1. 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.

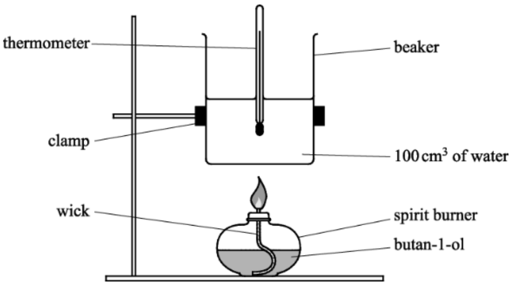
- The equation for the combustion of butan-1-ol.

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

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

	$CH_3(CH_2)_3OH(l)$	$O_2(g)$	$CO_2(g)$	$H_2O(l)$
$S^\ominus$ / 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.

Δ*G* = ...kJ mol^{-1} **[7]**

2(a). 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]

(b). 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]

(c). 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:

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

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]**

3. 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°/ JK^{-1} mol^{-1}	238	186	206

Calculate the standard entropy for H_2.

S°= .... 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]

4(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	

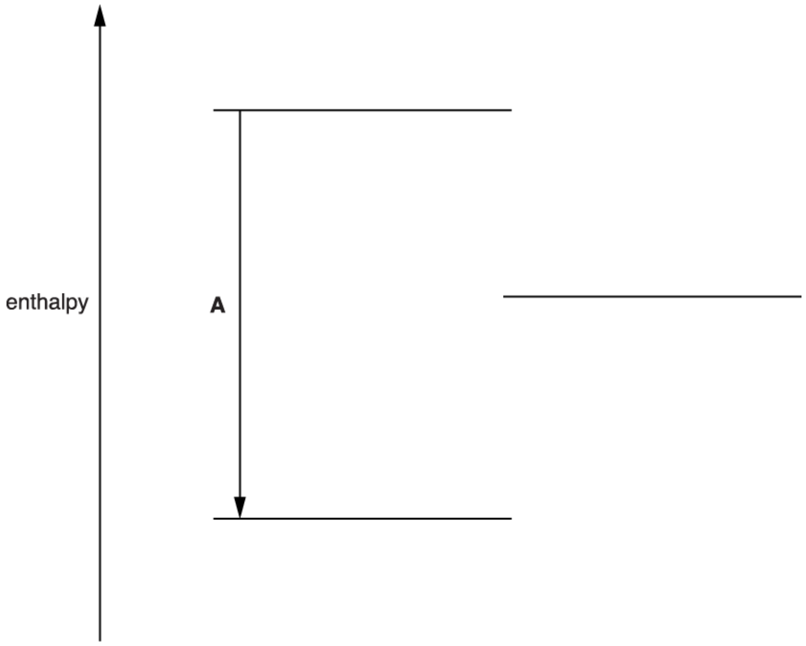
Table 3.1

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]

5(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.

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

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 Δ*G* 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]**

6. 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]

7(a). This question is about free energy changes, ΔG, enthalpy changes, ΔH, and temperature, T.

The Gibbs' equation is shown. $\Delta G = \Delta H - T\Delta S$

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

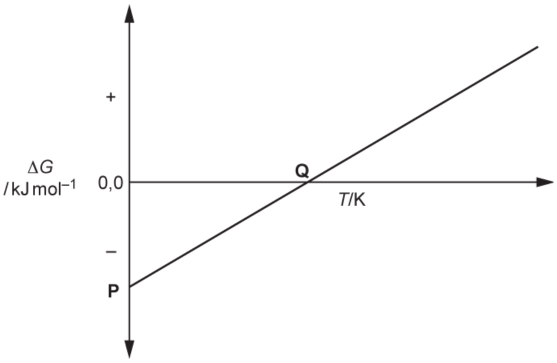


Fig. 18.1

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

Explain your reasoning.

[4]

(b). 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]**

8. 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]**

9. The standard enthalpy change of reaction, $\Delta_r H^{\ominus}$, and the standard free energy change, $\Delta G^{\ominus}$, for converting anhydrous sodium thiosulfate to hydrated sodium thiosulfate are shown below.

$Na_2S_2O_3(s) + 5H_2O(l) \rightarrow Na_2S_2O_3{\bullet}5H_2O(s)$ $\Delta_r H^{\ominus} = –55.8$ kJ mol^{-1}

$\Delta G^{\ominus} = –16.1$ kJ mol^{-1}

Standard entropies are given in the table.

Compound	**$S^{\ominus}$ / J K^{-1} mol^{-1}**
$Na_2S_2O_3{\bullet}5H_2O$(s)	372.4
H_2O(l)	69.9

Determine the **standard** entropy, $S^{\ominus}$, of anhydrous sodium thiosulfate, $Na_2S_2O_3$(s).

Give your answer to **3** significant figures.

$S^{\ominus}$.. J K^{-1} mol^{-1} **[4]**

10. Methanol, CH3OH, can be made industrially by the reaction of carbon monoxide with hydrogen, as shown in **equilibrium 1**.

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H = -91$ kJ mol^{-1} **Equilibrium 1**

Standard entropy values are given below.

Substance	CO(g)	H_2(g)	CH_3OH(g)
S^{θ} / J K^{-1} mol^{-1}	198	131	238

A chemist proposed producing methanol at 525 K using **equilibrium 1**.

Explain, with a calculation, whether the production of methanol is feasible at 525 K.

[5]

11. The feasibility of a chemical reaction depends on the temperature and the signs of ΔH and ΔS.

Which row has signs for ΔH and ΔS for a reaction that is feasible at high temperatures but is **not** feasible at low temperatures?

	ΔH	ΔS
A	+	+
B	+	-
C	-	+
D	-	-

Your answer ☐ **[1]**

12. This question is about chemical equilibrium.

Nitrogen monoxide, NO, and oxygen, O_2, react to form nitrogen dioxide, NO_2, in the reversible reaction shown in **Equilibrium 20.1**.

Equilibrium 20.1 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H = -114\ kJ\ mol^{-1}$

$\Delta S = -147\ J\ mol^{-1}\ K^{-1}$

i. Show that the formation of NO_2 in **Equilibrium 20.1** is feasible at 25 °C.

[2]

ii. Determine the maximum temperature, in K, for feasibility.

Give your answer to an **appropriate** number of significant figures.

maximum temperature = ... K **[1]**

13. For the condensation of ammonia gas, what are the signs of ΔH and ΔS?

A ΔH −ve ΔS −ve

B ΔH −ve ΔS +ve

C ΔH +ve ΔS +ve

D ΔH +ve ΔS −ve

Your answer ☐ **[1]**

14. This question is about energy changes.

Carbon disulfide, CS_2, reacts with dinitrogen oxide, N_2O, as shown in **Reaction 17.2**.

$4CS_2(l) + 8N_2O(g) \rightarrow S_8(s) + 4CO_2(g) + 8N_2(g)$ **Reaction 17.2**

Standard entropies, $S^{\ominus}$, are shown in the table.

Substance	$CS_2(l)$	$N_2O(g)$	$S_8(s)$	$CO_2(g)$	$N_2(g)$
$S^{\ominus}$/JK^{-1} mol^{-1}	151	220	256	214	192

i. Explain the term **entropy**.

[1]

ii. The free energy change, ΔG, of **Reaction 17.2** is −2672 kJ mol^{-1} at 25°C.

Calculate the enthalpy change, ΔH, of **Reaction 17.2**, in kJ mol^{-1}.

ΔH = ... kJ mol^{-1} **[3]**

iii. A student concludes that **Reaction 17.2** is feasible at all temperatures.

Explain whether the student is correct or not.

[2]

15. The table below shows standard entropies, $S^{\ominus}$.

Substance	$SO_2(g)$	$O_2(g)$	$SO_3(l)$
$S^{\ominus}$ /J K^{-1} mol^{-1}	248	204	96

What is the standard entropy change, $\Delta S^{\ominus}$, in J K mol^{-1}, for the formation of 1 mol of $SO_3(l)$ from $SO_2(g)$ and $O_2(g)$?

A –508

B –254

C +254

D +508

Your answer ☐ **[1]**

16. Chlorine trifluoride can be decomposed into its elements forming the equilibrium mixture below.

$2ClF_3(g)$	$\rightleftharpoons$	$Cl_2(g)$	+	$3F_2(g)$	$\Delta H = +318 \text{ kJ mol}^{-1}$
colourless gas		green gas		yellow gas	

Which statement(s) is/are correct?

1 The decomposition is a redox reaction.
2 When the equilibrium mixture is cooled, the colour fades.
3 The decomposition has a negative entropy change.

A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer ☐ **[1]**

17. This question is about enthalpy changes of reactions involving hydrocarbons.

Ethene can be produced from ethanol, as shown in **Reaction 2** below.

$C_2H_5OH(g) \rightarrow C_2H_4(g) + H_2O(g)$ **Reaction 2**

i. Predict the sign of the entropy change, Δ*S*, for **Reaction 2**.

Explain your reasoning.

[1]

ii. **Reaction 2** is repeated:

$C_2H_5OH(g) \rightarrow C_2H_4(g) + H_2O(g)$ **Reaction 2**

The Gibbs equation is shown below.

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

The enthalpy change, ΔH, and the entropy change, ΔS, can be assumed to be constant at different temperatures.

Fig. 18.1 shows values of the free energy change, ΔG, in kJ mol^{-1}, at different temperatures, T, in K, for **Reaction 2**.

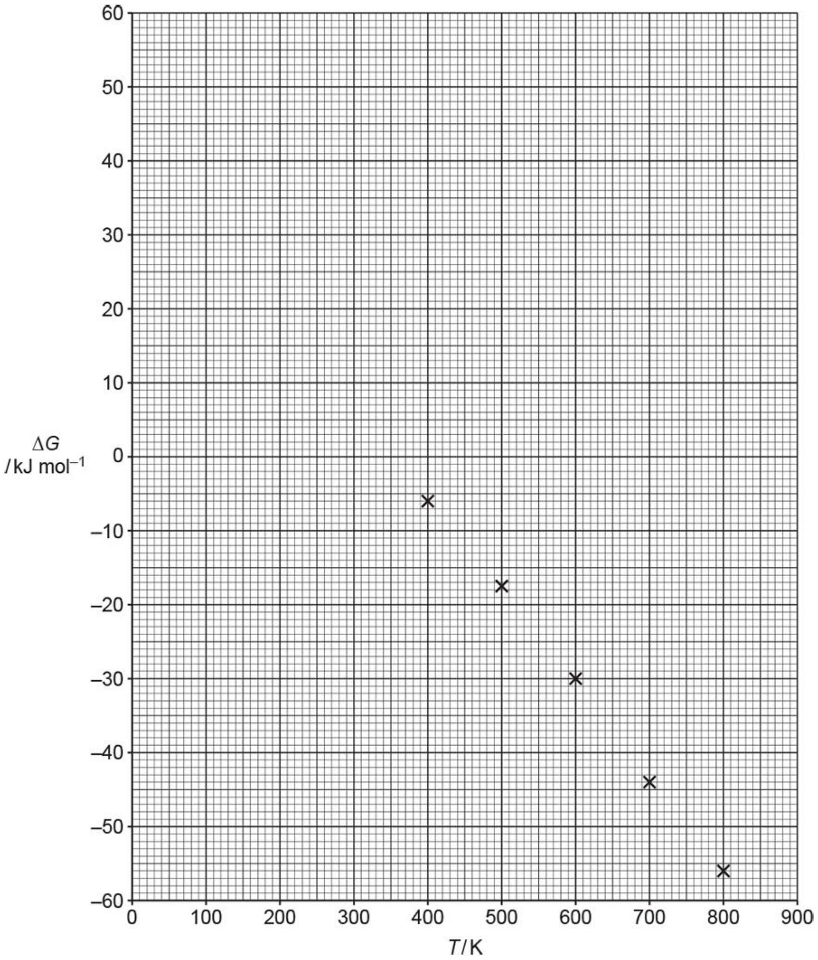


Fig. 18.1

Use the graph in **Fig. 18.1** to answer the following:

- Draw the best-fit line on the graph in **Fig. 18.1**.
- Determine ΔS, in J K^{-1} mol^{-1}, for **Reaction 2**.
- Determine the minimum temperature, T, at which the reaction is feasible.
- Determine ΔH for **Reaction 2**.

ΔS = ... J K^{-1} mol^{-1}

minimum T = ... K

ΔH = ... kJ mol^{-1}

[5]

18(a). This question is about energy changes.

Hydrogen peroxide decomposes as shown in **Reaction 16.1**.

$H_2O_2(l) \rightarrow H_2O(l) + \frac{1}{2}O_2(g)$ **Reaction 16.1**

The table shows enthalpy changes of formation and entropies.

	ΔH_f^e/kJ mol^1	**S^e / J K^{-1} mol^{-1}**
$H_2O_2(l)$	−188	110
$H_2O(l)$	−286	70.0
$O_2(g)$	0	205

i. Calculate the free-energy change, ΔG, in kJ mol^{-1}, of **Reaction 16.1** at 25 °C.

Give your answer to **3** significant figures.

ΔG = ... kJ mol^{-1} **[4]**

ii. The decomposition of hydrogen peroxide shown in **Reaction 16.1** is feasible.

Suggest why **Reaction 16.1** does **not** take place at 25 °C despite being feasible.

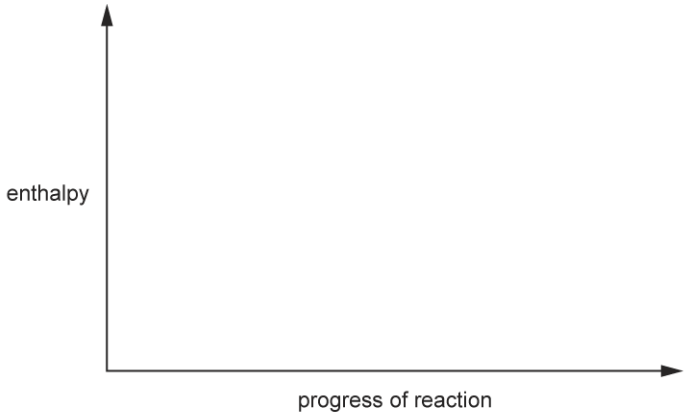
[1]

(b). The rate of decomposition of hydrogen peroxide shown in **Reaction 16.1** can be increased by adding a small amount of powdered manganese(IV) oxide, MnO_2.

The MnO_2 acts as a catalyst.

i. Complete the enthalpy profile diagram for **Reaction 16.1** using formulae for the reactants and products.

- Use E_a to label the activation energy **without** MnO_2.
- Use E_c to label the activation energy **with** MnO_2.
- Use ΔH to label the enthalpy change of reaction.



[3]

ii. Explain why MnO_2 is described as a **heterogeneous** catalyst for this reaction.

[1]

iii. Mn_3O_4 is a compound in which Mn has two different oxidation states. The two oxidation states are different from the Mn in MnO_2.

Suggest the two oxidation states of manganese in Mn_3O_4.

[1]

(c). Manganese(II) oxide, MnO, has a giant ionic lattice structure.

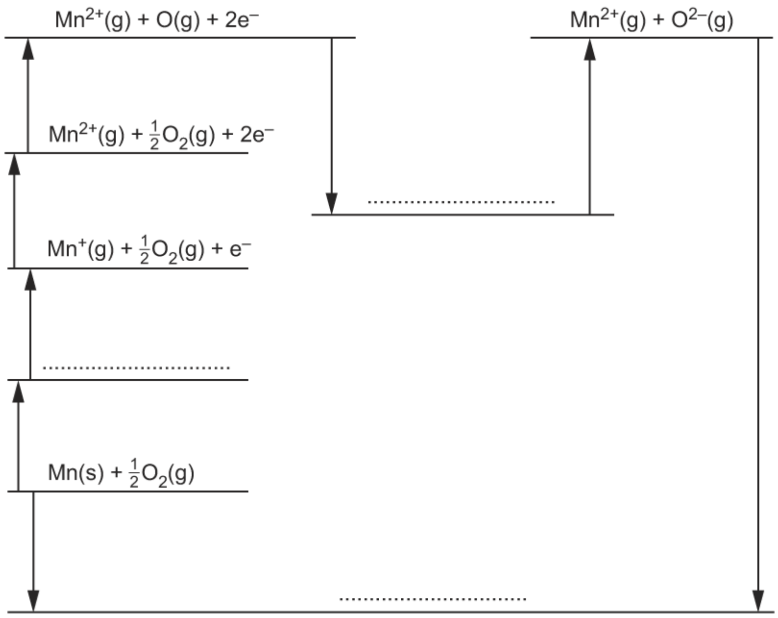
The table shows the enthalpy changes that are needed to determine the lattice enthalpy of MnO.

	enthalpy change / kJ mol^{-1}
atomisation of manganese	+281
atomisation of oxygen	+249
first ionisation energy of manganese	+717
second ionisation energy of manganese	+1509
first electron affinity of oxygen	−141
second electron affinity of oxygen	+798
formation of manganese(II) oxide	−385

i. Define the term **lattice enthalpy**.

[2]

ii. The diagram shows an incomplete Born-Haber cycle that can be used to determine the lattice enthalpy of MnO.



Complete the diagram by adding the species present on the dotted lines, include state symbols.

[3]

iii. Calculate the lattice enthalpy of MnO.

lattice enthalpy = ... kJ mol^{-1} **[2]**

END OF QUESTION PAPER

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			***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**	
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 **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. $1\frac{1}{2}O_2 \rightarrow O_3$; $O_2 + \frac{1}{2}O_2 \rightarrow O_3$ **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.

	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

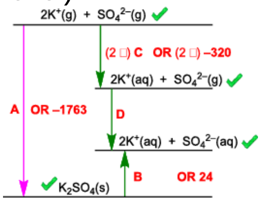
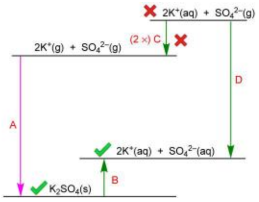
					was to compare the two key terms, ΔH and $T\Delta S$ and to relate these to feasibility from the sign of ΔG. Problems arose in responses that ignored the negative signs leading to ambiguous statements. The required '$T\Delta S$ becomes more negative' was often communicated as '$T\Delta S$ increases'. 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.
	c	i	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 75.962 **OR** 75.96 **OR** 76.0 **OR** 76, award **2 marks** .... $\Delta S = (33 + 3 \times 189) - (76 + 3 \times 131)$ $= (+)131\ (\text{J K}^{-1}\ \text{mol}^{-1})$ ✓ $\Delta G = 115 - (298 \times 0.131)$ = (+) 75.962 **OR** 75.96 **OR** 76.0 **OR** 76 (kJ $\text{K}^{-1}\ \text{mol}^{-1}$) ✓	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

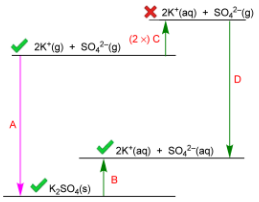
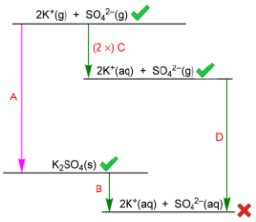
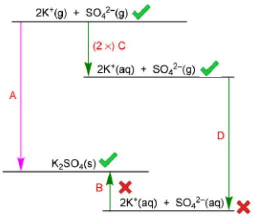
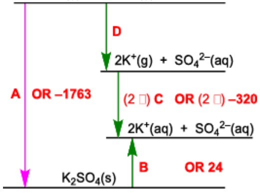
					K. Candidates are advised to check that correct provided values had been used: a common transcription error was use of −155 instead of −115 for the Δ*H* value. Answer: 76.0 kJ K^{-1} mol^{-1}
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 878 **OR** 877.9 **OR** 877.86, award **2 marks** …………………………………… (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: Δ*S*(total) = 0 **OR** Δ*S*(total) >0 **ALLOW ECF** from incorrect calculated value of Δ*S* 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 Δ*H* value and the candidate's calculated Δ*S* 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**	
3		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 Δ*G* **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** ΔG = −234 − 298 × −0.164 ✓		**ALLOW** Δ*G* correctly calculated from 3 SF up to calculator value of −185.128 **ALLOW** working in J, *ie*: Δ*G* = −234000 − 298 × −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. Δ*G* = −234 − 25 × −0.164 = −229.9 Δ*G* = −234 − 298 × −164 = +48638
		iii	**Feasibility comment for negative ΔG 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 (**2nd mark only available if 1st mark has been awarded** (Above 1427K / 1154°C), reaction is **not**	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

			feasible / **not** spontaneous ✓ **OR** 1427 K is maximum temperature that reaction happens		**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 **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**	
4	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** $2K^+(g) + SO_4^{2-}(g)$	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**

			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**  '2 ×' is **NOT** required – *part of calculation mark*		 **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 • 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}
	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*	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**

			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** $T\Delta S > \Delta H$ ✓		−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: $\Delta G = -43$ kJ mol^{-1}
			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 ✓	3	

			Mass S = 1(.00) × 10^6 × 95(.0)/100 × 32.1 = 3.05 × 10^7 (g) ✓		**ALLOW ECF** from incorrect volume of H_2S **3 SF AND standard form** required
	b	i	**FIRST, CHECK FOR A VALUE OF Δ*G*.** **IF** answer = − 89.96(34) (kJ mol^{-1}) award **3 marks** ……………………………………………… **Δ*S* calculation (2 marks)** $\Delta S = (3 \times 31.8) + (2 \times 188.7) - [(2 \times 205.7) + (248.1)]$ **OR** $\Delta S = 472.8 - 659.5$ ✓ $\Delta S = -186.7 \text{ J mol}^{-1} \text{ K}^{-1}$ **OR** $-0.1867 \text{ kJ mol}^{-1} \text{ K}^{-1}$ ✓ **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** $\Delta H - T\Delta S = 0$ ✓	5	**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**$-145.6 = (2 \times -241.8) - (2 \times -20.6 + \Delta_f H(SO2))$ ✓ **Calculation of $\Delta_f H(SO_2)$ 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		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**	
7	a		$\boldsymbol{\Delta G = \Delta H - T\Delta S}$ linked to $y = mx + c$ (somewhere) ✓	4	Could be: $\Delta G = -\Delta ST + \Delta H$ − sign required

			gradient = $-\Delta S$ ✓ **P:** ΔH / enthalpy change ✓ **Q:** (temperature) for reaction to be feasible/unfeasible **OR** (temperature) at which feasibility changes ✓		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 =) $p(\text{CO(g)})^4$ ✓	1	Allow species without state symbols and without brackets, e.g. $P\text{co}^4$, $pp\text{CO}^4$, $P\text{CO}^4$, $\text{p(CO}^4)$ etc. **DO NOT ALLOW** square brackets **Examiner's Comments** Marks were awarded for less than perfect versions of $K_p = \text{p(CO(g))}^4$. 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}) ✓ *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.
		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}) ✓	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 ....

<table>
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<td>Calculation of $\Delta_f H$(CO) formation
$\Delta_f H(\text{CO}) = -\frac{442}{4} = \mathbf{-110.5}$ (kJ mol^{-1}) ✓</td>
<td></td>
<td>Common errors
<table>
<tr><td>(+)110.5</td><td>wrong / omitted sign</td><td>2 marks</td></tr>
<tr><td>(+)184.625 / 184.63 / 184.6 / 185</td><td>No 4CO$_2$</td><td>2 marks</td></tr>
<tr><td>(+)738.5 / 739</td><td>No 4CO$_2$ and no CO/4</td><td>1 mark</td></tr>
<tr><td>−117.25 / −117.3 / −117</td><td>Wrong cycle</td><td>2 marks</td></tr>
<tr><td>−469</td><td>Wrong cycle, no CO/4</td><td>1 mark</td></tr>
<tr><td>(+)177.875 / 177.88 / 177.9 / 178</td><td>Wrong cycle, no 4CO2</td><td>1 mark</td></tr>
<tr><td>−360.5</td><td>Used 118.5</td><td>2 marks</td></tr>
</table>
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.</td>
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<td>Total</td>
<td>12</td>
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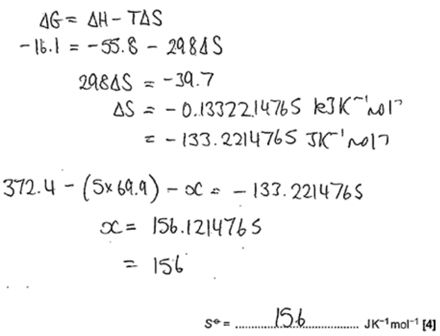
8			**A**	**1 (AO 1.2)**	<u>**Examiner's Comments**</u> The correct answer to this was known by the more able candidates. Lower ability candidates struggled.
			Total	**1**	
9			**FIRST CHECK THE ANSWER IN ON ANSWER LINE** **If answer = (+)156 (J K^{-1} mol^{-1}) award 4 marks** -- Part 1: Calc of $\Delta_r S$ **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* ✓ -- **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.	4 AO2.4×4	Using 298 K, ΔS $= \frac{-55.8 - (-16.1)}{298} = \frac{-39.7}{298}$ = –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 **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.

			• 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** ✓		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**  $\Delta G = \Delta H - T\Delta S$ $-16.1 = -55.8 - 298\Delta S$ $298\Delta S = -39.7$ $\Delta S = -0.1332214765$ kJK⁻¹mol⁻¹ $= -133.2214765$ JK⁻¹mol⁻¹ $372.4 - (5 \times 69.9) - x = -133.2214765$ $x = 156.1214765$ $= 156$ $S^\circ =$ ......156...... $JK^{-1}mol^{-1}$ **[4]**
			Total	**4**	
10			**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer =** 25.55 kJ mol^{-1} **OR** 25550 J mol^{-1} **award first 4 marks** --- $\Delta S = 238 - (198 + 2 \times 131)$ ✓ $= -222$ ($J K^{-1} mol^{-1}$) **OR** -0.222 ($kJ K^{-1} mol^{-1}$) ✓ $\Delta G = \Delta H - T\Delta S$ **OR** $\Delta G = -91 - (525 \times -0.222)$ **OR** $\Delta G = -91000 - (525 \times -222)$ ✓ = 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**	
11			A	1 (AO1.2)	
			Total	**1**	
12		i	$\Delta G = \Delta H - T\Delta S = -114 - (298 \times -0.147)$ ✓ $= -70.194$ ($kJ mol^{-1}$)	2 (AO2.2×2)	**ALLOW** $-114000 - (298 \times -147)$ **ALLOW** -70 up to calculator value of

			AND statement of ΔG < 0 **OR** ΔG is –ve **OR** ΔH < TΔS ✓		–70.194 correctly rounded, i.e. –70 **OR** –70.2 **OR** –70.19 **ALLOW** -70000 up to -70194 (J mol^{-1}) **ALLOW ECF** for an incorrectly calculated **negative** value of ΔG linked to feasibility statement **IGNORE** rounding after 3 SF **ORA** for comment about – sign required for feasibility
		ii	776 (K) ✓ i.e. Maximum temperature = $\frac{\Delta H}{\Delta S} = \frac{-114}{-0.147} = 776 \text{ (K)}$ **3 SF required** (appropriate from supplied data)	1 (AO2.2)	
			Total	**3**	
13			**A**	1(AO2.1)	**Examiner's Comments** Only some candidates chose the correct answer of A. Option D was a common incorrect answer through not recognising that the enthalpy change for condensation is negative.
			Total	**1**	
14		i	a measure of the dispersal of energy (in a system) ✓	1 (AO1.1)	**ALLOW** a measure/degree of the disorder (of a system) ORA **Examiner's Comments** Candidates needed to explain that entropy is a measure of the dispersal of energy in a system which is greater, the more disordered a system. A good number of correct answers but quite a few did not get across the required idea of 'a measure of'.
		ii	**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer = −2587 (kJ mol^{-1}) award 3 marks**	3 (AO2.2×3)	**ALLOW ECF throughout**

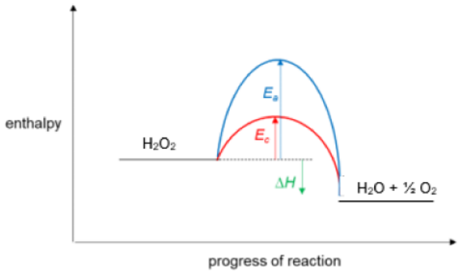
			--------- ΔS^{e} $\Delta S^{e} = 256 + 4(214) + 8(192) - 4(151) - 8(220)$ = (+)284 ($\text{J K}^{-1}\text{ mol}^{-1}$) **OR** (+)0.284 (kJ K−1 mol−1) ✓ *Use of* T = 298 (K) **AND** ΔS = 0.284 ($\text{kJ K}^{-1}\text{ mol}^{-1}$) ✓ $\Delta H = (\Delta G + T\Delta S)$ = −2587 (kJ mol^{-1}) ✓		M2 is for unit conversions seen anywhere. **ALLOW 3SF** up to the calculator value -2587.368 (kJ mol^{-1}) **ALLOW ECF** from incorrect unit conversions or incorrect ΔS. **Common errors 2 marks** -2664.9 (kJ mol^{-1}) (Use of 25°C) 81960 (kJ mol^{-1}) (Use of ΔS 284) 4428 (kJ mol^{-1}) (Use of 25°C and ΔS 284) -2756.632 (kJ mol^{-1}) (Use of ΔS = -0.284) __**Examiner's Comments**__ Almost all candidates had a good attempt at this calculation, with many gaining full marks. Most were able to calculate the entropy change. Almost all could reproduce the equation for free energy. Of those who did not get the correct final answer, the most common error was not converting the entropy value into kJ and/or the temperature to K There were also a few candidates who did not manipulate the equation correctly.
		iii	ΔS is positive/ + **AND** ΔH is negative/ − ✓	2 (AO3.1) (AO3.2)	**ALLOW** ΔH is exothermic **ALLOW** '-TΔS' is negative'

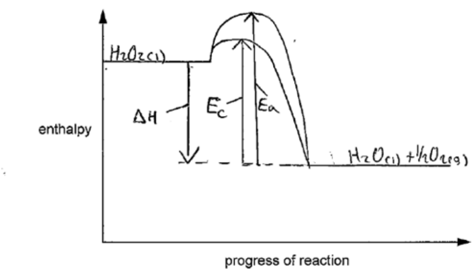
			ΔG is negative (− at all temperatures) **OR** ΔG is (always) negative/ − ✓		*ΔG comment is **dependent** on the signs assigned to ΔS **AND** ΔH (either in answer or from 17 cii).* **ALLOW ECF** from incorrect signs for ΔS and/or ΔH from c(ii) i.e. ΔS is positive/ + **AND** ΔH is positive/ + Reaction is feasible only at high temperatures ΔS is negative/ - **AND** ΔH is negative/ - Reaction is feasible only at low temperatures **IGNORE** ΔS is negative/ - **AND** ΔH is positive/ + (-ΔG given in 17 cii) **--** **Alternative Approach** **ALLOW** use of ΔG=0 for **2 marks** i.e. calculates T = - 9109K ✓ It is always feasible above - 9109K / calculated -ve value and all temperatures are above this ✓ **Examiner's Comments** Many candidates realised the significance of a negative free energy change, but they seemed to struggle to link this to the previous question, giving a more general answer about feasibility, rather than using their values of entropy change and enthalpy change to determine feasibility. If temperature of feasibility was calculated as -9110K many still thought that meant a temperature existed below this which was feasible.
			Total	**6**	
15			**B**	1 (AO 2.2)	**Examiner's Comments** Most candidates were able to use the data correctly. The correct answer

					was B. The main error was from not recognising the need to make 1 mole of SO_3, so the use of ½ mole of O_2, and therefore using the wrong molar ratio.
			Total	**1**	
16			**B**	1 (AO 2.1)	**<u>Examiner's Comments</u>** This question was for the most part answered correctly with B. Errors came from not recognising the reaction is endothermic and therefore its equilibrium would shift to the left when the temperature decreases, ruling out option 2. **Assessment for learning** Practice multiple choice questions can improve the skill in solving and identifying the distractors. Exposure to this type of question style will decrease the time taken over each question. These can often form the basis of end of topic tests. Multiple choice question quizzes can be found via the resource-finder on <u>Teach Cambridge</u> and there are <u>instructions</u> on how to use the online versions of the multiple choice quizzes.
			Total	**1**	
17		i	(ΔS) is positive **AND** more molecules / moles of (gaseous) product /produced✓	1 (AO 2.5 × 1)	**ALLOW** reaction produces more (gaseous) molecules /moles of products than reactants **IGNORE** explanations based on ΔG **<u>Examiner's Comments</u>** Candidates needed to explain the correct sign and understand that entropy is a measure of the dispersal of energy in a system. Most candidates linked the increase in

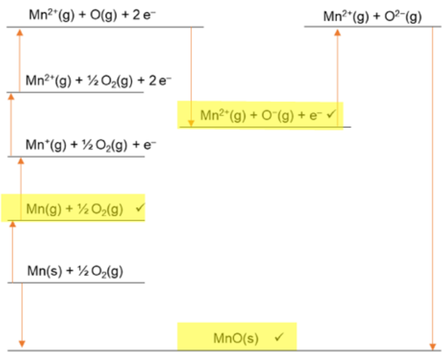
					disorder with the number of moles increasing and therefore the + sign for ΔS. Some candidates were not given the mark as they stated that entropy increases without giving the sign. Some candidates tried to answer using ΔG statements by suggesting ΔH and T values.
		ii	Best fit line drawn ✓ (–)Δ*S* = correct gradient from graph **OR** (–)0.127 (kJ K^{-1} mol^{-1}) ✓ Δ*S* = gradient × –1000 = (+)127 (J K^{-1} mol^{-1}) ✓ Minimum *T* (Δ*G* = 0) = 370 (K) ✓ Δ*H* (*y*-intercept) = (+)46 (kJ mol^{-1}) ✓	5 (AO 3.1 × 2) (AO 3.2 × 3)	Allow **ECF** throughout Place tick for line of best fit on the graph Allow lines that will extrapolate to y axis at 43–47 and x axis at 820–840 **DO NOT ALLOW** outside ranges **ALLOW** rounding to 2SF e.g. (–)Δ*S* = 105 / 830 = (–)0.127 **ALLOW** (–)0.122 to (–)0.131 **ALLOW** 122 to 131 This mark subsumes gradient mark **ALLOW** 340 to 370 **ALLOW** 67 to 97 **AND** °C **DO NOT ALLOW** -ve T in K **ALLOW** 43 to 47 Candidates can receive full credit for calculating Δ*S*, T and/or Δ*H* from previously determined values e.g $T = \frac{\Delta H}{\Delta S} = \frac{46}{0.127} = 362K$ **Examiner's Comments** Nearly all candidates were able to draw the line of best fit and linked the equation of a straight line to the equation for delta G. Some hadn't used a ruler to draw a straight line and candidates should be reminded of this requirement. Candidates were able to recognise that the gradient corresponded to (-) delta S but some did not to use the scale correctly. Some candidates tried to use very

					small triangles to get the gradient and candidates would be advised to use the largest scale possible to minimise errors in the line of best fit. Most candidates recognised that the minimum temperature was the x-intercept (when delta G = 0) and that delta H was the y-intercept. Some did not use this approach and instead used the ΔG=ΔH-TΔS equation, using previously obtained value(s), to calculate the minimum temperature, ΔS or ΔH. Some candidates used ΔH = -186 from a previous question or attempted to solve both ΔS and ΔH by simultaneous equations.
			Total	**6**	
18	a	i	**FIRST CHECK ANSWER ON ANSWER LINE** **If answer = -117 kJ mol^{-1}, award 4 marks.** --- $\Delta H = -286 - (-188)$ $= -98$ kJ mol^{-1} ✓ $\Delta S = 70 + ½(205) - 110 = 62.5$ (J K^{-1} mol^{-1}) or 0.0625 (kJ K^{-1} mol^{-1}) ✓ $\Delta G = \Delta H - T\Delta S$ $= -98 - (298 \times 0.0625)$ ✓ $\Delta G = -117$ kJ mol^{-1} **(3SF)** ✓	4	**ALLOW ECF** throughout **ALLOW** $-98000 - (298 \times 62.5)$ **Common Errors for ΔG** ***3 marks*** *−18700 (ΔS not converted to kJ)* −493 (ΔH = −286 + (−188) = −474) *−147 (ΔS = 165: not halving 205)* *− 99.6 (T not converted to K)* *−18.7 (ΔH not converted J but ΔS* J K^{-1} mol^{-1} *)* (+)79.4 (−188 − (−286) = +98) ***2 marks*** *(+) 117 (incorrect signs for ΔH and ΔS)* ***Final Answer MUST BE 3 SF*** **Examiner's Comments** Almost all candidates had a good attempt at this calculation, with many gaining full marks. Most were able to calculate the entropy change. Almost all could reproduce the equation for free energy. Of those who did not get the correct final answer, the most common error was not converting the entropy value into kJ and / or the temperature to K. There were a few

					candidates who did not manipulate the equation correctly. A few candidates incorrectly calculated ΔS, obtaining the value of 165 J K^{-1} mol^{-1} or ΔH, obtaining -474 kJ mol^{-1}. Candidates were given ECF in these cases.
		ii	(Rate of reaction) slow **OR** Activation energy high ✓	1	**ALLOW** Δ*G* takes no account of rate of reaction **ALLOW** molecules do not have sufficient energy to equal or exceed the activation energy. **IGNORE** molecules do not have sufficient energy to react. **DO NOT ALLOW** there is not enough activation energy **Examiner's Comments** Lots of good answers from candidates were seen for this question. A few candidates attempted the explanation via a ΔG / ΔS argument and misinterpreted the comment within the question.
	b	i	 H_2O_2 on LHS **AND** H_2O + ½ O_2 on RHS **AND** **Δ*H*** labelled with product line below reactant line **AND** Arrow downwards ✓ ***E*ₐ** correctly labelled ✓ **E_c** correctly labelled with $E_c < E_a$ ✓	3	**Care** enthalpy profile must match Δ*H* **sign** in16 a) i) – check calculation **ALLOW** endothermic profile as **ECF** from + Δ*H* calculated in 16 a) i) for all three marks State symbols not required **Δ*H* DO NOT ALLOW −**Δ*H* **DO NOT ALLOW** double headed arrow on Δ*H* **ALLOW** Δ*H* arrow even with small gap at the top and bottom, i.e. line does not quite reach reactant or product line. **E_a and E_c** **ALLOW** no arrowhead or arrowheads

					at both end of E_a or E_c lines E_a or E_c lines must reach maximum (**or near to maximum**) on curve **ALLOW** overlapping lines **OR** lines on side reaching maximum For E_a, **ALLOW** AE **OR** A_E **OR** Eact **OR** suitable alternatives **ALLOW ECF** marks for E_a **and** E_c for correctly labelled endothermic diagram from a $-\Delta H$ value (from16 a) i)) **Examiner's Comments** This question proved more difficult for candidates with lots of inaccuracies. The profile was dependent on the calculation for ΔH in Question 16 (a) (i). The arrowhead for ΔH needs to be pointing from the reactants to the products. The activation energies, again, need to start at the reactant line and go to the maximum level of the curve. Those that needed to draw an endothermic profile were far more likely to make an error with the E_a and E_c arrows, often starting from the product line or even from the base line of the graph. A significant number of candidates did not add arrows and instead labelled the curves E_a and E_c. Some candidates drew a Boltzmann distribution curve scoring 0 marks. Exemplar 1  The candidate has the correct exothermic profile but has the incorrect starting point for the

					activation energy going from the product line.
		ii	(MnO_2) is in different phase/state (to the reactant / H_2O_2) **OR** catalyst is a solid **AND** reactant is liquid ✓	1	**ASSUME** 'it' is MnO_2 **ALLOW** 'species in the reaction' **IGNORE** references to products **Examiner's Comments** This was a well answered question. A few candidates, incorrectly, suggested that it was heterogeneous due to the reactants and products being in different states, and did not mention the catalyst.
		iii	Mn is +2 **AND** +3 **OR** Mn is +1 **AND** +6 ✓	1	+ required **ALLOW** 2+ and 3+ **DO NOT ALLOW** Mn^{2+} Mn^{3+} **DO NOT ALLOW** + 4 (this is the oxidation state in MnO_2) **Examiner's Comments** This question proved more challenging for candidates. Candidates stating +4 was the most common error; this is the oxidation state in MnO_2. Some candidates stated fractions, negative values and gave the state symbol instead i.e. solid and liquid.
	c	i	(Enthalpy / heat energy change / released when) 1 mol of (ionic lattice) ✓ Is formed from its gaseous ions ✓	2	**ALLOW** 1 mol of (ionic) compound/product/substance **IGNORE** energy released/required **ALLOW** $M^+(g) + X^-(g) \rightarrow MX(s)$ **DO NOT ALLOW** one mole of gaseous ions **Examiner's Comments** This question required a standard definition to be recalled. The two components are (a) one mole of an ionic lattice and (b) formed from its gaseous ion. Some candidates

					produced answers combining all the various definitions, most often 1 mol of gaseous ions. In general, when enthalpy definitions are required, candidates should be mindful of whether energy is given out or taken in. The phrase 'enthalpy that accompanies' may be most appropriate when candidates are unsure of the energy change.
		ii		3	Care: State symbols are required **Examiner's Comments** Most candidates scored all three marks. Some candidates wrote illegible state symbols where (g) and (s) were impossible to tell apart, but this was improved on from last year. Also, many candidates choose to write state symbols as a very small sub-script e.g. $Mn_{(s)}$ or $O_{2(g)}$. The convention is to use lower case letters of normal size e.g. Mn(s) or $O_2(g)$. The most common errors were the manganese formula, i.e. MnO_2, and incorrect state symbol with (g) being used. Candidates also missed state symbols in one species, electron on the top left and an incorrect charge on either the Mn or O ions.
		iii	**FIRST CHECK ANSWER ON ANSWER LINE** **If answer = −3798 award 2 marks** **--** ΔH lattice = − 281 − 249 − 717 − 1509 − (−141) − 798 + (−385) ✓ ΔH lattice = −3798 (kJ mol^{-1}) ✓	2	**Common errors for 1 mark** -4080 (use of -141) -3674 (use of +249/2 and correctly rounded) -3673.5 (use of +249/2) -3236 (use of +281) -3300 (use of +249) -3028 (use of -385) -2364 (use of +717) -2202 (use of +798) -780 (use of +1509) +3798 (wrong sign on answer) **For other answers**, check for a **single** transcription error or calculation error which could merit 1 mark

					Examiner's Comments The correct answer was seen frequently, along with lots of the common errors listed on the mark scheme. Candidates tended to misjudge the mole ratio and divided +249 by two. Some candidates applied the cycle incorrectly and therefore used the wrong sign for an enthalpy change, leading to them attaining one mark. Candidates should check for transcription errors as -3789 was often written for -3798.
			Total	**17**	