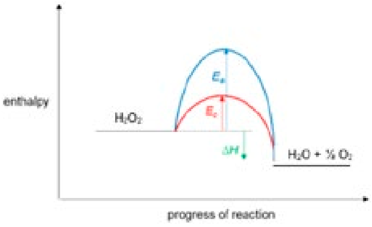
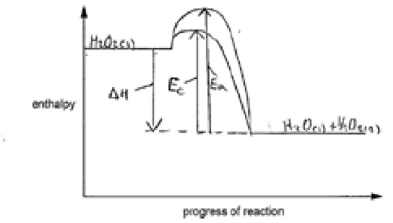
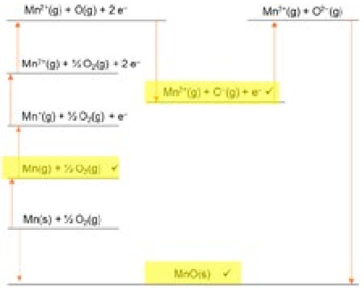
Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1	a	i	**FIRST CHECK ANSWER ON ANSWER LINE** **If answer = −117 kJ mol^{-1}, award 4 marks.** --- Δ*H* = −286− (−188) = −98 kJ mol^{-1} ✓ Δ*S* = 70 + ½(205) − 110 = 62.5 (J K^{-1} mol^{-1}) or 0.0625 (kJ K^{-1} mol^{-1}) ✓ Δ*G* = Δ*H* − TΔ*S* = −98 − (298 × 0.0625) ✓ Δ*G* = −117 kJ mol^{-1} **(3SF)** ✓	4	**ALLOW ECF** throughout **ALLOW** −98000 − (298 × 62.5) **Common Errors for Δ*G*** ***3 marks*** *−18700 (ΔS not converted to kJ)* −493 (Δ*H* = −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*** **<u>Examiner's Comments</u>** 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*** 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 −Δ*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 <u>solid</u> **AND** reactant is <u>liquid</u> ✓	1	**ASSUME** 'it' is MnO_2 **ALLOW** 'species in the reaction' **IGNORE** references to products **<u>Examiner's Comments</u>** 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**	1	+ required **ALLOW** 2+ and 3+

			Mn is +1 **AND** +6 ✓		**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**	
2			**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**	
3			**B**	1 (AO 2.1)	**Examiner's Comments** 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 Teach Cambridge and there are instructions on how to use the online versions of the multiple choice quizzes.
			Total	**1**	
4		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 **Examiner's Comments** 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 ✓ (–)ΔS = correct gradient from graph **OR** (–)0.127 (kJ K^{-1} mol^{-1}) ✓ ΔS = gradient × –1000 = (+)127 (J K^{-1} mol^{-1}) ✓ Minimum T (ΔG = 0) = 370 (K) ✓ ΔH (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. (–)ΔS = 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 ΔS, T and/or ΔH from previously determined values e.g $T = \frac{\Delta H}{\Delta S} = \frac{46}{0.127} = 362K$ **<u>Examiner's Comments</u>** 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**	
5		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 **<u>Examiner's Comments</u>** 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** --- ΔS^{e} ΔS^{e} = 256 + 4(214) + 8(192) − 4(151) − 8(220) = (+)284 (J K^{-1} mol^{-1}) **OR** (+)0.284 (kJ K−1 mol−1) ✓ *Use of* T = 298 (K) **AND**	3 (AO2.2×3)	**ALLOW ECF throughout** 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)

			$\Delta S = 0.284$ (kJ K^{-1} mol^{-1}) ✓ $\Delta H = (\Delta G + T\Delta S)$ = −2587 (kJ mol^{-1}) ✓		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 $\Delta S = -0.284$) **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/ − ✓ ΔG is negative (− at all temperatures) **OR** ΔG is (always) negative/ − ✓	2 (AO3.1) (AO3.2)	**ALLOW** ΔH is exothermic **ALLOW** '$-T\Delta S$' is 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/ + ($-\Delta G$ given in 17 cii) **--** **Alternative Approach** **ALLOW** use of $\Delta G=0$ 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**	
6			**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**	