ENTHALPY & ENTROPY (5.2.2)

1. This question looks at different aspects of entropy.

Three processes are given below.

For each process, state and explain whether the change would be accompanied by an increase or decrease in entropy.

(i) The freezing of water.

increase or decrease ____

explanation ____

____

[1]

(ii) The reaction of calcium carbonate with hydrochloric acid.

increase or decrease ____

explanation ____

____

[1]

(iii) The formation of O_3(g) from O_2(g).

increase or decrease ____
explanation ____

____

[1]

2. Two changes are described below.

For each change,

- write an equation, including state symbols,
- state and explain how the entropy changes.

(i) The reaction of aqueous barium nitrate with aqueous sodium sulfate.

Full equation with state symbols

Explanation of entropy change ---

--- [2]

(ii) The change that accompanies the standard enthalpy change of atomisation of iodine.

Equation with state symbols

Explanation of entropy change ---

--- [2]

3. Iron can be extracted from its ore Fe_3O_4 using carbon.

Several equilibria are involved including **equilibrium 18.1**, shown below.

equilibrium 18.1 $Fe_3O_4(s) + 4C(s) \rightleftharpoons 3Fe(s) + 4CO(g)$ $\Delta H = +676.4\ \text{kJ mol}^{-1}$

$\Delta S = +703.1\ \text{J K}^{-1}\ \text{mol}^{-1}$

(i) Why is **equilibrium 18.1** a *heterogeneous* equilibrium?

--- **[1]**

(ii) Write the expression for K_p for **equilibrium 18.1**.

[1]

(iii) The forward reaction in **equilibrium 18.1** is only feasible at high temperatures.

- Show that the forward reaction is **not** feasible at 25 °C.
- Calculate the minimum temperature, in K, for the forward reaction to be feasible.

minimum temperature = ________________ K **[3]**

(iv) Another equilibrium involved in the extraction of iron from Fe_3O_4 is shown below.

$Fe_3O_4(s) + 4CO(g) \rightleftharpoons 3Fe(s) + 4CO_2(g)$ $\Delta H = -13.5\ \text{kJ mol}^{-1}$

Enthalpy changes of formation, $\Delta_f H$, for Fe_3O_4(s) and CO_2(g) are shown in the table.

Compound	**$\Delta_f H$ / kJ mol^{-1}**
Fe_3O_4(s)	–1118.5
CO_2(g)	–393.5

Calculate the enthalpy change of formation, $\Delta_f H$, for CO(g).

$\Delta_f H$, for CO(g) = ... kJ mol^{-1} **[3]**

4. The table below shows standard entropies, S^{e}

Substance	$CO(g)$	$H_2(g)$	$CHM_3OH(l)$
S^{e} / J mol^{-1} K^{-1}	197.6	130.6	239.7

What is the entropy change, ΔS^{e}, in J mol^{-1} K^{-1}, for the following reaction?

$$CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$$

A –219.1

B –88.5

C +88.5

D +219.1

Your answer ☐ **[1]**

5. This question is about free energy changes, ΔG, enthalpy changes, ΔH, and temperature, T.

The Gibbs' equation is shown below.

$\Delta G = \Delta H - T\Delta S$

A chemist investigates a reaction to determine how ΔG varies with T.
The results are shown in **Fig. 18.1**.

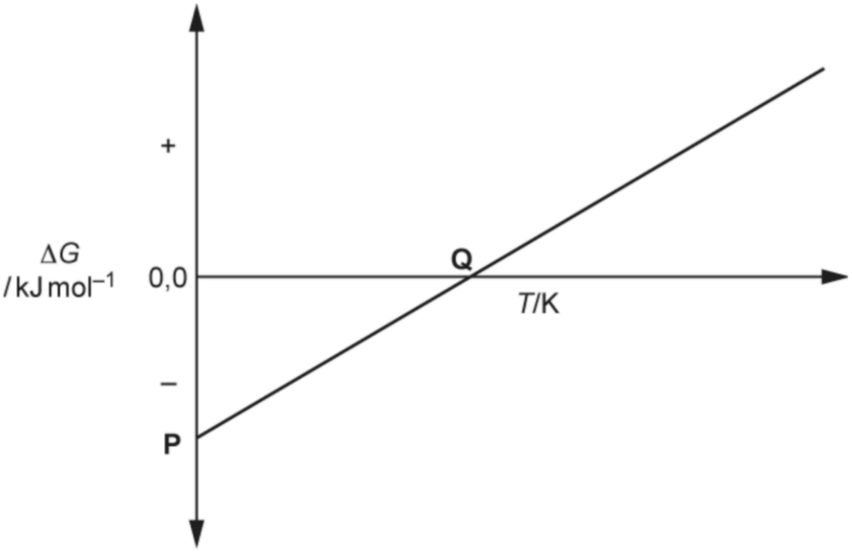


Fig. 18.1

What is significant about the gradient of the line and the values **P** and **Q** shown in **Fig. 18.1**?
Explain your reasoning.

-- [4]

6(a). Much of the sulfur required for production of sulfuric acid is obtained from sulfur impurities in natural gas, such as hydrogen sulfide, H_2S.

The H_2S is converted into sulfur in two steps.

Step 1: Some of the H_2S is reacted with oxygen to form sulfur dioxide, SO_2.

$$2H_2S(g) + 3O_2(g) \rightarrow 2SO_2(g) + 2H_2O(g)$$

Step 2: The remaining H_2S is reacted with the SO_2 to produce sulfur.

$$2H_2S(g) + SO_2(g) \rightarrow 3S(s) + 2H_2O(g)$$

(i) Construct the overall equation for the two steps above.

____ **[1]**

(ii) A natural gas supply contains 16.0% H_2S by volume.
The $H_2S(g)$ in 1.50×10^8 dm^3 of this natural gas supply, measured at RTP, is processed into sulfur with an overall percentage yield of 95.0%.

Calculate the mass of sulfur, in g, obtained from 1.50×10^8 dm^3 of natural gas supply.

Give your answer to **three** significant figures and in standard form.

mass of sulfur = ______________________________ g **[3]**

(b). The enthalpy change for the equation in **step 2** is shown below.

$$2H_2S(g) + SO_2(g) \rightarrow 3S(s) + 2H_2O(g) \quad \Delta H = -145.6 \text{ kJ mol}^{-1}$$

Standard entropies, *S*, and enthalpy changes of formation, $\Delta_f H$, are given in the table.

Substance	$H_2S(g)$	$SO_2(g)$	S(s)	$H_2O(g)$
***S* / J mol^{-1} K^{-1}**	205.7	248.1	31.8	188.7
$\Delta_f H$ / kJ mol^{-1}	–20.6	▨	0	–241.8

(i) Calculate ΔG at 25 °C, and explain whether the reaction in **step 2** is feasible at 25 °C.

Calculate the temperature, in K, at which the feasibility changes.

Show your working and explain your reasoning.

[5]

(ii) Calculate $\Delta_f H$ for $SO_2(g)$.

$\Delta_f H$ for $SO_2(g)$ = ____________________________ kJ mol^{-1} **[2]**

7(a). The enthalpy and entropy changes of a reaction both have a negative sign.

Discuss how the feasibility of this reaction will change as the temperature increases.

-- **[2]**

(b). The metal tungsten is obtained on a large scale from its main ore, wolframite.
Wolframite contains tungsten(VI) oxide, WO_3.

Tungsten is extracted from wolframite by reduction with hydrogen:

$$WO_3(s) + 3H_2(g) \rightarrow W(s) + 3H_2O(g) \qquad \Delta H = +115\,kJ\,mol^{-1}$$

Standard entropies are given in the table below.

Substance	$WO_3(s)$	$H_2(g)$	$W(s)$	$H_2O(g)$
$S^{\ominus}$ / J K^{-1} mol^{-1}	76	131	33	189

(i) Calculate the free energy change, ΔG, in kJ mol^{-1}, for this reaction at 25 °C.

Show your working.

ΔG at 25 °C = ______________________________ kJ mol^{-1} **[2]**

(ii) Calculate the minimum temperature, in K, at which this reaction becomes feasible.

Show your working.

minimum temperature = ____________________________ K **[2]**

8. This question looks at two reactions involving sulfur compounds.

Hydrogen reacts with carbon disulfide as shown below.

$$4H_2(g) + CS_2(g) \rightarrow CH_4(g) + 2H_2S(g)$$

For this reaction, $\Delta H = -234$ kJ mol^{-1} and $\Delta S = -164$ J K^{-1} mol^{-1}.

(i) Why does the reaction have a negative entropy change?

____

____**[1]**

(ii) Standard entropies are shown in the table below.

substance	$CS_2(g)$	$CH_4(g)$	$H_2S(g)$
$S^\ominus$ / JK^{-1} mol^{-1}	238	186	206

Calculate the standard entropy for H_2.

$S^\ominus$ = ______________________ J K^{-1} mol^{-1}**[2]**

(iii) Explain, with a calculation, whether this reaction is feasible at 25°C.

Show your working.

---[3]

(iv) Explain, with a calculation, the significance of temperatures above 1154°C for this reaction.

---[2]

9(a). This question is about four enthalpy changes, **A**–**D**, that can be linked to the dissolving of potassium sulfate, K_2SO_4, in water.

	Name of enthalpy change	Enthalpy change / kJ mol^{-1}
A	lattice enthalpy of potassium sulfate	–1763
B	enthalpy change of solution of potassium sulfate	+24
C	enthalpy change of hydration of potassium ions	–320
D	enthalpy change of hydration of sulfate ions	

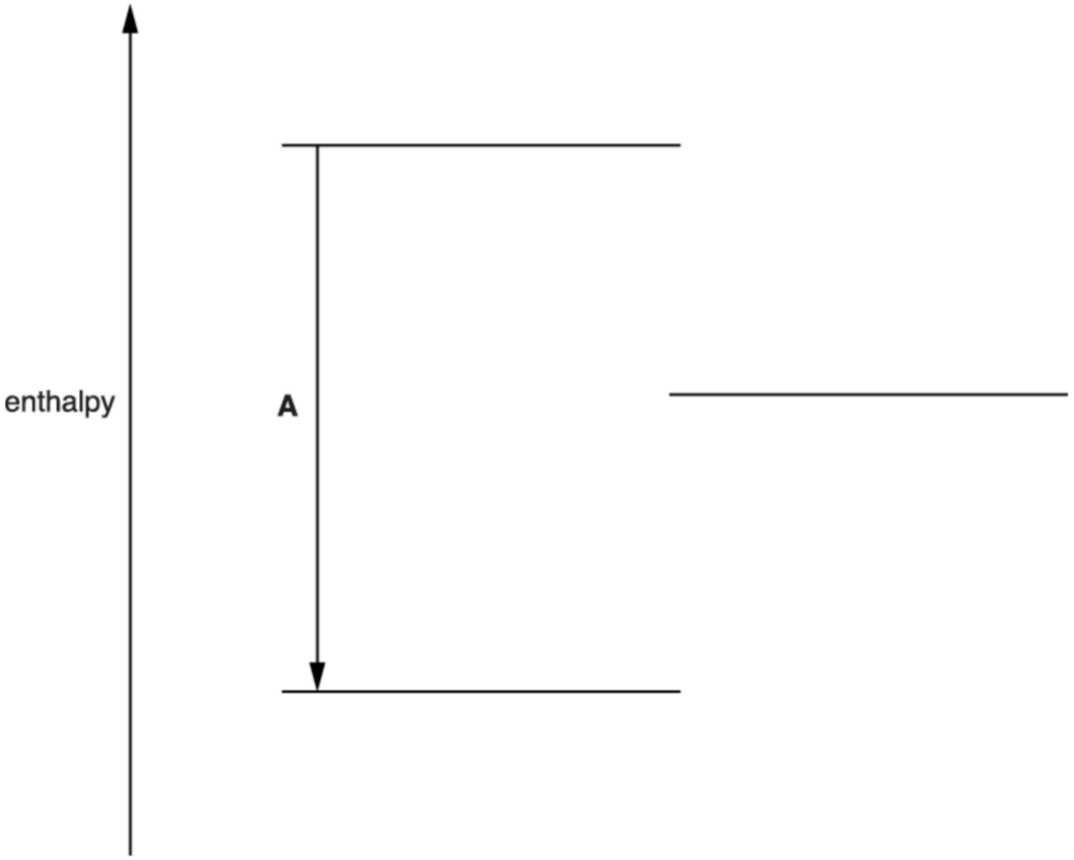
Table 3.1

Define the term *enthalpy change of hydration.*

---[2]

(b). The diagram below is an incomplete energy cycle linking the four enthalpy changes in **Table 3.1**. One of the four energy levels is missing.

Include state symbols for all species.



(i) Complete the energy cycle as follows.

- Add the missing energy level to the diagram. Add the species on all **four** energy levels.
- Add arrows to show the direction of the three missing enthalpy changes. Label these enthalpy changes using the letters **B**–**D** from **Table 3.1**.

[5]

(ii) Calculate the enthalpy change of hydration of sulfate ions.

ΔH = ______________________________ kJ mol^{-1} **[1]**

(c). The entropy change of solution of K_2SO_4 is +225 J K^{-1} mol^{-1}.

(i) Suggest, in terms of the states of the particles involved, why this entropy change is positive.

--- [1]

(ii) Explain, using a calculation, why K_2SO_4 dissolves in water at 25 °C, despite the enthalpy change of solution being endothermic.

--- [3]

10. A student is asked to calculate Δ*G* at 25 °C for the combustion of butan-1-ol. The teacher provides two pieces of information.

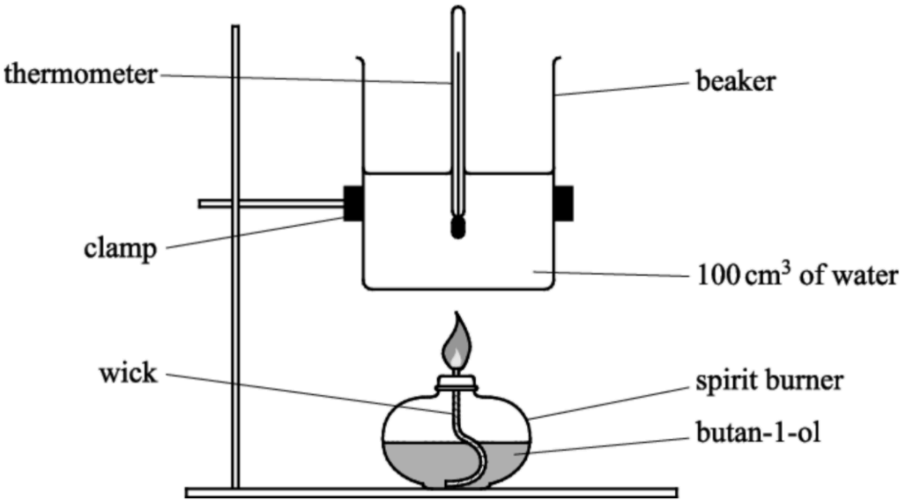
- The equation for the combustion of butan-1-ol.

$CH_3(CH_2)_3OH(l) + 6O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$ **Equation 2**

- Standard entropies of butan-1-ol, oxygen, carbon dioxide and water.

	$CH_3(CH_2)_3OH(l)$	$O_2(g)$	$CO_2(g)$	$H_2O(l)$
$S^{\square}$ / J K^{-1} mol^{-1}	228	205	214	70

The student carries out an experiment using the apparatus below and obtains the following results. The specific heat capacity of water is 4.18 J g^{-1} K^{-1}.



Mass of burner and butan-1-ol before burning / g	98.997
Mass of burner and butan-1-ol after burning / g	98.738
Initial temperature / °C	18.5
Maximum temperature reached / °C	39.0

Use the information on the previous page to calculate Δ*G*, in kJ mol^{-1}, for the combustion of butan-1-ol according to **Equation 2** at 25 °C.

Show **all** your working.

ΔG = ____________________ kJ mol^{-1} **[7]**

END OF QUESTION PAPER

Question			Answer/Indicative content	Marks	Guidance
1		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.

Question			Answer/Indicative content	Marks	Guidance
		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 **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.
			Total	3	

Question			Answer/Indicative content	Marks	Guidance
2		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	

Question			Answer/Indicative content	Marks	Guidance
3		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.

Question			Answer/Indicative content	Marks	Guidance
		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}) ✓ *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 ✓	3	**IGNORE** units **ALLOW** (+) 467 up to calculator value of 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.

Question			Answer/Indicative content	Marks	Guidance
		iv	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = –110.5, Award 3 marks. - Correct expression $-13.5 = (4 \times -393.5) - (-1118.5 + 4 \times \Delta_f H(\text{CO}))$ ✓ Correct subtraction using ΔH and $\Delta_f H(\text{Fe}_3\text{O}_4)$ $4 \times \Delta_f H(\text{CO}) = (4 \times -393.5) - (-1118.5) + 13.5$ $= \mathbf{-442(.0)}$ (kJ mol^{-1}) ✓ Calculation of $\Delta_f H(\text{CO})$ formation $\Delta_f H(\text{CO}) = -\frac{442}{4} = \mathbf{-110.5}$ (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 $\Delta_f H(\text{CO})$ 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	8	

Question			Answer/Indicative content	Marks	Guidance
4			A	1 (AO 1.2)	**Examiner's Comments** The correct answer to this was known by the more able candidates. Lower ability candidates struggled.
			Total	1	
5			$\Delta G = \Delta H - T\Delta S$ 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 $\Delta S = -\textit{gradient}$ **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.
			Total	4	

Question			**Answer/Indicative content**	**Marks**	**Guidance**
6	a	i	$2H_2S(g) + O_2(g)$ ☐ $2S(s) + 2H_2O(g)$ ✓	1	**ALLOW** multiples, e.g. $6H_2S(g) + 3O_2(g)$ ☐ $6S(s) + 6H_2O(g)$
		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

Question			Answer/Indicative content	Marks	Guidance
	b	i	**FIRST, CHECK FOR A VALUE OF ΔG.** **IF** answer = – 89.96(34) (kJ mol^{-1}) award **3 marks** - **ΔS calculation (2 marks)** ΔS = (3 × 31.8) + (2 × 188.7) – [(2 × 205.7) + (248.1)] **OR** ΔS = 472.8 – 659.5 ✓ ΔS = –186.7 J mol^{-1} K^{-1} **OR** –0.1867 kJ mol^{-1} K^{-1} ✓ **ΔG calculation (1 mark)** $\Delta G = \Delta H - T\Delta S$ = –145.6 – (298 × –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 ΔG **OR** $\Delta H - T\Delta S = 0$ ✓	5	**ALLOW** (–) 187 OR 0.187 **ALLOW ECF** from incorrect ΔH **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** Δ_fH(SO_2) = (2 × –241.8) – (2 × –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	

Question			Answer/Indicative content	Marks	Guidance
7	a		**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 ✓	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** ΔG < 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
			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** $\mid T\Delta S \mid$ increases ✓		**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, ΔH and $T\Delta S$ and to relate these to feasibility from the

Question			Answer/Indicative content	Marks	Guidance
					sign of ΔG. Problems arose in responses that ignored the negative signs leading to ambiguous statements. The required '$T\Delta S$ becomes more negative' was often communicated as '$T\Delta S$ increases'. The latter term is ambiguous, its meaning depending on whether the sign is included or omitted. The comparison of $T\Delta S$ with ΔH caused more problems with many responses seen of $T\Delta S > \Delta H$. Mathematically, the opposite is true as both values are negative. The better approach was to communicate this relationship in text as '$T\Delta S$ is more negative that ΔH.' The responses from the best candidates used this precise language but many candidates did not score marks here because of the ambiguity.
	b	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 **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 ΔG. 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 ΔH value. Answer: 76.0 kJ K^{-1} mol^{-1}

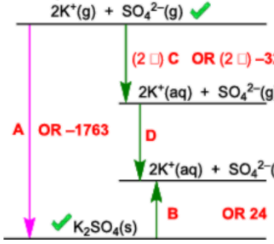
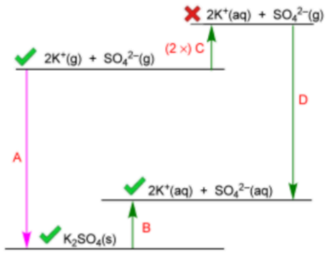
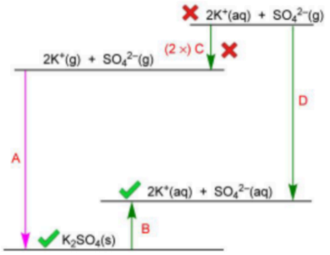
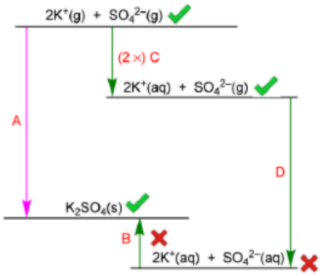
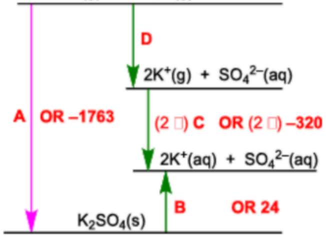
Question			Answer/Indicative content	Marks	Guidance
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 878 **OR** 877.9 **OR** 877.86, award **2 marks** (Minimum temperature when) $\Delta G = 0$ **OR** $\Delta H - T\Delta S = 0$ **OR** (For feasibility) $\Delta G = 0$ **OR** $\Delta G < 0$ **OR** $\Delta H - T\Delta S < 0$ **OR** $T = \frac{\Delta H}{\Delta S}$ ✓ $T = \frac{115}{0.131} = 878$ 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 **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	6	
8		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**

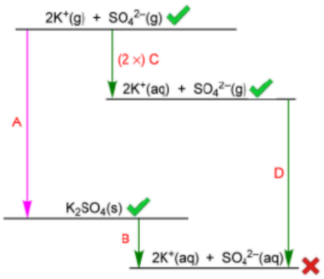
Question	Answer/Indicative content	Marks	Guidance
ii	S = (+)131 (J K^{-1} mol^{-1}) ✓	2	–131 wrong final sign 49 wrong sign for 164 79.5 no use of 2 524 no division by 4 38 wrong sign for 186 –75 wrong sign for 206 250 wrong sign for 238 Any other number: **CHECK** for **ECF** from 1st marking point 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 ΔG calculation** ----------------------------- **ΔG calculation: 2 marks** $\Delta G = -234 - 298 \times -0.164$ ✓		**ALLOW** ΔG correctly calculated from 3 SF up to calculator value of –185.128 **ALLOW** working in J, *ie*: $\Delta G = -234000 - 298 \times -164$ ✓
iii	= –185 (kJ mol^{-1}) ✓ **IGNORE** units (even if wrong) –185 subsumes 1st mark)	2	= –185000 (J mol^{-1}) ✓ **ALLOW** 1 mark for use of 25 **OR** mixture of kJ and J, e.g. $\Delta G = -234 - 25 \times -0.164 = -229.9$ $\Delta G = -234 - 298 \times -164 = +48638$

Question			Answer/Indicative content	Marks	Guidance
		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}

Question			Answer/Indicative content	Marks	Guidance
		iv	(ΔG =) $-234 - 1427 \times \frac{-164}{1000} = 0$ (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 $\Delta G = 0$) $T = \frac{-234}{-0.164} = 1427$ 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 $T\Delta S$ 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 ΔG calculation from (iii) to show that ΔG 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 ΔG 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 ΔG 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	

Question			Answer/Indicative content	Marks	Guidance
9	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.

Question			Answer/Indicative content	Marks	Guidance
	b	i	**4 marks** for species **AND** state symbols on all 4 energy levels (including added energy level) 	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**
			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.		 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: 

Question			Answer/Indicative content	Marks	Guidance
			Top arrow is shown **FROM** K_2SO_4(s) and arrow directions correct. Letter labels correct so last mark is awarded. **4/5 marks**  '2 ×' is **NOT** required – *part of calculation mark*		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 - 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	Δ*H*(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}

Question			Answer/Indicative content	Marks	Guidance
	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.

Question			Answer/Indicative content	Marks	Guidance
		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	

Question			Answer/Indicative content	Marks	Guidance
10			*ΔH calculation from experiment* q = 100 × 4.18 × 20.5 **OR** 8569 J **OR** 8.569 kJ (1) Amount of butan-1-ol = $\frac{0.259}{74}$ = 3.5×10^{-3} mol (1) ΔH = –2448 kJ mol^{-1} (1) *ΔS calculation* $\Delta S = S_{products} - S_{reactants}$ ΔS = (4 × 214) + (5 × 70) – [(228) + (6 × 205)] **OR** ΔS = 1206 – 1458 (1) ΔS = –252 J K^{-1} mol^{-1} **OR** –0.252 kJ K^{-1} mol^{-1} (1) *ΔG calculation* $\Delta G = \Delta H - T\Delta S$ ΔG = –2448 – (298 × –0.252) (1) ΔG = –2373 (kJ mol^{-1}) (1)	7	**allow** calculator value for ΔH = –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**	