)</p> $169300 = T \times 171.9$ $T = 169300/171.9 \text{ (1)}$ <p>TE on ΔS_{system} from 4(a)(i)</p>	(3)



Q10.

Question Number	Answer	Additional Guidance	Mark																				
*	<p>This question assesses the student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning.</p> <p>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.</p> <p>The following table shows how the marks should be awarded for indicative content.</p> <table border="1"> <thead> <tr> <th>Number of indicative marking points seen in answer</th> <th>Number of marks awarded for indicative marking points</th> </tr> </thead> <tbody> <tr> <td>6</td> <td>4</td> </tr> <tr> <td>5-4</td> <td>3</td> </tr> <tr> <td>3-2</td> <td>2</td> </tr> <tr> <td>1</td> <td>1</td> </tr> <tr> <td>0</td> <td>0</td> </tr> </tbody> </table> <p>The following table shows how the marks should be awarded for structure and lines of reasoning</p> <table border="1"> <thead> <tr> <th></th> <th>Number of marks awarded for structure of answer and sustained lines of reasoning</th> </tr> </thead> <tbody> <tr> <td>Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td> <td>2</td> </tr> <tr> <td>Answer is partially structured with some linkages and lines of reasoning</td> <td>1</td> </tr> <tr> <td>Answer has no linkages between points and is unstructured</td> <td>0</td> </tr> </tbody> </table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5-4	3	3-2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained lines of reasoning	Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	<p>Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, a response with four indicative marking points that is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there were no linkages between the points, then the same indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and zero marks for linkages).</p> <p>Accept any six indicative content points</p> <p>More than one indicative marking point may be made within the same comment or explanation</p>	(6)
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																						
6	4																						
5-4	3																						
3-2	2																						
1	1																						
0	0																						
	Number of marks awarded for structure of answer and sustained lines of reasoning																						
Answer shows a coherent logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2																						
Answer is partially structured with some linkages and lines of reasoning	1																						
Answer has no linkages between points and is unstructured	0																						



	<p>Indicative content</p> <ul style="list-style-type: none"> ΔG needs to be negative for a reaction to be feasible if ΔS_{system} and ΔH are both negative then a reaction is feasible if the magnitude of $\Delta H > (\text{magnitude of}) T\Delta S_{\text{system}}$ if ΔS_{system} and ΔH are both positive then a reaction is feasible if the magnitude of $T\Delta S_{\text{system}} > (\text{magnitude of}) \Delta H$ if ΔS_{system} is positive and ΔH is negative then the reaction is (always) feasible if ΔS_{system} is negative and ΔH is positive then the reaction is never feasible even if it is feasible the reaction may not occur because of kinetic factors 	<p>High activation energy/energy barrier/physical barrier e.g. oxide layer</p> <p>Ignore just reference to slow rate of reaction</p> <p>Ignore reference to non-standard conditions</p>	
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Q11.

Question Number	Acceptable Answer	Additional Guidance	Mark
	<ul style="list-style-type: none"> use of $\Delta S_{\text{surroundings}} = -\Delta H/T$ (1) calculation of $\Delta S_{\text{surroundings}}$ (1) calculation of ΔS_{total} and sign and units (1) 	<p><u>Example of calculation</u></p> <p>$-(178000 \div 298) / -(178 \div 298)$</p> <p>$-597(.315) \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$</p> <p>or</p> <p>$-0.597(315) \text{ (kJ K}^{-1} \text{ mol}^{-1}\text{)}$</p> <p>TE on equation with minus sign missing</p> <p>$160 + (-0.597315) = -0.437(315) \text{ kJ K}^{-1} \text{ mol}^{-1}$</p> <p>1000</p> <p>or</p> <p>$160 + (-0.597315 \times 1000)$</p> <p>$= -437.(315) \text{ J K}^{-1} \text{ mol}^{-1}$</p> <p>TE on $\Delta S_{\text{surroundings}}$</p> <p>Allow correct units shown once in answer for ΔS_{total} or $\Delta S_{\text{surroundings}}$</p> <p>Ignore SF except 1SF</p> <p>Correct answer with sign and units without working scores 3 marks</p>	(3)