Mark scheme – Enthalpy and Entropy

Question	Answer/Indicative content	Marks	Guidance
1	**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer =** 25.55 kJ mol^{-1} **OR** 25550 J mol^{-1} **award first 4 marks** ---------- ΔS = 238 – (198 **+** 2 × 131) ✓ = –222 (J K^{-1} mol^{-1}) **OR** –0.222 (kJ K^{-1} mol^{-1}) ✓ $\Delta G = \Delta H - T\Delta S$ **OR** ΔG = –91 – (525 × –0.222) **OR** ΔG = –91000 – (525 × –222) ✓ = 25.55 kJ mol^{-1} **OR** 25550 J mol^{-1} ✓ (Reaction is) not feasible **AND** $\Delta G > 0$ ✓	5 (AO 2.2×4) (AO 3.2×1)	**ALLOW ECF** **IGNORE** units at this stage Units for ΔG required **ALLOW** 26 kJ mol^{-1} **OR** 26000 J mol^{-1} up to calculator value.
	Total	**5**	
2	**FIRST CHECK THE ANSWER IN ON ANSWER LINE** **If answer = (+)156 (J K^{-1} mol^{-1}) award 4 marks** ---------- Part 1: Calc of $\Delta_r S$ **Use of 298 K** (seen anywhere) **1 mark** ✓ • e.g. –16.1 = –55.8 – 298 × ΔS _____ **CORRECT** use of Gibbs' equation **1 mark** • using candidate's temperature (e.g. 298) • with –16.1 **AND** –55.8 • to calculate ΔS in *kJ* ***OR*** *J* ✓	4 AO2.4×4	Using 298 K, $\Delta S = \frac{-55.8 - (-16.1)}{298} = \frac{-39.7}{298}$ = –0.133…(kJ K^{-1}mol^{-1}) **OR** –133… (J K^{-1}mol^{-1}) ***Sign required IGNORE*** *units* Calculator: –0.133221 (kJ K^{-1} mol^{-1}) –133.221 (J K^{-1} mol^{-1}) **ALLOW ECF** from incorrect temperature. _____ Using –133: $S(Na_2S_2O_3)$ = 372.4– 349.5 – (–133) = 22.9 + 133 = (+)156 (J K^{-1} mol^{-1}) **3 SF** required

			--- **Part 2: Calc of *S*($Na_2S_2O_3$)** **1 mark** **CORRECT** use of standard S data in question ✓ Seen anywhere (could be within an expression) e.g. • 372.4 – [S(Na2S2O3) + (5 × 69.9)] • OR 372.4 – (5 × 69.9) • OR 372.4 – 349.5 • OR 22.9 **IGNORE** sign, i.e. **ALLOW** –22.9, etc **CORRECT** calculation of S($Na_2S_2O_3$) using candidate's calculated Δ*S* in Part 1 **to 3 SF** **1 mark** ✓		**ALLOW ECF** from incorrect $\Delta_r S$ (Part 1) **<u>Examiner's Comments</u>** This was a testing question. This question discriminated very well but lower ability candidates struggled to score marks. This unfamiliar scenario required candidates to first decide on a strategy for solving the problem. Candidates needed to use the Gibbs' equation and supplied data to determine the entropy change. They then needed to combine this value with other supplied data to determine the unknown standard entropy. The data provided were all standard, signified by the standard sign. Candidates were expected to use 298 K as the standard temperature to first determine the entropy change. Although many candidates chose 298 K, many different temperatures were seen, with 273 K and 286.5 K (the temperature change in 5a(i)) being common. Some candidates were obviously thrown by the absence of a stated temperature and many omitted T from their Gibbs' equation, using Δ*G* = Δ*H* – Δ*S* instead. This calculated value for Δ*S* (correct: –0.133 kJ) then needed to be combined with the supplied entropy data to determine the unknown standard entropy (correct: 156 J) to three significant figures. ECF could be applied during marking but this second calculation first required a unit conversion from kJ to J. Many candidates did not make this conversion. Some candidates made errors combining this information, e.g. incorrect signs, adding rather than subtracting and no unit conversions. Finally, some candidates, successful in their calculation, did not follow the instruction to quote their answer to three significant figures. Exemplar 5 shows a very clear response. The candidate has used the Gibbs' equation to determine ΔS first in kJ and then, in preparation for the second part of the determination, in J. The ΔS value is combined with the supplied entropy data to obtain the unknown entropy change, shown by 'x' in the response. This calculated value is then rounded to the required three significant figures. **Exemplar 5**

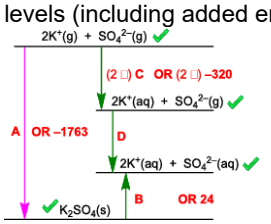
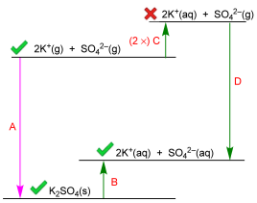
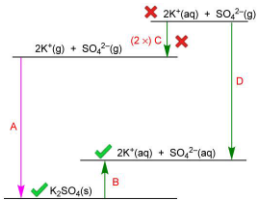
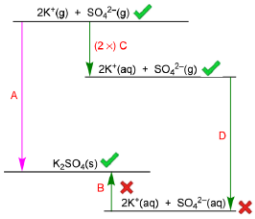
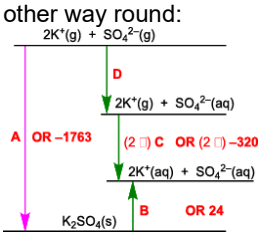
					$\Delta G = \Delta H - T\Delta S$ $-16.1 = -55.8 - 298\Delta S$ $298\Delta S = -39.7$ $\Delta S = -0.133221476\,5\ kJK^{-1}mol^{-1}$ $= -133.2214765\ JK^{-1}mol^{-1}$ $372.4 - (5 \times 69.9) - x = -133.2214765$ $x = 156.1214765$ $= 156$ $S^{\ominus}$ = ...156..... $JK^{-1}mol^{-1}$ [4]
			Total	**4**	
3		i	*Equation* $Ba(NO_3)_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaNO_3(aq)$ ✓ *Entropy change **and** explanation* entropy decreases **OR** entropy change negative **AND** ($BaSO_4$) solid / ppt has less disorder / more order / fewer ways of arranging energy / less freedom / less random particles / dispersal of energy ✓	2	**ALLOW** multiples M2 is dependent on $BaSO_4(s)$ (even if formula is incorrect – eg $Ba(SO_4)_2(s)$) seen as a product in the attempted equation as long as reactants are not solid. $BaSO_4$ solid / ppt may be assumed from $BaSO_4(s)$ seen in the attempted equation. **Examiner's Comments** Candidates who correctly identified barium sulfate as a solid product tended to realise that entropy had decreased, although a significant number failed to state that this decrease in entropy was as a result of less disorder being created.
		ii	*Equation* $\frac{1}{2} I_2(s) \rightarrow I(g)$ ✓ *state symbols required* *Entropy change **and** explanation* entropy increases **OR** entropy change positive **AND** gas has more disorder / less order / more ways of arranging energy / more freedom / more random particles / more dispersal of energy ✓	2	**DO NOT ALLOW** $I_2(s) \rightarrow 2I(g)$ **DEPENDENT** on $\frac{1}{2}I_2(s) \rightarrow I(g)$ **OR** $I_2(s) \rightarrow 2I(g)$ **Examiner's Comments** Most candidates failed to produce a correct equation for the standard enthalpy change of atomisation of iodine. Of those who were able to produce the correct equation, a significant number failed to state that the increase in entropy was as a result of increased disorder being created.
			Total	**4**	

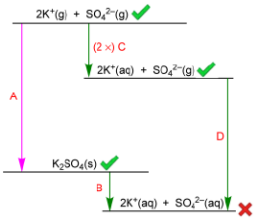
4	a		**$\Delta G = \Delta H - T\Delta S$** linked to $y = mx + c$ (somewhere) ✓ **gradient** = $-\Delta S$ ✓ **P:** ΔH / enthalpy change ✓ **Q:** (temperature) for reaction to be feasible/unfeasible **OR** (temperature) at which feasibility changes ✓	4	Could be: $\Delta G = -\Delta ST + \Delta H$ − sign required ALLOW $\Delta S = -gradient$ **ALLOW** 'point of feasibility' For Feasibility: **ALLOW** can take place/happen **OR** is spontaneous **IGNORE** 'minimum/maximum temperature' **Examiner's Comments** For the minority of candidates who recognised that the Gibbs' equation could be expressed in y = mx + c format, this question was very straightforward. For others, the realisation that Q was the point at which feasibility changed was the only mark scored.
	b	i	(Species have) different states / phases ✓	1	**Examiner's Comments** All but a few candidates realised that the term heterogeneous equilibrium could be applied because carbon monoxide was in a different physical state to the other reactants and products.
		ii	(K_p =) $p(CO(g))^4$ ✓	1	Allow species without state symbols and without brackets, e.g. Pco^4, $ppCO^4$, PCO^4, $p(CO^4)$ etc. **DO NOT ALLOW** square brackets **Examiner's Comments** Marks were awarded for less than perfect versions of $K_p = p(CO(g))^4$. As long as a 'p' or a 'P' was seen and curved, rather than square, brackets, along with the correct power, the mark was awarded. This was to differentiate between the candidates who knew that only the partial pressures of gaseous species should feature in a K_p expression from the candidates who used all four species to write the expression.
		iii	ΔG at 25 C $\Delta G = \Delta H - T\Delta S = 676.4 - (298 \times 0.7031)$ = (+) 467 (kJ mol^{-1}) **OR** (+) 466876 (J mol^{-1}) ✓	3	**IGNORE** units **ALLOW** (+) 467 up to calculator value of

			Non-feasibility statement Non-feasible when $\Delta G > 0$ **OR** $\Delta G > 0$ **OR** $\Delta H > T\Delta S$ ✓ *Minimum temperature* minimum temperature = $\frac{\Delta H}{\Delta S} = \frac{676.4}{0.7031}$ = 962(.0) K ✓		466.8762 correctly rounded ECF for any positive value determined in M1 **ALLOW** 962 up to calculator value of 962.0253165 correctly rounded **Examiner's Comments** Candidates coped well with the calculation and, apart from a significant number of rounding errors, could provide a positive value of ΔG and therefore could show the reaction to not be feasible. Candidates were also able to calculate that the minimum temperature required for the reaction to be feasible was 962.023165 K which was sensibly rounded to 962 K. A significant number of candidates chose to give 963 K as the final answer despite showing a correct value to several decimal places in their working.
		iv	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer = −110.5, Award 3 marks.** …… **Correct expression** $-13.5 = (4 \times -393.5) - (-1118.5 + 4 \times \Delta_f H(CO))$ ✓ **Correct subtraction using ΔH and $\Delta_f H(Fe_3O_4)$** $4 \times \Delta_f H(CO) = (4 \times -393.5) - (-1118.5) + 13.5$ = **−442(.0)** (kJ mol^{-1}) ✓ **Calculation of $\Delta_f H(CO)$ formation** $\Delta_f H(CO) = -\frac{442}{4}$ = **−110.5** (kJ mol^{-1}) ✓	3	**For answer,** **ALLOW −111 (kJ mol^{-1})** …… **NOTE:** IF any values are omitted, **DO NOT AWARD** any marks. e.g. **−**393.5 OR **−**13.5 may be missing …… **Common errors** **(+)110.5** — *wrong / omitted sign* — **2 marks** **(+)184.625 / 184.63 / 184.6 / 185** — *No $4CO_2$* — **2 marks** **(+)738.5 / 739** — *No $4CO_2$ and no CO/4* — **1 mark** **−117.25 / −117.3 / −117** — *Wrong cycle* — **2 marks** **−469** — *Wrong cycle, no CO/4* — **1 mark**

					(+)177.875 / 177.88 / 177.9 / 178 — *Wrong cycle, no 4CO2* — **1 mark** **−360.5** — *Used 118.5* — **2 marks** 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.395.3 for 393.5 **Examiner's Comments** The general method of determining $\Delta_f H$(CO) was known to most candidates, but many examples of avoidable errors were seen. For example, transcription errors in recording $\Delta_f H$ values (−393 for −393.5 and −118.5 for −1118.5). Candidates should be advised to show every step in their calculation. This would allow method marks to be applied in the absence of a correct final answer.
			Total	**12**	
5	a	i	$2H_2S(g) + O_2(g) \longrightarrow 2S(s) + 2H_2O(g)$ ✓	1	**ALLOW** multiples, e.g. $6H_2S(g) + 3O_2(g) \longrightarrow 6S(s) + 6H_2O(g)$
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer =** 3.05×10^7 (g) award 3 marks …… volume of H_2S $= 1.50 \times 10^8 \times 16(0)/100 = 2.4(0) \times 10^7$ dm^3 of H_2S ✓ n (H_2S) (= n(S)) $2.4(0) \times 10^7/24.0$ mol $= 1(.00) \times 10^6$ mol ✓ Mass S $= 1(.00) \times 10^6 \times 95(.0)/100 \times 32.1$ $= 3.05 \times 10^7$ (g) ✓	3	**ALLOW ECF** from incorrect volume of H_2S **3 SF AND standard form** required
	b	i	**FIRST, CHECK FOR A VALUE OF ΔG.** **IF** answer = − 89.96(34) (kJ mol^{-1}) award **3 marks** …… **ΔS calculation (2 marks)** $\Delta S = (3 \times 31.8) + (2 \times 188.7) - [(2 \times 205.7) + (248.1)]$ **OR** $\Delta S = 472.8 - 659.5$ ✓ $\Delta S = -186.7$ J mol^{-1} K^{-1} **OR** −0.1867 kJ mol^{-1} K^{-1} ✓	5	

			Δ*G* calculation (1 mark) $\Delta G = \Delta H - T\Delta S = -145.6 - (298 \times -0.1867)$ $= -89.96(34)$ (kJ mol^{-1}) ✓ **Comment (1 mark)**− sign shows the (forward) reaction is feasible ✓ **Temperature at which feasibility changes (1 mark)** $T = \frac{\Delta H}{\Delta S} = \frac{-145.6}{-0.1867} = 780$ k **AND** comment that Δ*G* **OR** $\Delta H - T\Delta S = 0$ ✓		**ALLOW** (−) 187 OR 0.187 **ALLOW ECF** from incorrect Δ*H* **ALLOW** −90 up to calculator value of −89.9634 correctly rounded **ORA** for comment about − sign required for feasibility
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer** = −296.8 (kJ mol^{-1}) award 2 marks …… **Correct expression**−145.6 = (2 × −241.8) − (2 × −20.6 + Δ_fH(SO2)) ✓ **Calculation of Δ_fH(SO_2) formation** $\Delta_f H(SO_2) = (2 \times -241.8) - (2 \times -20.6) + 145.6$ = **−296.8** (kJ mol^{-1}) ✓	2	**ALLOW ECF** **ALLOW** 1 mark for (+)296.8 *Subtraction the wrong way around*
			Total	**11**	
6	a		(enthalpy change for) 1 mole of gaseous ions **OR** 1 mole of hydrated ions / aqueous ions ✓ gaseous ions forming aqueous / hydrated ions ✓	2	**one mole** can be stated just once **EITHER** with gaseous ions **OR** with aqueous ions, e.g. • 1 mole of gaseous ions **forms** hydrated ions / aqueous ions • Gaseous ions **form 1 mole of** hydrated ions / aqueous ions **ALLOW** 1 mol for 1 mole **IGNORE** 'energy released' **OR** 'energy required' For 2nd mark **IGNORE** gaseous ions are hydrated **IGNORE** gaseous ions dissolve in water ***Particles formed not stated*** **ALLOW** 1 mark for: 1 mole of gaseous **IONS** forms aqueous / hydrated **atoms / particles / molecules** **Examiner's Comments** This question assessed enthalpy changes in

					aqueous solutions. Most candidates were awarded both marks for a clear definition stating that 1 mole of gaseous ions formed 1 mole of aqueous ions. Some candidates instead gave a definition for enthalpy change of solution.
	b	i	**4 marks** for species **AND** state symbols on all 4 energy levels (including added energy level)  **1 mark** for **B**, **C AND D** labels **OR** enthalpy values **AND** arrow directions correct ✓ **ALLOW** $K_2SO_4(aq)$ for $2K^+(aq) + SO_4^{2-}(aq)$ **ALLOW** arrows not touching lines. **Direction** is important: • **FROM** $2K^+(g) + SO_4^{2-}(g)$ line • **FROM** $K_2SO_4(s)$ line Extra energy line placed **ABOVE** top line 3 out of 4 marks awarded for energy lines and species. Top arrow is shown **FROM** $2K^+(g) + SO_4^{2-}(g)$ and arrow directions correct. Letter labels correct so last mark is awarded. **4/5 marks**  Extra energy line placed **BELOW** bottom line 3 out of 4 marks awarded for energy lines and species. Top arrow is shown **FROM** $K_2SO_4(s)$ and arrow directions correct. Letter labels correct so last mark is awarded. **4/5 marks**	5	**IF** extra energy level is **above** top line **OR below** bottom line, **DO NOT ALLOW** mark for species on this line. Same as left-hand response **BUT** top arrow shown **TO** $2K^+(g) + SO_4^{2-}(g)$ so last mark not awarded **3/5 marks**  Same as left-hand response **BUT** bottom arrow shown **TO** $K_2SO_4(s)$ so last mark not awarded **3/5 marks**  **ALLOW C** and **D** with associated labels, the other way round:  State symbols are **essential** **IF** no extra energy level is shown with **C** and **D** combined forming $2K^+(aq) + SO_4^{2-}(aq)$, • No mark for the extra energy level with species

			 '2 ×' is **NOT** required – *part of calculation mark*		• No mark for labels as **C** and **D** are combined Therefore 3 max for species on energy levels provided **Examiner's Comments** This question assessed enthalpy changes in aqueous solutions. Many candidates successfully completed the energy cycle to obtain all marks. Correct species and state symbols are essential in such cycles and marks could not be awarded for species such as $K^-(g)$ or $SO_4^-(g)$. Poorly-prepared candidates often scored no marks at all, having shown random species on the energy levels. Candidates are advised to ensure that the state symbols (s) and (g) are clearly distinguished.
		ii	ΔH(hydration) SO_4^{2-} = **−1099** (kJ mol^{-1}) ✓	1	**ONLY** correct answer **Examiner's Comments** This question assessed enthalpy changes in aqueous solutions. Although many candidates correctly calculated the lattice enthalpy, errors were common. A common error was use of −320 (instead of 2 × −320) giving −1419. Answer = −1099 kJ mol^{-1}
	c	i	**Aqueous** particles are more disordered than **solid** (particles) **OR** **Solid** particles are more ordered than **aqueous** (particles) ✓	1	For particles, **ALLOW** ions **DO NOT ALLOW** molecules / atoms **ALLOW** 'When the state changes from solid to aqueous, disorder increases' For more disordered, **ALLOW** less ordered / more freedom / more ways of arranging energy / more random For aqueous particles, **ALLOW particles in solution** **IGNORE** dissolved **Examiner's Comments** This question assessed enthalpy changes in aqueous solutions.

					In this part, candidates needed to recognise that solid particles are forming aqueous particles with an increase in disorder. Many candidates incorrectly used 'liquid' instead of aqueous and others started from gaseous particles, perhaps confusing enthalpy change of solution with hydration.
		ii	***Calculation (2 marks)*** ΔG = 24 − (298 × 0.225) **OR** 24 − 67.05 *(in kJ)* **OR** 24000 − (298 × 225) **OR** 24000 − 67050 *(in J)* ✓ **Calculation of ΔG (IGNORE UNITS)** ΔG = −43 (kJ mol^{-1}) **OR** −43000 (J mol $^{-1}$) ✓ *Subsumes 1st calculation mark* **Reason for solubility** Calculated value of ΔG that is **negative** **AND** Statement that: ΔG is negative **OR** $\Delta G < 0$ **OR** −43 < 0 **OR** $\Delta H - T\Delta S < 0$ **OR** $T\Delta S > \Delta H$ ✓	3	**Contact TL if solely entropy approach rather than ΔG** **ALLOW** −43.1 OR −43.05 (*calculator value*) **ALLOW 1 calculation mark (IGNORE units) for** −67.(026) **OR** −67026 ***ECF*** *from 225 instead of 0.225* 18.(375) **OR** +18.375 ***ECF*** *from 25* instead of 298 **ALLOW other ECF** from **ONE** error in 1st step of calc, e.g. incorrect value for ΔH such as −1099 from 3bii → −1166.05 **TAKE CARE** that same units used for ΔH and ΔS **NO reason mark from a +ve value of ΔG** **Examiner's Comments** This question assessed enthalpy changes in aqueous solutions. The majority of candidates recognised that the Gibbs' equation was required. Usually the correct enthalpy change of +24 kJ mol^{-1} was used to obtain a negative value for ΔG. The majority then went on to link the negative value to feasibility for the dissolving process. A significant number of candidates used the wrong enthalpy change (or no enthalpy change at all) or mixed units of J and kJ. Answer: ΔG = −43 kJ mol^{-1}
			Total	**12**	
7		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)

					Examiner's Comments This part was usually answered correctly in terms of fewer moles or molecules of gaseous products, with most candidates linking also to decreasing disorder. A significant number just mentioned decreasing disorder without including the reason for the decrease.
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer =(+)131 (J K^{-1} mol^{-1}), award 2 marks** …… −164 = (186 + 2 × 206) − (4 × *S* + 238) **OR** 4 *S* = 164 + (186 + 2 × 206) − 238 ✓		**NOTE**: IF any values are omitted, **DO NOT AWARD** any marks. e.g. −164 may be missing **ALLOW FOR 1 mark**
		ii	*S* = (+)131 (J K^{-1} mol^{-1}) ✓	2	−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 **Examiner's Comments** Although this part required candidates to calculate a standard entropy, rather than the more common entropy change assessed in previous exam papers, most candidates dealt with the problem with ease. Examiners rewarded partial success, usually where there was one incorrect sign or omitting to divide by 4. Answer: S = +131 J K^{-1} mol^{-1}
		iii	**NOTE: DO NOT ALLOW answer to (ii) for Δ*G* calculation** …… **Δ*G* calculation: 2 marks**		**ALLOW** Δ*G* correctly calculated from 3 SF up to calculator value of −185.128

		iii	ΔG = −234 − 298 × −0.164 ✓ = −185 (kJ mol^{-1}) ✓ **IGNORE** units (even if wrong) −185 subsumes 1st mark)	2	**ALLOW** working in J, *ie*: Δ*G* = −234000 − 298 × −164 ✓ = −185000 (J mol^{-1}) ✓ **ALLOW** 1 mark for use of 25 **OR** mixture of kJ and J, e.g. Δ*G* = −234 − 25 × −0.164 = −229.9 Δ*G* = −234 − 298 × −164 = +48638
		iii	**Feasibility comment for negative Δ*G* answer: 1 mark** (Forward) reaction is feasible / spontaneous **AND** Δ*G* < 0 / ΔH − TΔS < 0 ✓	1	**ALLOW ECF** if calculated value for Δ*G* is +ve Then 'correct' response for 3rd mark would be **not** feasible / not spontaneous **AND** Δ*G* > 0 / ΔH − TΔS > 0 **Examiner's Comments** The majority of candidates used the Gibbs equation to obtain the correct value of Δ*G*. Many weak candidates used −164, rather than −0.164, in the expression, resulting in a positive value for Δ*G*. A few used 25 °C instead of 298 K. Candidates are far more adept with this calculation that used to be the case. The comment on feasibility was marked dependent on the sign obtained for Δ*G*. Answer: Δ*G* = −185 kJ mol^{-1}
		iv	(Δ*G* =) $-234 - 1427 \times \frac{-164}{1000}$ = 0 (calculator 0.028(kJ) OR 28 (J) **2nd mark only available if 1st mark has been awarded** (Above 1427K / 1154°C), reaction is **not** feasible / **not** spontaneous ✓ **OR** 1427 K is maximum temperature that reaction happens	2	**ALLOW** (When Δ*G* = 0) $T = \frac{-234}{-0.164}$ = 1427 K **OR** $\frac{-234000}{-164}$ = 1427 K For 2nd mark, **IF** ΔG is +ve from **(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 *TΔS* and *ΔH, e.g IGNORE TΔS is more negative than ΔH* **Examiner's Comments** Although answered well, this part discriminated well. Two strategies were see. The first and more common repeated the Δ*G* calculation from (iii) to show that Δ*G* was just positive (0.028 kJ mol^{-1}) and hence that the reaction was now not feasible. The second strategy showed that

					1427K and therefore 1154°C is the temperature at which Δ*G* has a value of 0 kJ mol^{-1}. Although most candidates were successful here, many weaker candidates seemed unaware of what to do. It was then common to see random numbers being used and °C, instead of K, in the Δ*G* expression (much more common than in (iii). The best candidates also identified that the reaction becomes unfeasible above 1147°C. The explanation was marked consequentially of the sign obtained in (iii).
			Total	**8**	
8	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 **Examiner's Comments** This part was usually answered, the best responses linking the state change from liquid to solid with increased order and a decrease in entropy.
		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 **Examiner's Comments** Candidates were expected to predict an increase in entropy from formation of a gas (CO^2). This was communicated either in text or as an equation with state symbols and both approaches were credited.
		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. $1½O_2 \rightarrow O_3$; $O_2 + ½O_2 \rightarrow O_3$ **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

					Examiner's Comments This part caused more problems as candidates were expected to recognise the different gaseous moles on formation of ozone. Candidates were expected to state the 3:2 ratio from $3O_2(g) \rightarrow 2O_3(g)$ or 2:1 ratio from $O_2 + O \rightarrow O_3(g)$; the best responses did this, either by quoting the molar ratio or from use of the equation. Vaguer responses such as 'efewer moles' were not credited. Strangely, some candidates gave a 'correct' response for the reverse reaction.
	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 ✓ **Examiner's Comments** Comparison of negative numbers is a difficult skill, shown by the many contradictions seen in

					the candidate responses. The key to success here was to compare the two key terms, Δ*H* and *T*Δ*S* and to relate these to feasibility from the sign of Δ*G*. Problems arose in responses that ignored the negative signs leading to ambiguous statements. The required '*T*Δ*S* becomes more negative' was often communicated as '*T*Δ*S* increases'. The latter term is ambiguous, its meaning depending on whether the sign is included or omitted. The comparison of *T*Δ*S* with Δ*H* caused more problems with many responses seen of *T*Δ*S* > Δ*H*. Mathematically, the opposite is true as both values are negative. The better approach was to communicate this relationship in text as '*T*Δ*S* is more negative that Δ*H*.' The responses from the best candidates used this precise language but many candidates did not score marks here because of the ambiguity.
	c	i	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 75.962 **OR** 75.96 **OR** 76.0 **OR** 76, award **2 marks** …… Δ*S* = (33 + 3 × 189) − (76 + 3 × 131) = (+)131 (J K^{-1} mol^{-1}) ✓ Δ*G* = 115 − (298 × 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 Δ*S* **Examiner's Comments** Almost all candidates successfully showed that the entropy change was 131 J K^{-1} mol^{-1}. The majority then went on to use the Gibbs equation to obtain the correct value of Δ*G*. It was only the weaker candidates who succumbed to use of 131, rather than 0.131 in the expression, resulting in a negative absolute temperature. Some candidates used 25 °C instead of 298 K. Candidates are advised to check that correct provided values had been used: a common transcription error was use of −155 instead of −115 for the Δ*H* value. Answer: 76.0 kJ K^{-1} mol^{-1}
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 878 **OR** 877.9 **OR** 877.86, award **2 marks** ……	2	**ALLOW** total entropy statement: Δ*S*(total) = 0 **OR** Δ*S*(total) >0

			(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** $T = \frac{\Delta H}{\Delta S}$ ✓ $T = \frac{115}{0.131} = 878$ K ✓		**ALLOW ECF** from incorrect calculated value of ΔS from **2(c)(i)** **ALLOW** 878 up to calculator value of 877.862595 correctly rounded **Examiner's Comments** This part was answered correctly by almost all candidates, using the provided ΔH value and the candidate's calculated ΔS value from (c)(i). Some candidates unexpectedly converted their correct K value into °C. The only significant error seen here was with incorrect rounding. Answer: 878 K
			Total	**9**	
9			***ΔH calculation from experiment*** $q = 100 \times 4.18 \times 20.5$ **OR** 8569 J **OR** 8.569 kJ (1) Amount of butan-1-ol = $\frac{0.259}{74} = 3.5 \times 10^{-3}$ mol (1) $\Delta H = -2448$ kJ mol^{-1} (1) ***ΔS calculation*** $\Delta S = S_{products} - S_{reactants}$ $\Delta S = (4 \times 214) + (5 \times 70) - [(228) + (6 \times 205)]$ **OR** $\Delta S = 1206 - 1458$ (1) $\Delta S = -252$ J K^{-1} mol^{-1} **OR** -0.252 kJ K^{-1} mol^{-1} (1) ***ΔG calculation*** $\Delta G = \Delta H - T\Delta S$ $\Delta G = -2448 - (298 \times -0.252)$ (1) $\Delta G = -2373$ (kJ mol^{-1}) (1)	7	**allow** calculator value for $\Delta H = -2448.285714$ correctly rounded to three or more significant figures mark for use of correct expression with ΔS in kJ K^{-1} mol^{-1} **allow** three or more sig figs for ΔG
			Total	**7**	