Question			Answer	Marks	Guidance
1	(a)	(i)	5 mol/molecules (of gas) forms 3 mol/molecules (of gas) ✓	1	**ALLOW** reaction forms fewer moles/molecules **IF** stated, numbers of molecules **MUST** be correct **IGNORE** comments related to ΔG **OR** disorder (even if wrong)
	(a)	(ii)	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer =(+)131 (J K^{-1} mol^{-1}) , award 2 marks** --- $-164 = (186 + 2 \times 206) - (4 \times S + 238)$ **OR** $4\,S = 164 + (186 + 2 \times 206) - 238$ ✓ $S = (+)131$ (J K^{-1} mol^{-1}) ✓	2	**NOTE:** IF any values are omitted, **DO NOT AWARD** any marks. e.g. −164 may be missing **ALLOW FOR 1 mark** −131 wrong final sign 49 wrong sign for 164 79.5 no use of 2 524 no division by 4 38 wrong sign for 186 −75 wrong sign for 206 250 wrong sign for 238 Any other number: **CHECK** for **ECF** from 1st marking point for expressions using **ALL** values with **ONE** error only e.g. one transcription error:, e.g.146 for 164

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Question			Answer	Marks	Guidance
(a)	(iii)		**NOTE: DO NOT ALLOW answer to 3(a)(ii) for $\triangle G$ calculation** --- **$\triangle G$ calculation: 2 marks** $\triangle G = -234 - 298 \times -0.164$ ✓ $= -185$ (kJ mol^{-1}) ✓ **IGNORE** units (even if wrong) -185 subsumes 1st mark)	2	**ALLOW** $\triangle G$ correctly calculated from 3 SF up to calculator value of -185.128 **ALLOW** working in J, *ie*: $\triangle G = -234000 - 298 \times -164$ ✓ $= -185000$ (J mol^{-1}) ✓ **ALLOW** 1 mark for use of 25 **OR** mixture of kJ and J, e.g. $\triangle G = -234 - 25 \times -0.164 = -229.9$ $\triangle G = -234 - 298 \times -164 = +48638$
			Feasibility comment for negative $\triangle G$ answer: 1 mark (Forward) reaction is feasible / spontaneous **AND** $\triangle G < 0$ / $\Delta H - T\Delta S < 0$ ✓	1	**ALLOW ECF** if calculated value for $\triangle G$ is +ve Then 'correct' response for 3rd mark would be **not** feasible/not spontaneous **AND** $\triangle G > 0$ / $\Delta H - T\Delta S > 0$
(a)	(iv)		$(\triangle G =) -234 - 1427 \times \dfrac{-164}{1000} = 0$ (calculator 0.028(kJ) OR 28 (J)) ✓ **2nd mark only available if 1st mark has been awarded** (Above 1427K/1154ºC), reaction is **not** feasible/**not** spontaneous ✓ **OR** 1427 K is maximum temperature that reaction happens	2	**ALLOW** (When $\triangle G = 0$) $T = \dfrac{-234}{-0.164} = 1427$ K **OR** $\dfrac{-234000}{-164} = 1427$ K For 2nd mark, **IF** $\triangle G$ is +ve from **(a)(iii)** **ALLOW ECF** for: Above 1427 K, reaction is feasible / spontaneous **OR** 1427 K is minimum temperature that reaction happens **IGNORE LESS feasible** **IGNORE** comparisons of the signs of $T\Delta S$ and ΔH, e.g *IGNORE $T\Delta S$ is more negative than ΔH*

Question			Answer	Marks	Guidance
(b)	(i)		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 57.6 $dm^3\ mol^{-1}$, award **6 marks** **IF** answer = 57.6 with incorrect units, award **5 mark** --- **Equilibrium amounts in mol 2 MARKS** $n(SO_2)$ = 0.180 (mol) **ALL 3** correct: ✓✓ $n(O_2)$ = 0.090 (mol) **ANY 2** correct: ✓ $n(SO_3)$ = 0.820 (mol) **Equilibrium concentrations (moles $\times$ 4) 1 MARK** SO_2 = 0.720 $(mol\ dm^{-3})$ **AND** O_2 = 0.360 $(mol\ dm^{-3})$ **AND** SO_3 = 3.28 $(mol\ dm^{-3})$ ✓ **Calculation of K_c and units 3 MARKS** $K_c = \dfrac{[SO_3]^2}{[SO_2]^2\ [O_2]}$ **OR** $\dfrac{3.28^2}{(0.720)^2 \times (0.360)}$ ✓ = 57.6 ✓ $dm^3\ mol^{-1}$ ✓ *At least 3SF is required*	**6**	**FULL ANNOTATIONS NEEDED** **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below --- **ALLOW ECF** from incorrect moles of SO_2, O_2 **AND** SO_2 **ALL three** concentrations required for this mark **ALLOW ECF** from incorrect concentrations **NO ECF** for numerical value with a square missing For K_c, **ALLOW** 3 significant figures up to calculator value of 57.64746228 correctly rounded For units, **ALLOW** $mol^{-1}\ dm^3$ **DO NOT ALLOW** dm^3/mol **ALLOW ECF** from incorrect K_c expression for both calculation and units **COMMON ERRORS** 0.0294 ***3 marks + units mark*** from SO_2 = 0.820, O_2 = 0.410, SO_3 = 0.180 (mol)
(b)	(ii)		(Pressure) decreases **AND** fewer molecules/moles ✓	**1**	For fewer moles, **ALLOW** 3 mol $\rightarrow$ 2 mol **ALLOW** more moles **of reactants**

Question			Answer	Marks	Guidance
(b)	(iii)		ΔH is negative / '– ' / –ve **AND** yield of SO_3 decreases ✓	1	**IGNORE** exothermic and endothermic
(b)	(iv)		**IGNORE** le Chatelier responses --- ***Each marking point is independent*** ***K_c*** K_c does not change (with pressure/ concentration) ✓ ***Comparison of conc terms with more O_2*** $[O_2]$/concentration of oxygen is greater **OR** denominator/bottom of K_c expression is greater ✓ ***QWC: yield of SO_3 linked to K_c*** (Yield of) SO_3 is greater/increases **AND** numerator/top of K_c expression is greater/increases ✓	3	**FULL ANNOTATIONS NEEDED** **ALLOW** K_c **only** changes with temperature **IF** 1st marking point has been awarded, **IGNORE** comments about 'K_c decreasing' or 'K_c increasing' and assume that this refers to how the ratio subsequently changes. i.e **DO NOT CON** 1st marking point. **IGNORE** O_2 is greater/increases **ALLOW** **(Yield of) SO_3 is greater/increases** **AND** to reach/restore K_c value ✓
			Total	19	

	Question		Answer	Marks	Guidance
2	**(a)**	**(i)**	(entropy) decreases **AND** (solid/ice has) less disorder/ more order/ fewer ways of arranging energy/ less freedom/ less random molecules ✓	**1**	**ORA** **decreases and reason required for mark** **ASSUME change is for freezing of water unless otherwise stated** **DO NOT ALLOW** atoms are more ordered
	(a)	**(ii)**	(entropy) increases **AND** (CO_2) **gas** is **formed** ✓ *Could be from equation with $CO_2(g)$*	**1**	**increases and reason required for mark** **ASSUME** gas is CO_2 unless otherwise stated **BUT DO NOT ALLOW** an incorrect gas (e.g. H_2) **ALLOW** more gas
	(a)	**(iii)**	entropy decreases **AND** 3 mol O_2 form 2 mol O_3 **OR** $3O_2 \rightarrow 2O_3$ **OR** 3 mol gas form 2 mol gas ✓	**1**	**decreases and reason required for mark** For mol, **ALLOW** molecules **ALLOW** multiples, e.g. $1\frac{1}{2}O_2 \rightarrow O_3$; $O_2 + \frac{1}{2}O_2 \rightarrow O_3$ **ALLOW** $O_2 + O \rightarrow O_3$ **Note: DO NOT ALLOW** 2 mol gas forms 1 mol gas unless linked to $O_2 + O \rightarrow O_3$ **IGNORE** reaction forms fewer moles/molecules

| 2 | (b) | | CARE: responses involve changes of negative values
----
Feasibility AND ΔG
  Reaction becomes/is less feasible/not feasible
  AND
  ΔG increases
  OR ΔG becomes/is less negative/more positive
  OR $\Delta G > 0$ **OR** $\Delta H - T\Delta S > 0$
  OR $\Delta H - T\Delta S$ becomes/is less negative/more positive
  OR $\Delta H > T\Delta S$ ✓
  OR $T\Delta S$ becomes/is more negative than ΔH ✓

Effect on $T\Delta S$
  $T\Delta S$ becomes more negative **OR** $T\Delta S$ decreases
  OR $-T\Delta S$ becomes more positive **OR** $-T\Delta S$ increases
  OR magnitude of $T\Delta S$ increases
  OR $\lvert T\Delta S \rvert$ increases ✓
--- | 2 | *FULL ANNOTATIONS MUST BE USED*

As alternative for 'less feasible'
ALLOW 'less spontaneous'
OR a comment that implies 'reaction no longer take place'

ALLOW for ΔG increases
$\Delta G < 0$ **only** at low T

DO NOT ALLOW $T\Delta S > \Delta H$ (*comparison wrong way round*)

NOTE: Last statement automatically scores 2nd mark ALSO

IGNORE significance
IGNORE magnitude for 1st marking point

DO NOT ALLOW $T\Delta S$ increases
IGNORE significance

APPROACH BASED ON TOTAL ENTROPY:
Feasibility with increasing temperature
  Reaction becomes less feasible/not feasible
  AND
  $\Delta S - \Delta H/T$ **OR** ΔS_{total} decreases/ less positive ✓
Effect on $\Delta H/T$
  $\Delta H/T$ is less negative **OR** $\Delta H/T$ increases
  OR $-\Delta H/T$ decreases
OR magnitude of $\Delta H/T$ decreases ✓ |

2	(c)	(i)	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 75.962 **OR** 75.96 **OR** 76.0 **OR** 76, award **2 marks** --- $\Delta S = (33 + 3 \times 189) - (76 + 3 \times 131)$ $= (+)131 \ (J \ K^{-1} \ mol^{-1})$ ✓ $\Delta G = 115 - (298 \times 0.131)$ $= (+) \ 75.962$ **OR** 75.96 **OR** 76.0 **OR** 76 (kJ K^{-1} mol^{-1}) ✓	 2	 **DO NOT ALLOW** −131 **ALLOW ECF** from incorrect calculated value of ΔS
2	(c)	(ii)	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 878 **OR** 877.9 **OR** 877.86, award **2 marks** --- (Minimum temperature when) $\Delta G = 0$ **OR** $\Delta H - T\Delta S = 0$ **OR** (For feasibility) $\Delta G = 0$ **OR** $\Delta G < 0$ **OR** $\Delta H - T\Delta S < 0$ **OR** $T = \dfrac{\Delta H}{\Delta S}$ ✓ $T = \dfrac{115}{0.131} = 878 \ K$ ✓	 2	**ALLOW** total entropy statement: ΔS(total) = 0 **OR** ΔS(total) >0 **ALLOW ECF** from incorrect calculated value of ΔS from **2(c)(i)** **ALLOW** 878 up to calculator value of 877.862595 correctly rounded
			Total	9	

Question			er	Marks	Guidance
3	**(a)**	**(i)**	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 218, award **2 marks** -- $-256 = (6 \times 205) + S(C_6H_{12}O_6) - (6 \times 214 + 6 \times 70)$ **OR** $S(C_6H_{12}O_6) = -256 - (6 \times 205) + (6 \times 214 + 6 \times 70)$ **OR** $-256 + 474$ ✓ $= 218$ (J K^{-1} mol^{-1}) ✓	2	**IF** there is an alternative answer, check to see if there is any **ECF** credit possible. Note that **ALL** 4 S values must be used for **ECF** --- **ALLOW** 1 mark for -218 **ALLOW** 1 mark for $+730$ (*products – reactants*) **Note:** -3190 for simple addition of products + reactants scores zero marks

		(ii)	$\Delta G = +2879 - 298 \times -0.256$ ✓
			$= (+)2955$ (kJ mol^{-1}) ✓
				2	**ALLOW** 3 SF: 2960 to calculator value of 2955.288
					
					Award 1 mark for the following:
					• $\Delta G = 2890$ to calculator value of 2885.4
					   25 ºC used rather than 298 K:
					• $\Delta G = 79200$ to calculator value of 79167
					   ΔS *not converted from J K^{-1} mol^{-1} to kJ K^{-1}mol^{-1}*
					• expressions with **one** transcription error:
					   e.g. +2897 instead of +2879; 0.265 instead of 0.256
					• $\Delta G = 2814.036$
					   use of 218 rather than -256
					• Use of 'answer to **(a)(i)**'/1000 (by **ECF**)

		(iii)	ΔH is positive **OR** $\Delta H > 0$ **AND** ΔS is negative **OR** $T\Delta S$ is negative **OR** $\Delta S < 0$ **OR** $T\Delta S < 0$ **AND** ΔG will always be positive **OR** $\Delta G > 0$ ✓	1	**ALLOW** ΔH is endothermic for ΔH is +ve **ALLOW** ΔG will never be less than 0 **DO NOT ALLOW** S or H i.e. **change** in entropy, ΔS and change in enthalpy ΔH are essential

Question			er	Marks	Guidance
	(b)		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 3.12 x 10^{17} g, award **2 marks** --- amount of CO_2 removed = $3.4 \times 10^{18} \times 6 / 2879$ **OR** 7.09×10^{15} (mol) ✓ mass of CO_2 = $44.0 \times 7.09 \times 10^{15}$ = 3.12×10^{17} g ✓	2	**ALLOW** 2 SF (7.1×10^{15} (mol)) up to calculator value of 7.085793678, correctly rounded **ALLOW** 2 SF (3.1×10^{17} g) up to calculator value, correctly rounded **Correct units required for 2nd mark** e.g. 3.12×10^{14} kg; 3.12×10^{11} tonne **ALLOW** 1 mark for 3.1×10^{17} with no unit **ALLOW** ECF from incorrectly calculated amount of CO_2 provided that both 3.4 x 10^{18} **AND** 2879 have been used e.g. Omission of x 6 gives 1.181 x 10^{15} mol CO_2 and 5.196 x 10^{16} g CO_2
			Total	**7**	

Question			Answer	Marks	Guidance

4	**(a)**	**(i)**	*initial rates data:*
			    From Experiment 1 to **Experiment 2**
			    AND
			    $[NO_2]$ x 1.5, rate x 1.5 ✓
			
			    1st order with respect to NO_2 ✓
			
			    From Experiment 2 to **Experiment 3**
			    AND
			    $[O_3]$ is doubled, rate x 2 ✓
			
			    1st order with respect to O_3 ✓
			
			rate equation and rate constant:
			    rate = $k[NO_2]$ $[O_3]$ ✓
			
			    $k = \dfrac{rate}{[NO_2][O_3]}$ **OR** $\dfrac{4.80 \times 10^{-8}}{0.00150 \times 0.00250}$ ✓
			
			    = 0.0128 ✓ dm^3 mol^{-1} s^{-1} ✓
				8	***ANNOTATIONS MUST BE USED***
					Quality of Written Communication:
					--- 	
					Changes **MUST** be linked to Experiment numbers **in writing** (*Could be described unambiguously*)
					IGNORE annotations in the table
					--- 	
					For 2nd condition, **ALLOW** 'when $[NO_2]$ increases by half, rate increases by half
					
					NOTE: Orders may be identified within a rate equation
					
					ALLOW: working from any of the Experiments
					: All give the same calculated answer
					0.0128 subsumes previous rearrangement mark
					
					ALLOW: mol^{-1} dm^3 s^{-1} ✓
					DO NOT ALLOW 0.013 *over-rounding*
					--- 	
					ALLOW ECF from inverted k expression: $k = \dfrac{[NO_2][O_3]}{rate}$:
					k = 78.125 ✓
					ALLOW 3 SF or more
					NOTE units must be from rate equation ✓

	Question		Answer	Marks	Guidance
4	(a)	(ii)	**step 1**: $NO_2 + O_3$ LHS of step one ✓ $\longrightarrow NO_3 + O_2$ **step 2**: $NO_2 + NO_3 \longrightarrow N_2O_5$ rest of equations for step 1 **AND** step 2 ✓ **CHECK** that each equation is balanced **CARE:** **Step 1 AND Step 2** must add up to give overall equation In **Step 2**, **IGNORE** extra species shown on both sides, e.g. $NO_2 + NO_3 + O_2 \longrightarrow N_2O_5 + O_2$ **Step 2** can only gain a mark when **Step 1** is correct	2	State symbols **NOT** required For 'rest of equations', **ALLOW** other combinations that together give the overall equation, *e.g.:* $\longrightarrow NO_5$ $NO_2 + NO_5 \longrightarrow N_2O_5 + O_2$ *e.g.:* $\longrightarrow NO + 2O_2$ $NO + NO_2 + O_2 \longrightarrow N_2O_5$ **DO NOT ALLOW** use of algebraic species, e.g. X
	(b)	(i)	3 **gaseous** moles $\longrightarrow$ 2 **gaseous** moles ✓ Less randomness **OR** becomes more ordered ✓	2	**ALLOW** products have fewer **gaseous** moles **ORA** **ALLOW** 'molecules' instead of 'moles' **ALLOW** fewer ways of distributing energy **OR** fewer degrees of freedom **OR** fewer ways to arrange
		(ii)	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = −148 award **3 marks** --- $\Delta G = \Delta H - T\Delta S$ ✓ = −198 − (298 x −168/1000) ✓ = −148 (kJ mol^{-1}) ✓	3	**IF** there is an alternative answer, check calculator value and working for intermediate marks by **ECF** --- 2nd mark subsumes 1st mark for $\Delta G = \Delta H - T\Delta S$ **ALLOW** −148 to calculator value of −147.936 **ALLOW for 2 marks:** 49866 (kJ mol^{-1}): *not converting ΔS from J to kJ (no ÷ 1000)* −193.8 (kJ mol^{-1}) *use of 25 instead of 298*

	Question		Answer	Marks	Guidance

4	(b)	(iii)	**CARE: responses involve changes of negative values**
			
			-- 	
			
			Feasibility with increasing temperature
			    Reaction becomes less feasible/not feasible
			    AND
			    ΔG increases **OR** ΔG becomes less negative
			    OR $\Delta G = 0$ **OR** $\Delta G > 0$ **OR** ΔG is positive
			    OR ΔG approaches zero ✓
			
			***IF** a candidate makes a correct statement about the link between ΔG and feasibility, **IGNORE** an incorrect ΔH and $T\Delta S$ relationship
			IF there is no ΔG statement, then mark any ΔH and $T\Delta S$ relationship in line with the mark scheme
			---------------------- 	
			Effect on $T\Delta S$
			    $T\Delta S$ becomes more negative **OR** $T\Delta S$ decreases
			    OR $-T\Delta S$ increases
			    OR magnitude of $T\Delta S$ increases ✓
			
			-- 	
				2	***ANNOTATIONS MUST BE USED***
					
					-- 	
					As alternative for 'not feasible'
					ALLOW 'not spontaneous'
					OR a comment that implies 'reaction does not take place'
					
					ALLOW for ΔG increases
					    $\Delta H = T\Delta S$ **OR** $\Delta H > T\Delta S$ **OR** $\Delta H - T\Delta S$ is positive
					    OR $T\Delta S$ becomes more significant than ΔH
					    OR $T\Delta S$ becomes the same as ΔH
					    OR $T\Delta S$ becomes more negative than ΔH
					NOTE Last statement will also score 2nd mark
					
					------------------- 	
					
					DO NOT ALLOW $T\Delta S$ increases
					
					-- 	
					APPROACH BASED ON TOTAL ENTROPY:
					Feasibility with increasing temperature
					    Reaction becomes less feasible/not feasible
					        AND
					    $\Delta S - \Delta H/T$ **OR** ΔS_{total} decreases/ less positive
					    OR ΔS outweighs/ is less significant than $\Delta H/T$ ✓
					Effect on $\Delta H/T$
					    $\Delta H/T$ is less negative **OR** $\Delta H/T$ increases
					    OR $-\Delta H/T$ decreases
					    OR magnitude of $\Delta H/T$ decreases ✓

			Total	17	