

Question Number	Acceptable Answers	Reject	Mark
1 (a)(i)	$\Delta S_{\text{system}} = ((2 \times 192.3) - (2 \times 95.8) - (2 \times 3 \times 65.3)) \quad \mathbf{(1)}$ $= \mathbf{-198.8 / -199} \text{ (J mol}^{-1} \text{ K}^{-1} \text{)}$ Allow – 200 (2 SF) If units are not those in which data is given, must be correct. (1) <i>Note check working</i> Correct answer without working (2) Correct choice of multiples and data but wrong answer scores first mark (1) Correct value with wrong sign based on entropy of reactants – entropy of products (giving +199) (1) TE for second mark if multiples for hydrogen, nitrogen and ammonia are missed/ incorrect, but correct data used. or multiples correct and one error in data.	198	2

Question Number	Acceptable Answers	Reject	Mark
1 (a)(ii)	If answer to (a)(i) is negative: Disorder decreases / order increases (as reaction goes forward) (1) Reference to order or disorder required for the mark. As number of (gas)molecules/moles/particles decreases (1) OR 4 moles of gas produces 2 moles Ignore comments on number of different types of molecule in equilibrium mixture If answer to (a)(i) is positive: Must say this is unexpected with correct reasons to score 2 marks No marks if the positive answer is expected	Just "entropy decreases"	2

Question Number	Acceptable Answers	Reject	Mark
1 (b) (i)	$\Delta S_{\text{surr}} = -(-110.2 \times 1000) / 700$ (1) $(+157.4285)$ $= (+) \mathbf{157.4 / 157}$ (J mol ⁻¹ K ⁻¹) OR $(+) 0.1574 / 0.157$ kJ mol⁻¹ K⁻¹ (1) Ignore sf except 1 Correct answer without working (2) Correct value with negative sign (1) Use of $\Delta S_{\text{surr}} = -\Delta H/T$ but wrong answer (1)		2

Question Number	Acceptable Answers	Reject	Mark
1 (b) (ii)	$(\Delta S_{\text{system}} = \Delta S_{\text{total}} - \Delta S_{\text{surr}})$ $= (-78.7 - 157.4)$ $= \mathbf{-236.1 / -236}$ (J mol ⁻¹ K ⁻¹) OR $-0.2361 / -0.236$ (kJ mol ⁻¹ K ⁻¹) Allow -235.7 if 157 used and -238.7 if 160 used Ignore units unless value in kJ given as J or vice versa TE from (b)(i)	values in kJ added to values in J	1

Question Number	Acceptable Answers	Reject	Mark
1 (b) (iii)	Reactants predominate / more nitrogen and hydrogen (than ammonia)	Just "Equilibrium lies to the left" Just "no ammonia is present". The gases are present in ratio 1:3:2	1

Question Number	Acceptable Answers	Reject	Mark
1 (c) (i)	$K_p = (p\text{NH}_3)^2 / (p\text{N}_2)(p\text{H}_2)^3$ (1) Can be written in other formats eg $p^2\text{NH}_3$ etc $p\text{H}_2 = (150 - 21 - 36) = \mathbf{93}$ (atm) (1) $K_p = ((36)^2 / (21)(93)^3) = (7.6724994 \times 10^{-5})$ $= \mathbf{7.67 \times 10^{-5}}$ (1) Ignore sf except 1 TE on incorrect $p\text{H}_2$ atm^{-2} (1) TE for units on incorrect K_p expression Correct answer including units without quoting K_p expression scores 3	Square brackets in first mark No TE for value on incorrect K_p Expression Units other than atm	4

Question Number	Acceptable Answers	Reject	Mark
1 (c) (ii)	(Yield of ammonia is increased) because there are fewer moles / molecules (of gas) on the right OR System tries to reduce the pressure by going to the side with fewer moles/ molecules (of gas) Ignore comments about value of K_p changing Ignore comments about more collisions occurring/more molecules having energy greater than or equal to activation energy	Just 'equilibrium moves right'	1

Question Number	Acceptable Answers	Reject	Mark
* 1 (c) (iii)	<p>First mark At higher temperature ΔS_{surr} is less positive/ decrease/more negative (1)</p> <p>Second mark making ΔS_{total} more negative / less positive/decreases</p> <p>No TE for 2nd mark if ΔS_{surr} is said to increase. (1)</p> <p>Third mark (so) K_p decreases (1) Third mark depends on second mark being correct/neutral answer</p> <p>Fourth mark so equilibrium position further left /in endothermic direction/ in reverse direction</p> <p>OR</p> <p>lower yield of ammonia / reaction is less feasible (1) Fourth mark is a stand alone mark</p>		4

Question Number	Acceptable Answers	Reject	Mark
1 (c) (iv)	<p>Rate (of reaching equilibrium) is higher / faster</p> <p>Ignore comments about increasing numbers of successful collisions at higher temperature</p>		1

Question Number	Acceptable Answers	Reject	Mark
2 (a)(i)	$\Delta S_{\text{system}}^{\ominus} = 109.2 + (6 \times 69.9) - 343 \quad (1)$ $= (+)185.6 (\text{J mol}^{-1} \text{K}^{-1}) / (+)186 (\text{J mol}^{-1} \text{K}^{-1}) \quad (1)$ OR $(+)0.186 (\text{kJ mol}^{-1} \text{K}^{-1}) \quad (2)$ IGNORE units even if incorrect correct answer with no working scores 2 Value using 1 for H ₂ O = -163.9 scores 1 Use of value for H ₂ O(g) (188.7) gives $898.4 (\text{J mol}^{-1} \text{K}^{-1}) \quad (1)$ correct value with incorrect sign scores 1	185	2

Question Number	Acceptable Answers	Reject	Mark
2 (a)(ii)	Yes as (solid and) liquid forms (from solid) / number of moles increases OR If $\Delta S_{\text{system}}^{\ominus}$ in (i) is negative the sign is not as expected as liquid forms from solid / number of moles increases	Disorder increases, with no ref to liquid or number of moles	1

Question Number	Acceptable Answers	Reject	Mark
2 (a)(iii)	<p>First mark $\Delta S^{\circ}_{\text{surroundings}} = \frac{-88.1 \times (1000)}{298} \quad (1)$</p> <p>Second mark $= -295.6375$ $= -295.6 \text{ J mol}^{-1} \text{ K}^{-1} \quad (1)$ correct units must be shown but order not important</p> <p>OR</p> <p>$-0.2956 \text{ kJ mol}^{-1} \text{ K}^{-1} \quad (1)$ correct units must be shown but order not important</p> <p>correct answer with or without working and correct units scores (2) ignore sf except 1</p> <p>correct value with positive sign scores 1</p>		2

Question Number	Acceptable Answers	Reject	Mark
2 (a)(iv)	<p>(185.6-295.6) $= -110 \text{ (J mol}^{-1} \text{ K}^{-1} \text{)}$</p> <p>OR</p> <p>$-0.110 \text{ (kJ mol}^{-1} \text{ K}^{-1} \text{)}$</p> <p>could use 186 or 296 etc</p> <p>TE from (a)(i) and (iii)</p> <p>(+)602.8 (J mol⁻¹ K⁻¹) if value for 6H₂O(g) was used in (a) (i)</p> <p>-459.5 (J mol⁻¹ K⁻¹) if value for one H₂O was used in (a) (i)</p>	Answers where values in J are added to kJ	1

Question Number	Acceptable Answers	Reject	Mark
2 (a)(v)	<p>Decomposition (at 298 K) will not occur as $\Delta S^{\circ}_{\text{total}}$ is negative / Reactions are only spontaneous if total entropy change is positive / decomposition not thermodynamically feasible / (hydrated cobalt chloride) is thermodynamically stable</p> <p>TE if answer to (a)(iv) is positive showing decomposition (at 298 K) may occur</p> <p>OR</p> <p>Positive total entropy change doesn't indicate rate of reaction</p>		1

Question Number	Acceptable Answers	Reject	Mark
2 (b)(i)	<p>First mark Thermometer (1)</p> <p>Second mark (dependent on first) depends on choosing thermometer</p> <p>as temperature change is small / (%) error in balance smaller than for temperature reading (%) error in pipette smaller than for temperature reading (can be shown by calculation) / as scale with greater degree of precision needed / scale with more graduations needed (1) <i>IGNORE</i> any references to 'accurate thermometer'</p>		2

Question Number	Acceptable Answers	Reject	Mark
2 (b)(ii)	Use more cobalt chloride / less water (1) To increase temperature rise (1) Mark independently	Just 'use more reactants' Use more cobalt chloride and more water repeat expt add a lid or extra insulation to beaker use distilled water	2

Question Number	Acceptable Answers	Reject	Mark
2 (c)(i) QWC	Radius (of cation) increases (down group) OR any two values of radius: $\text{Mg}^{2+} = 0.072$, $\text{Ca}^{2+} = 0.100$ / $\text{Sr}^{2+} = 0.113$ (nm) data may be shown beside the table (1) Radius $\text{Co}^{2+} = 0.065$ nm OR Co^{2+} radius smaller than other ions (1) Data on EITHER Co^{2+} OR data showing increase in radius down Group II required for BOTH of first two marks Force of attraction between ions decreases (as radius of ions increases) / charge density of ions decreases / negative ion can come closer to nucleus of positive ion (1) <i>ALLOW "weaker ionic bonds"</i> Predict lattice energy -2550 to -2900 (kJ mol^{-1}) (1) IGNORE sign	Atomic radii unless ionic radii also given Radius of cobalt chloride Polarising power decreases	4

Question Number	Acceptable Answers	Reject	Mark
2 (c)(ii) QWC	<p>First mark Reference to enthalpy of hydration (may be in equation $\Delta H_{\text{solution}} = -LE + \Delta H_{\text{hydration}}$) (1)</p> <p>Second mark Solubility depends on relative size of lattice energy and enthalpy of hydration (1)</p> <p>Third mark EITHER Solubility more likely if $\Delta H_{\text{solution}}$ is negative</p> <p>OR</p> <p>(If $\Delta H_{\text{solution}}$ is positive,) may / will dissolve if ΔS_{total} is positive</p> <p><i>ACCEPT</i> solvation instead of hydration</p>		3

Question Number	Acceptable Answers	Reject	Mark
2 (d) QWC	<p>First mark Third ionization energy high(er) for Mg / Mg = 7733 kJ mol⁻¹, (third ionization energy for Co = 3232 kJ mol⁻¹) (1)</p> <p>Second mark (Third ionization energy for Mg is high) because the electron is being removed from an inner shell / full shell / 2p level / 2p orbital (1)</p> <p>OR</p> <p>Not compensated by higher lattice energy for Mg³⁺ (and so $\Delta H_{\text{formation}}$ of MgCl₃ would be highly endothermic) (1)</p>		2

Question Number	Acceptable Answers	Reject	Mark
3(a)	(It has) three (moles of) COOH groups / three (moles of) carboxylic acid groups / three (moles of) protons / three (moles of) H ⁺ / it is tribasic / three acid groups/ three (moles of) replaceable hydrogens/triprotic ALLOW Three acid groups	'carbonyl'/'carboxylate'	1

Question Number	Acceptable Answers	Reject	Mark
3(b) (i)	<p>FIRST, CHECK THE FINAL ANSWER IF answer = +546 (J mol⁻¹ K⁻¹) award 2 marks "546" (J mol⁻¹ K⁻¹) scores (1) as sign omitted) ($\Delta S_{\text{system}}^{\circ}$ =) [200.5 + (3 x 213.6) + (3 x 69.9)] - 99.9 + (3 x 101.7)] (1) = [+1051] - [+ 505] = +546 (J mol⁻¹ K⁻¹) (1)</p> <p>Allow + 0.546 kJ mol⁻¹ K⁻¹ 2nd mark is CQ on entropy values used for example</p> <p>EITHER Omission of factor of x3 for some or all substances in the equation</p> <p>OR The use of one incorrect entropy value(s) from the data book</p> <p>OR One missing value</p> <p>Note If two or more of the above three errors are made together, (0) awarded.</p> <p>IGNORE sf except 1 sf</p>	<p>Incorrect units (no 2nd mark)</p>	2

Question Number	Acceptable Answers	Reject	Mark
3(b)(ii)	<p>First mark Gas formed (from solid) OR Liquid formed (from solid) OR Gas and liquid formed (from solid) (1)</p> <p>Second mark EITHER More moles of product than reactants / more moles formed OR 4 mol (of reactants) to 7 mol (of products) OR 4 'molecules' to 7 'molecules' NOTE: If specific numbers are stated, these must be correct (ie 4→7) OR Increase in disorder / increase in ways of arranging particles (1)</p> <p>IGNORE 'entropy increases'</p> <p>NOTE: Both points may be made in the same sentence</p>	<p>Just 'more product' / 'more particles formed'</p> <p>2 substances going to 3 substances</p>	2

Question Number	Acceptable Answers	Reject	Mark
3(b)(iii)	$(\Delta S^{\circ}_{\text{surroundings}} =) \frac{-\Delta H}{T} \text{ OR } \frac{-70000}{298}$ <p style="text-align: right;">(1)</p> $= -234.8993289$ $= -235 \text{ J mol}^{-1} \text{ K}^{-1}$ <p style="text-align: right;">(1)</p> <p>OR</p> $(\Delta S^{\circ}_{\text{surroundings}} =) \frac{-\Delta H}{T} \text{ OR } \frac{-70}{298}$ <p style="text-align: right;">(1)</p> $= -0.235 \text{ kJ mol}^{-1} \text{ K}^{-1}$ <p style="text-align: right;">(1)</p> <p>IGNORE sf except 1 sf NOTE: Correct units are required for the award of the second mark +235 with units scores (1)</p>	<p>Incorrect rounding (e.g. -234 / -234.89) no 2nd mark</p> <p>+235 with no units (0) overall</p>	2

Question Number	Acceptable Answers	Reject	Mark
3(b)(iv)	$(\Delta S^{\circ}_{\text{total}} = \Delta S^{\circ}_{\text{system}} + \Delta S^{\circ}_{\text{surroundings}})$ $= (+546) + (-235)$ $= (+)311 \text{ (J mol}^{-1} \text{ K}^{-1}\text{)}$ OR $= (+)0.311 \text{ kJ mol}^{-1} \text{ K}^{-1}$ CQ on (i) and (iii) IGNORE sf except 1 sf	Incorrect units	1

Question Number	Acceptable Answers	Reject	Mark
3(b)(v)	Positive so feasible / spontaneous / will occur / reaction goes / reacts (at 298 K) NOTE: LOOK BACK at answer to (b)(iv) IF answer to (b)(iv) has a positive sign (the + sign can be stated or implied) THEN ALLOW JUST feasible / spontaneous / will occur / reaction goes / reacts (at 298 K) Mark CQ on sign of answer to (iv)		1

Question Number	Acceptable Answers	Reject	Mark
4 (a)(i)	(+)186.2 (J mol ⁻¹ K ⁻¹)		1

Question Number	Acceptable Answers	Reject	Mark
4(a)(ii)	(266.9 + 186.2) – 310.1 (1) = + 143 (J mol ⁻¹ K ⁻¹) (1) – 143 scores (1) Correct answer with sign and no working scores (2) marks ALLOW TE from (i)		2

Question Number	Acceptable Answers	Reject	Mark
4(a)(iii)	Yes, as reaction produces 2 molecules/moles from one/more molecules/moles (1) (and) all products are gases (1) IGNORE references to volumes More moles/molecules of gas produced scores (2) OR Yes, (as the reaction is endothermic) $\Delta S_{\text{surroundings}}$ is negative (1) Since the reaction takes place/goes (spontaneously) ΔS_{total} is positive and therefore ΔS_{system} is positive (1) ALLOW TE from (a)(ii) i.e. 'No, as....'		2

Question Number	Acceptable Answers	Reject	Mark
4(a)(iv)	$\Delta S_{\text{surr}} = -\Delta H/T$ (1) $= -71900/700$ $= -102.7 \text{ J K}^{-1} \text{ mol}^{-1}/- 0.1027 \text{ kJ K}^{-1} \text{ mol}^{-1}$ (1) Correct answer and sign with no working scores (2) $- 0.103 \text{ J K}^{-1} \text{ mol}^{-1}$ scores (1) Third mark So ΔS_{total} is positive (so reaction is feasible) (1) OR $\Delta S_{\text{total}} = +40.3 \text{ J K}^{-1} \text{ mol}^{-1}$ (so reaction is feasible) (1) ALLOW TE from (a)(ii)	1 or 2 sf	3

Question Number	Acceptable Answers	Reject	Mark
4(a)(v)	$\Delta S_{\text{total}} = 0$ OR $\Delta S_{\text{surroundings}} = -143$ (1) $T = \Delta H \div \Delta S_{\text{surroundings}}$ OR $T = (-) 71900 \div (-)143$ (1) $= 502.8 \text{ (K)}$ (1) IGNORE sf except 1sf Correct answer with no working scores (3) ALLOW 0.5028 (K) for (2) marks ALLOW $- 502.8 \text{ (K)}$ for (2) marks ALLOW $- 0.5028 \text{ (K)}$ for (1) mark ALLOW TE from (a)(ii) If the calculation is not based on $\Delta S_{\text{total}} = 0$ then a maximum of (2) marks can be awarded if done correctly		3

Question Number	Acceptable Answers	Reject	Mark
4(b)	<p>The catalyst is in a different state/phase to the reactants (1) IGNORE references to products</p> <p>Any two from It provides an alternative (reaction) route/mechanism/gases adsorbed on catalyst surface (1)</p> <p>Of lower activation energy/weakens bonds in reactants (1)</p> <p>Greater proportion of molecules have $E \geq E_a$ (1)</p>		3