Question Number	Acceptable Answers	Reject	Mark
1 (a)(i)	$\Delta S_{system,}$ = ((2 x 192.3) –(2 x 95.8) – (2x3x65.3)) **(1)** = **-198.8 / -199** (J mol^{-1} K^{-1}) Allow – 200 (2 SF) If units are not those in which data is given, must be correct. **(1)** *Note check working* 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)	ΔS_{surr} = -(-110.2 x 1000)/ 700 **(1)** (+157.4285) **=** (+) **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 $\Delta S_{surr} = -\Delta H/T$ but wrong answer **(1)**		**2**

Question Number	Acceptable Answers	Reject	Mark
1 (b)(ii)	($\Delta S_{system} = \Delta S_{total} - \Delta S_{surr}$) =(-78.7-157.4)) = **-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)	$K_p = (pNH_3)^2 / (pN_2)(pH_2)^3$ **(1)** Can be written in other formats eg p^2NH_3 etc $pH_2 = (150 - 21 - 36) =$ **93** (atm) **(1)** $K_p = ((36)^2 / (21)(93)^3) = (7.6724994 \times 10^{-5})$ $=$ **7.67×10^{-5} (1)** Ignore sf except 1 TE on incorrect pH_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)**	**First mark** At higher temperature ΔS_{surr} is less positive/ decrease/more negative **(1)** **Second mark** making ΔS_{total} more negative / less positive/decreases No TE for 2nd mark if ΔS_{surr} is said to increase. **(1)** **Third mark** (so) K_p decreases **(1)** **Third mark depends on second mark being correct / neutral answer** **Fourth mark** so equilibrium position further left /in endothermic direction/ in reverse direction OR lower yield of ammonia / reaction is less feasible **(1)** **Fourth mark is a stand alone mark**		**4**

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

Question Number	Acceptable Answers	Reject	Mark
2 (a)(i)	$\Delta S^{\ominus}_{system}$ = 109.2 + (6x 69.9) – 343 **(1)** =(+)185.6(J mol^{-1} K^{-1}) / (+)186 (J mol^{-1} K^{-1}) **(1)** **OR** (+)0.186 (kJ mol^{-1} K^{-1}) **(2)** IGNORE units even if incorrect correct answer with no working scores 2 Value using 1 for H_2O = -163.9 scores 1 Use of value for $H_2O(g)$ (188.7) gives 898.4 (J mol^{-1} K^{-1}) **(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 $\Delta S^{\ominus}_{system}$ 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)	**First mark** $\Delta S^{\ominus}_{surroundings} = -\frac{88.1 \times (1000)}{298}$ **(1)** **Second mark** = -295.6375 = -295.6 J mol^{-1} K^{-1} **(1)** correct units must be shown but order not important **OR** -0.2956 kJ mol^{-1} K^{-1} **(1)** correct units must be shown but order not important correct answer with or without working and correct units scores **(2)** ignore sf except 1 correct value with positive sign scores 1		**2**

Question Number	Acceptable Answers	Reject	Mark
2 (a)(iv)	(185.6–295.6) **= -110 (J mol^{-1} K^{-1})** OR **-0.110 (kJ mol^{-1} K^{-1})** could use 186 or 296 etc TE from (a)(i) and (iii) **(+)602.8 (J mol^{-1} K^{-1}) if value for $6H_2O(g)$ was used in (a) (i)** **-459.5 (J mol^{-1} K^{-1}) if value for one H_2O was used in (a) (i)**	Answers where values in J are added to kJ	**1**

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

Question Number	Acceptable Answers	Reject	Mark
2 (b)(i)	**First mark** Thermometer **(1)** **Second mark** (dependent on first) depends on choosing thermometer 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)** *IGNORE* any references to 'accurate thermometer'		**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: Mg^{2+} = 0.072, Ca^{2+} = 0.100 / Sr^{2+} = 0.113 (nm) data may be shown beside the table **(1)** Radius 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)** *ALLOW* "weaker ionic bonds" 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**	**First mark** Reference to enthalpy of hydration (may be in equation $\Delta H_{solution}$ = -LE + $\Delta H_{hydration}$) **(1)** **Second mark** Solubility depends on relative size of lattice energy and enthalpy of hydration **(1)** **Third mark** **EITHER** Solubility more likely if $\Delta H_{solution}$ is negative **OR** (If $\Delta H_{solution}$ is positive,) may / will dissolve if ΔS_{total} is positive *ACCEPT* solvation instead of hydration		**3**

Question Number	Acceptable Answers	Reject	Mark
2 (d) **QWC**	**First mark** **Third** ionization energy **high(er)** for Mg / Mg = 7733 kJ mol^{-1}, (third ionization energy for Co = 3232 kJ mol^{-1}) **(1)** **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)** **OR** Not compensated by higher lattice energy for Mg^{3+} (and so $\Delta H_{formation}$ of $MgCl_3$ would be highly endothermic) **(1)**		**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)	**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) ($\Delta S^{\ominus}_{system}$ =)[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)** Allow **+** 0.546 **kJ** mol^{-1} K^{-1} 2nd mark is CQ on entropy values used for example EITHER Omission of factor of x3 for some or all substances in the equation OR The use of one incorrect entropy value(s) from the data book OR One missing value Note If two or more of the above three errors are made together, (0) awarded. **IGNORE** sf except 1 sf	**Incorrect** units (no 2nd mark)	**2**

Question Number	Acceptable Answers	Reject	Mark
3(b)(ii)	**First mark** Gas formed (from solid) OR Liquid formed (from solid) OR Gas and liquid formed (from solid) **(1)** **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)** IGNORE 'entropy increases' **NOTE:** Both points may be made in the same sentence	**Just** 'more product' / 'more particles formed' 2 substances going to 3 substances	**2**

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

Question Number	Acceptable Answers	Reject	Mark
3(b)(iv)	($\Delta S^{\ominus}_{total} = \Delta S^{\ominus}_{system} + \Delta S^{\ominus}_{surroundings}$) = (+546) + (−235) = (+)311 (J mol^{-1} K^{-1}) OR = (+)0.311 **kJ mol^{-1} 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) $\Delta S_{surroundings}$ 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)	$\Delta S_{surr} = -\Delta H/T$ **(1)** $= -71900/700$ $= -102.7$ **J** K^{-1} mol^{-1}/$-$ 0.1027 **kJ** K^{-1} mol^{-1} **(1)** Correct answer and sign with no working scores (2) — 0.103 **J** K^{-1} mol^{-1} scores (1) **Third mark** So ΔS_{total} is positive (so reaction is feasible) **(1)** OR ΔS_{total} = **+**40.3 J K^{-1} 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)	$\Delta S_{total} = 0$ OR $\Delta S_{surroundings} = —143$ **(1)** $T = \Delta H \div \Delta S_{surroundings}$ OR T = (—) 71900 ÷ (—)143 **(1)** = 502.8 (K) **(1)** IGNORE sf except 1sf Correct answer with no working scores (3) ALLOW 0.5028 (K) for (2) marks ALLOW — 502.8 (K) for (2) marks ALLOW — 0.5028 (K) for (1) mark ALLOW TE from (a)(ii) If the calculation is not based on $\Delta S_{total} = 0$ then a maximum of (2) marks can be awarded if done correctly		**3**

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