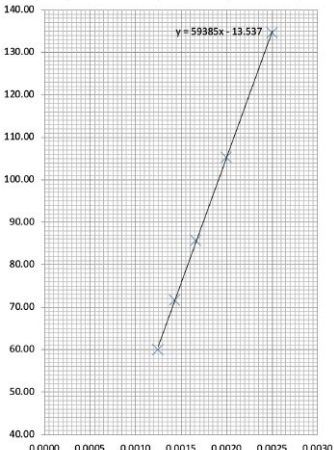


Mark scheme – How Far

Question	Answer/Indicative content	Marks	Guidance
1	<p>FIRST CHECK THE ANSWER ON ANSWER LINE If answer = 7.4 award 4 marks</p> <hr/> <p style="text-align: center;">Initial moles of reactants 1 mark</p> $n(\text{CH}_3\text{OH})_{\text{initial}} = \frac{9.6}{32} = 0.3 \text{ (mol)}$ <p>AND</p> $n(\text{CH}_3\text{COOH})_{\text{initial}} = \frac{12}{60} = 0.2 \text{ (mol)} \checkmark$ <p style="text-align: center;">Equilibrium moles 2 marks</p> $n(\text{CH}_3\text{COOH})_{\text{reacted}} = 0.2 - 0.03 = 0.17 \text{ (mol)}$ <p>AND</p> $n(\text{CH}_3\text{OH})_{\text{equil}} = 0.3 - 0.17 = 0.13 \text{ (mol)} \checkmark$ <p>$n(\text{CH}_3\text{COOCH}_3)_{\text{equil}} = 0.17 \text{ (mol)}$</p> <p>AND</p> $n(\text{H}_2\text{O})_{\text{equil}} = 0.17 \text{ (mol)} \checkmark$ <p style="text-align: center;">K_c calculation 1 marks</p> $K_c = \frac{0.17/V \times 0.17/V}{0.13/V \times 0.03/V} = 7.4 \checkmark$	<p style="text-align: center;">4</p> <p>(AO 1.2×1)</p> <p>(AO 2.8×3)</p>	<p>ALLOW minimum of 2SF throughout</p> <p>ALLOW ECF from initial moles</p> <p>ALLOW ECF from equilibrium moles Use of V not required but K_c expression must be correct</p> <p>ALLOW up to calculator answer of 7.41025641</p> <p>Examiner's Comments</p> <p>This question asked the candidate to calculate K_c. Higher-attaining students tended to gain full marks. Some candidates made full use of tables (e.g. RICE: Reaction, Initial concentration, Change in concentration, Equilibrium concentration) which allowed for credit to be given through error carried forward.</p> <p>Some candidates did not use 0.03 as the change, and lower-attaining candidates did not use water in the K_c expression. Candidates should remember to provide written indications of what it is they are working out – presenting the calculations without any annotations can make it harder for error carried forward marks to be given if there is an error in their calculation.</p>
	Total	4	
2	<p>FIRST CHECK THE ANSWER ON ANSWER LINE If answer = 2.22×10^4 award first 2 marks</p> <hr/> $\ln K_p = -\Delta G/RT = \frac{2.48 \times 10^4}{8.314 \times 298} = 10.01 \checkmark$ <p>$K_p = 2.22 \times 10^4$ (3SF required) \checkmark</p> <p>Units = atm^{-2} \checkmark</p>	<p style="text-align: center;">3</p> <p>(AO 3.1×2)</p> <p>(AO</p>	<p>ALLOW ECF for transcription errors in first sum</p> <p>ALLOW 10 up to calculator value of 10.00979992</p> <p>ALLOW 22200 ALLOW 2.20×10^4 OR 22000 (use of 10)</p> <p>ALLOW alternatives (k)Pa⁻² OR N⁻² m⁴ OR mmHg⁻² OR PSI⁻² OR bar⁻²</p>

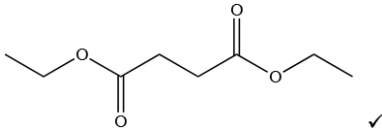
5.1.2 How Far

	c	<p>Plotting of graph All points correctly plotted AND best-fit straight line ✓</p> <p>Gradient Correct gradient of best-fit straight line within the range $\pm 57000 \rightarrow \pm 63000$ ✓</p> <p>ΔH calculation (subsumes mark for gradient) $\Delta H = (-)$ gradient $\times 8.31(4)$ OR calculated value ✓ <i>e.g. from ± 60000, $\Delta H = (+)498840$ (J) OR ± 498.840 (kJ)</i></p> <p>ΔH in kJ mol^{-1} ΔH correct in kJ mol^{-1} AND 3SF AND – sign ✓ <i>e.g. from ± 498840, $\Delta H = -499$ (kJ mol^{-1})</i></p>	<p>4 (AO 3.1)</p> <p>(AO 3.1)</p> <p>(AO 3.2)</p> <p>(AO 3.2)</p>	 <p>ALLOW 4 points on graph Tolerance 1 small square</p> <p>ALLOW ΔH in range: $-480 \rightarrow -530$ (kJ mol^{-1}) This mark subsumes gradient mark</p> <p>Examiner's Comments</p> <p>Candidates were required to plot a graph using their calculated values from the above part. The axes for the graph had been provided. It was expected that the plotting of 5 points, with a best-fit straight line, would be straightforward. Many candidates plotted one or more points incorrectly, particularly the point at $1/T = 1.25 \times 10^{-3}$.</p> <p>Candidates then needed to recognise that the gradient is equal to $-\Delta H/R$ from Equation 5.1, to measure the gradient, and then to determine ΔH. Most candidates recognised that the gradient needed to be measured but its value was then not taken any further. The higher-attaining candidates correctly multiplied the gradient by R but did not always convert the calculated J mol^{-1} value into kJ mol^{-1}, or to express their value to 3 significant figures, as required in the question.</p> <p>Significantly, nearly a third of candidates did not collect any of the four available marks. The question was an excellent discriminator.</p>
	d	<p>Extrapolate line to (y) intercept OR Measure/Use (y) intercept ✓ Intercept $= \frac{\Delta S}{R}$ OR $\Delta S = R \times$ (y) intercept ✓ <i>This statement automatically subsumes 1st mark</i></p> <p>NOTE: If 'x' intercept, DO NOT ALLOW 1st mark but 2nd mark available for $\times R$ as BOD</p>	<p>2 (AO 3.1x2)</p>	<p>ALLOW substitute values of $\ln K_p$, $1/T$ and gradient into Equation 5.1 ✓</p> <p>From provided values and gradient = 60000: $= \frac{\Delta S}{R} = \ln K_p - \text{gradient} \times 1/T$ OR $135 - 60000 \times 2.50 \times 10^{-3} = -15$ ✓</p> <p>Examiner's Comments</p>

5.1.2 How Far

					<p>Mathematically able candidates used the $y = mx + c$ equation for a straight line with the supplied mathematical relationship (Equation 5.1) to identify the y intercept as $\Delta S/R$. They then stated that ΔS could be determined by multiplying the value of the y intercept by R.</p> <p>Many candidates found the mathematical requirements of the above parts difficult. Responses for this part were often in terms of the gradient instead of 'intercept'.</p>
			Total	9	
4			$p(\text{O}_2) = 0.21 \times 1.00 \times 10^5$ $= \mathbf{21,000 / 2.1 \times 10^4 \text{ (Pa)}} \checkmark$	1 AO 2.2	<p><u>Examiner's Comments</u></p> <p>This question tested an understanding of 'partial pressure' as a concept. Most candidates obtained the correct response of 21,000 Pa or 2.1×10^4 Pa. Scaling proved to be a common error with 2.1×10^{-4} Pa being seen, presumably from dividing, instead of multiplying, 0.21 by 1×10^4.</p> <p>In calculations, candidates are advised to think about whether their answer is sensible, rather than relying just on the answer displayed on the calculator.</p>
			Total	1	
5	i		Titration \checkmark	1	<p>IGNORE type of titration</p> <p><u>Examiner's Comments</u></p> <p>Candidates found this part difficult and only higher ability candidates identified that a titration could easily determine the concentration of succinic acid.</p> <p>The answers seen covered most of the techniques encountered in the course. Candidates should consider the information provided in a practical context to arrive at an informed response rather than what sometimes seemed to be a guess.</p>
		ii	$(\text{CH}_2\text{COOH})_2 + 2\text{C}_2\text{H}_5\text{OH} \rightleftharpoons$ $(\text{CH}_2\text{COOC}_2\text{H}_5)_2 + 2\text{H}_2\text{O} \checkmark$	1	<p>ALLOW \rightarrow instead of \rightleftharpoons sign</p> <p>ALLOW molecular formulae or hybrid formulae <i>Structures provided on</i> e.g. $\text{C}_4\text{H}_6\text{O}_4 + 2\text{C}_2\text{H}_6\text{O} \rightleftharpoons \text{C}_8\text{H}_{14}\text{O}_4 + 2\text{H}_2\text{O}$</p> <p><u>Examiner's Comments</u></p> <p>Candidates were required to derive the equation</p>

5.1.2 How Far

				<p>from which the supplied K_c expression had been written.</p> <p>Overall, this part was answered well but some candidates struggled with the brackets or used CH_2COOH_2 for succinic acid.</p>
	iii		1	<p>IGNORE displayed formulae</p> <p>Examiner's Comments</p> <p>This part discriminated extremely well with many candidates finding it difficult to convert the bracketed structural formula into a skeletal formula. Common errors were drawing of the mono-ester or omitting a carbon atom in the centre of the structure.</p> <p>Even when incorrect, most attempted answers were skeletal formulae.</p>
	i v	<p>Volume cancels OR Same number of moles on each side of equation ✓</p>	1	<p>ALLOW units cancel</p> <p>ALLOW (sum of) balancing numbers/coefficients on each side of equation are the same OR same number of (moles of) reactants and products</p> <p>IGNORE volume is the same; K_c has no units</p> <p>Examiner's Comments</p> <p>Many candidates did not seem to realise that the supplied equation used moles, not concentrations. Those who did often stated that the mole representation could be used because the volume was the same for all. Of those who went on to state that the volume would cancel, only a few explained why that was true in this particular case.</p> <p>This challenging part discriminated very well. The best responses showed the units as n/V in the expression and showed that the volumes cancel.</p>
	v	<p>Moles of equilibrium products 1 mark</p> <p>$n((\text{CH}_2\text{COOC}_2\text{H}_5)_2) = 0.0300 \text{ (mol)}$ AND $n(\text{H}_2\text{O}) = 0.0600 \text{ (mol)} \checkmark$</p> <p>Moles of $\text{C}_2\text{H}_5\text{OH}$ 1 mark</p> <p>$n(\text{C}_2\text{H}_5\text{OH}) = 0.150 - 0.060 = 0.0900 \text{ (mol)} \checkmark$</p>	3	

5.1.2 How Far

		<p>K_c calculated</p> $= \frac{0.03 \times 0.06^2}{0.02 \times 0.09^2} = 0.667 \text{ OR } 0.67 \checkmark$ <p>NOTE: 0.02 must be used for n(succinic acid)</p>	<p>1 mark</p>	<p>ALLOW ECF</p> <p>ALLOW 0.66, 0.666, etc. (2 SF and more) <i>Treated as meaning 0.6 recurring</i></p> <p>ALLOW 2/3 IGNORE any units</p> <p><u>Examiner's Comments</u></p> <p>Overall, this part discriminated well with many candidates obtaining the correct answer of 0.67. Common errors included a one significant figure answer of 0.6 or 0.7 and 0.375, by using 0.12 mol instead of 0.09 mol for the moles of ethanol.</p> <p>Many successful answers were well-presented and included a table of initial and final values. This gave a systematic way of deriving the equilibrium moles.</p>
		Total	7	
6	a	$K_c = \frac{[\text{NO}_2]^2}{[\text{NO}]^2 [\text{O}_2]} \checkmark$ <p>Units = $\text{dm}^3 \text{ mol}^{-1} \checkmark$</p>	2	<p>Must be square brackets IGNORE state symbols</p> <p>ALLOW $\text{mol}^{-1} \text{ dm}^3$ ALLOW mol dm^{-3} as ECF from inverted K_c expression</p> <p><u>Examiner's Comments</u></p> <p>The expression and the units were almost universally known by the candidates.</p>
	b	<p>FIRST CHECK THE ANSWER ON THE ANSWER LINE IF answer = 1.2 (mol) award 4 marks</p> <p>Unless otherwise stated, marks are for correctly calculated values. Working shows how values have been derived.</p> $[\text{NO}] = \frac{0.40}{4.0} = 0.1(0) \text{ (mol dm}^{-3}\text{)} \checkmark$ <p>AND</p> $[\text{O}_2] = \frac{0.80}{4.0} = 0.2(0) \text{ (mol dm}^{-3}\text{)} \checkmark$ $[\text{NO}_2]^2 = 45 \times 0.102 \times 0.20 \text{ OR } = 0.09(0) \checkmark$ $[\text{NO}_2] = \sqrt{(45 \times 0.10^2 \times 0.20)} \text{ OR } = 0.3(0) \text{ (mol dm}^{-3}\text{)} \checkmark$ <p>amount $\text{NO}_2 = 0.30 \times 4 = 1.2 \text{ (mol)} \checkmark$</p>	4	<p><i>ANNOTATIONS MUST BE USED</i></p> <p>For all parts, ALLOW numerical answers from 2 significant figures up to the calculator value</p> <p>Ignore rounding errors after second significant figure</p> <p>1st mark is for realising that concentrations need to be calculated.</p> <p>ALLOW ECF</p> <p>Correct numerical answer with no working would score all previous calculation marks</p> <p>Making point 2 subsumes point 1</p>

5.1.2 How Far

				<p>Making point 3 subsumes points 2 and 1</p> <p>Common errors 9.6 = 3 marks mol of NO and O₂ used 0.36 = 3 marks mol of NO₂ calculated from [NO₂]² 2.4 = 2 marks mol of NO and O₂ used and no mol of NO₂ calculated</p> <p><u>Examiner's Comments</u></p> <p>There were three steps to this calculation:</p> <p>Conversion of molar quantities of NO and O₂ to molar concentrations.</p> <p>Insertion into the K_c expression and determination (via a square root calculation) of the molar concentration of NO₂.</p> <p>Conversion of the molar concentration of NO₂ to a molar quantity.</p> <p>Steps 1 and/or 3 of the calculation were occasionally omitted but if the calculation was presented in a coherent manner, even here, partial credit was awarded.</p>
c	i	<p>Exothermic</p> <p>AND</p> <p>K_p decreases as temperature increases ✓</p>	1	<p>ALLOW K_c for K_p</p> <p>ALLOW Equilibrium shifts to left hand side as temperature increases</p> <p><u>Examiner's Comments</u></p> <p>Most candidates knew the forward reaction was exothermic due to K_p decreasing as temperature increased.</p> <p>A common error was to write vague responses such as 'K_p decreases with temperature'.</p>
		<p><i>Equilibrium shift</i></p> <p>(Equilibrium position) shifts to right / forward / towards products ✓</p> <p><i>Effect of increased pressure on K_p expression</i></p> <p>Ratio (in K_p expression) decreases OR</p>	3	<p>FULL ANNOTATIONS NEEDED</p> <p>ALLOW K_c for K_p throughout the response.</p> <p>ALLOW K_p (initially) decreases for second marking point IF K_p is seen to be restored later in the process.</p>

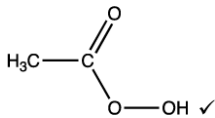
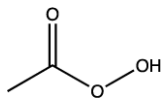
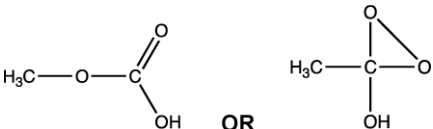
5.1.2 How Far

		<p>Calculation of [SO₃(g)] 2 MARKS</p> $[\text{SO}_3] = \sqrt{(K_c \times [\text{SO}_2]^2 \times \text{O}_2)}$ <p>OR $\sqrt{(3.045 \times 10^4 \times 0.135^2 \times 0.0675)}$ ✓</p> $= 6.12039291 \text{ (mol dm}^{-3}\text{)} \checkmark$ <p><i>Answer scores both [SO₃] marks automatically</i></p> <p>Calculation of n(SO₃) in 400 cm³ 1 MARK</p> $n(\text{SO}_3) = 6.12039291/2.5 = 2.45 \text{ (mol)} \checkmark$ <p>3SF required (Appropriate number)</p>		<p>ALLOW ECF from incorrect [SO₃]</p> <p>ALLOW 3 SF, 6.12, up to calculator value of 6.12039291 correctly rounded.</p> <p>Common errors</p> <p>37.5 1 mark <i>No √ for [SO₃]² and no scaling by 1/2.5</i></p> <p>15.0 2 marks <i>No √ for [SO₃]²</i></p> <p>0.619 3 marks <i>Use of mol of SO₂ and O₂</i></p> <p>1.55 2 marks <i>No conc used and Use of mol of SO₂ and O₂</i></p> <p>Examiner's Comments There were three steps to this calculation:</p> <ul style="list-style-type: none"> • Conversion of molar quantities of SO₂ and O₂ to molar concentrations. • Insertion into the K_c expression and determining of the molar concentration of SO₃. • Conversion of the molar concentration of SO₃ to a molar quantity including an appropriate number of significant figures. <p>Steps 1 and / or 3 of the calculation were occasionally omitted but as long as the calculation was presented in a coherent manner, partial credit was awarded.</p>
		Total	6	
8	i	(Species have) different states / phases ✓	1	<p>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.</p>
	ii	(K _p =) p(CO(g)) ⁴ ✓	1	<p>Allow species without state symbols and without brackets, e.g. Pco⁴, ppCO⁴, PCO⁴, p(CO⁴) etc.</p>

5.1.2 How Far

				<p>DO NOT ALLOW square brackets</p> <p>Examiner's Comments Marks were awarded for less than perfect versions of $K_p = p(\text{CO}(\text{g}))^4$. 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.</p> <p>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.</p>
	iii	<p>ΔG at 25 C</p> $\Delta G = \Delta H - T\Delta S = 676.4 - (298 \times 0.7031)$ $= (+) 467 \text{ (kJ mol}^{-1}\text{) OR (+) 466876}$ $\text{(J mol}^{-1}\text{) } \checkmark$ <p><i>Non-feasibility statement</i></p> <p>Non-feasible when $\Delta G > 0$ OR $\Delta G > 0$ OR $\Delta H > T\Delta S$ ✓</p> <p><i>Minimum temperature</i></p> $\text{minimum temperature} = \frac{\Delta H}{\Delta S} = \frac{676.4}{0.7031}$ $= 962(.0) \text{ K } \checkmark$	3	<p>IGNORE units ALLOW (+) 467 up to calculator value of 466.8762 correctly rounded</p> <p>ECF for any positive value determined in M1</p> <p>ALLOW 962 up to calculator value of 962.0253165 correctly rounded</p> <p>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.</p> <p>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.</p> <p>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.</p>
	i v	<p>FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = -110.5, Award 3 marks.</p> <p>.....</p> <p>Correct expression</p> $-13.5 = (4 \times -393.5) - (-1118.5 + 4$	3	<p>For answer, ALLOW -111 (kJ mol⁻¹)</p> <p>.....</p> <p>....</p>

5.1.2 How Far

		<p>$\times \Delta_f H(\text{CO}) \checkmark$</p> <p>Correct subtraction using ΔH and $\Delta_f H(\text{Fe}_3\text{O}_4)$</p> $4 \times \Delta_f H(\text{CO}) = (4 \times -393.5) - (-1118.5)$ $+ 13.5$ $= -442(.0) \text{ (kJ mol}^{-1}\text{)} \checkmark$ <p>Calculation of $\Delta_f H(\text{CO})$ formation</p> $\Delta_f H(\text{CO}) = -\frac{442}{4} = -110.5 \text{ (kJ mol}^{-1}\text{)} \checkmark$		<p>NOTE: IF any values are omitted, DO NOT AWARD any marks. e.g. -393.5 OR -13.5 may be missing</p> <p>.....</p> <p>....</p> <p>Common errors</p> <table> <tbody> <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 4CO_2</td> <td>1 mark</td> </tr> <tr> <td>-360.5</td> <td>Used 118.5</td> <td>2 marks</td> </tr> </tbody> </table> <p>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</p> <p>Examiner's Comments</p> <p>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.</p>	(+)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 4CO_2	1 mark	-360.5	Used 118.5	2 marks
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(+)177.875 / 177.88 / 177.9 / 178	Wrong cycle, no 4CO_2	1 mark																							
-360.5	Used 118.5	2 marks																							
		Total	8																						
9	i	 <p>ALLOW skeletal OR displayed formula OR mixture of the above as long as non-ambiguous, e.g.</p> 	1	<p>ALLOW</p>  <p>Structure must include OH as part of COOH group</p> <p>ALLOW $-\text{O}^- \text{H}^+$ in structure</p>																					

5.1.2 How Far

			<p>Examiner's Comment: This part was attempted well, with many providing a structure containing the correct COOOH functional group. The mark scheme did allow alternatives provided that the three O atoms were bonded to the C atom, e.g. H₃C-O-COOH</p>
ii		<p>FIRST CHECK THE ANSWER ON THE ANSWER LINE IF answer = 0.023(125) (mol) award 3 marks for calculation</p> <p>.....</p> <p><i>K_c expression</i></p> $(K_c =) \frac{[\text{CH}_3\text{COOOH}]}{[\text{H}_2\text{O}_2][\text{CH}_3\text{COOH}]} \checkmark$ <p>[CH₃COOOH]</p> $= 0.37 \times 0.500 \times 0.500 = 0.0925$ <p>(mol dm⁻³) ✓ <i>Subsumes K_c expression</i></p> <p>n(CH₃COOOH)</p> $= 0.0925 \times \frac{250}{1000} = 0.023(125) \text{ (mol)} \checkmark$	<p>If there is an alternative answer, check for any ECF credit</p> <p>.....</p> <p>....</p> <p>ALLOW $0.37 = \frac{[\text{CH}_3\text{COOOH}]}{0.500 \times 0.500}$</p> <p>ALLOW ECF but ONLY if 0.37 AND 0.5 × 0.5 have been used</p> <p>Common errors</p> <p>0.076 2 marks <i>Use of [CH₃COOOH]²</i></p> <p>0.675 2 marks <i>Use of 0.5 for [H₂O] on K_c</i></p> <p>0.169 2 marks <i>Inverted K_c</i></p> <p>0.338 1 mark <i>Inverted K_c AND 0.5 for [H₂O]</i></p> <p>5.78 × 10⁻³ 2 marks <i>× $\frac{250}{1000}$ before [CH₃COOOH]</i></p> <p>Examiner's Comment: Many candidates obtained the correct answer but water was often seen in the K_c expression. Candidates then assigned arbitrary values to the concentration of the water, often the same as CH₃COOH, unity, or even 55.6 from 1000/18.</p>

5.1.2 How Far

				The mark scheme allowed some credit by use of error carried forwards. Answer: 0.023 mol
		Total	4	
1 0	a	<p>FIRST, CHECK THE ANSWER ON ANSWER LINE IF $K_c = 104 \text{ dm}^3 \text{ mol}^{-1}$ award 4 marks: 3 for calculation of 104 from data, 1 for units </p> <p>Equilibrium concentrations (mol × 5) (1 mark)</p> <p>$I_2 = 4.00 \times 10^{-5} \times 5 = 2.00 \times 10^{-4} \text{ (mol dm}^{-3}\text{)}$ AND $I^- = 9.404 \times 10^{-2} \times 5 = 0.4702 \text{ (mol dm}^{-3}\text{)}$ ✓ AND $I_3^- = 1.96 \times 10^{-3} \times 5 = 9.80 \times 10^{-3} \text{ (mol dm}^{-3}\text{)}$</p> <p>Calculation of K_c and units (3 marks)</p> $K_c = \frac{[I_3^-(aq)]}{[I_2(aq)] \times [I^-(aq)]} \text{ OR } \frac{9.80 \times 10^{-3}}{2.00 \times 10^{-4} \times 0.4702} \checkmark$ <p>= 104 ✓ Must be 3 SF</p> <p>$\text{dm}^3 \text{ mol}^{-1}$ OR $\text{mol}^{-1} \text{ dm}^3$ ✓</p>	4	<p>FULL ANNOTATIONS MUST BE USED </p> <p>Throughout, at least 3SF but ALLOW absence of trailing zeroes e.g. for 9.80×10^{-3} ALLOW 9.8×10^{-3} FOR I^- 0.4702, ALLOW 0.47(0) (mol dm⁻³) still → 104 for calc</p> <p>State symbols not required in K_c expression ALLOW ECF from incorrect concentrations</p> <p>Any ECF value MUST be to 3 SF for K_c value </p> <p>COMMON ERRORS 104.2 → 104.2109741 (calc) > 3 SF 2 marks + units</p> <p>521 no × 5 for concs 2 marks + units</p> <p>521.1 → 521.0548703 as above and > 3SF 1 mark + units</p> <p>2610 ÷ 5 instead of × 5 for concs 2 marks + units</p> <p>9.60 × 10⁻³ K_c upside down, correct concs 2 marks + units</p> <p>1.92 × 10⁻³ K_c upside down, no × 5 for concs 1 mark + units</p> <p>NOTE: With K_c upside down, units become mol dm⁻³ by ECF</p> <p>Examiner's Comments</p> <p>This question was about equilibrium, set in the context of the solubility of iodine.</p> <p>Most candidates are comfortable with</p>

5.1.2 How Far

				<p>calculations of equilibrium constants. The correct numerical answer of 104 and units of $\text{dm}^3 \text{mol}^{-1}$ were seen often. The commonest calculation error was use of the equilibrium moles, rather than concentrations, giving 521.</p> <p>This question asked for the final value to be expressed to the most appropriate number of significant figures. Candidates should use the least significant number of significant figures in the provided data, in this case 3. Many candidates lost a mark by using more than 3 significant figures (e.g. 104.2 and 104.21). Answer: $K_c = 104 \text{ dm}^3 \text{mol}^{-1}$</p>
	b	<p>Ag^+ / silver nitrate reacts with I^- to form AgI / silver iodide OR $\text{Ag}^+ + \text{I}^- \rightarrow \text{AgI} \checkmark$</p> <p>yellow precipitate / solid forms \checkmark</p> <p>Equilibrium 2 shifts to the left \checkmark</p> <p>Equilibrium 1 shifts to left AND I_2 comes out of solution / less I_2 dissolves / I_2 precipitates / black solid / grey solid / violet solid \checkmark</p>	4	<p>FULL ANNOTATIONS MUST BE USED DO NOT ALLOW cream OR cream73–yellow ALLOW just ‘yellow’ if supported by AgI(s) somewhere</p> <p>Examiner’s Comments</p> <p>This question was about equilibrium, set in the context of the solubility of iodine.</p> <p>This part required candidates to apply their knowledge and understanding of equilibria to a novel situation. Candidates were expected to predict that $\text{Ag}^+(\text{aq})$ and $\text{I}^-(\text{aq})$ ions would react together to form AgI(s), a yellow precipitate, shifting equilibrium 2 to the left. Equilibrium 1 would then shift to the left forming solid iodine. Responses in terms of equilibrium 2 were seen far more often than for Equilibrium 1.</p>
		Total	8	
1 1	i	<p>FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = $57.6 \text{ dm}^3 \text{mol}^{-1}$, award 6 marks IF answer = 57.6 with incorrect units, award 5 mark</p> <p>Equilibrium amounts in mol 2 MARKS</p> <p>$n(\text{SO}_2) = 0.180 \text{ (mol)}$ ALL 3 correct: $\checkmark \checkmark$ $n(\text{O}_2) = 0.090 \text{ (mol)}$ ANY 2 correct: \checkmark $n(\text{SO}_3) = 0.820 \text{ (mol)}$</p> <p>Equilibrium concentrations (moles \times 4) 1 MARK</p> <p>$\text{SO}_2 = 0.720 \text{ (mol dm}^{-3}\text{)}$ AND $\text{O}_2 = 0.360 \text{ (mol dm}^{-3}\text{)}$ AND $\text{SO}_3 = 3.28 \text{ (mol dm}^{-3}\text{)} \checkmark$</p>	6	<p>FULL ANNOTATIONS NEEDED</p> <p>IF there is an alternative answer, check to see if there is any ECF credit possible using working below</p> <p>ALLOW ECF from incorrect moles of SO_2, O_2 AND SO_3</p> <p>ALL three concentrations required for this mark</p> <p>ALLOW ECF from incorrect concentrations</p> <p>NO ECF for numerical value with a square</p>

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		<p>Calculation of K_c and units 3 MARKS</p> $K_c = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2 [\text{O}_2]} \text{ OR } \frac{3.28^2}{(0.720)^2 \times (0.360)} \checkmark$ $= 57.6 \checkmark \text{ dm}^3 \text{ mol}^{-1} \checkmark$ <p><i>At least 3SF is required</i></p>	<p>missing</p> <p>For K_c, ALLOW 3 significant figures up to calculator value of 57.64746228 correctly rounded</p> <p>For units, ALLOW $\text{mol}^{-1} \text{ dm}^3$ DO NOT ALLOW dm^3 / mol</p> <p>ALLOW ECF from incorrect K_c expression for both calculation and units</p> <p>COMMON ERRORS 0.0294 3 marks + units mark from $\text{SO}_2 = 0.820$, $\text{O}_2 = 0.410$, $\text{SO}_3 = 0.180$ (mol)</p> <p>Examiner's Comments</p> <p>Many candidates are now well-rehearsed for this type of question. Candidates were expected to determine the equilibrium amounts, convert to concentrations by multiplying by 4 or dividing by 0.250, and to use the concentration values to obtain the K_c value. Three easy marks were available for the K_c expression, a correct calculation using calculated concentrations, and the units. As expected the equilibrium amounts caused the biggest problems for candidates. Most correctly obtained 0.180 mol for SO_2 and 0.820 mol for SO_3 (although some had these reversed or even the same). The amount of O_2 was often incorrect with 0.410 mol (0.500 – 0.090), rather than 0.090 mol, being commonly seen. The majority used 1000/250 or $\div 0.250$ to calculate concentrations from their equilibrium amounts. Some omitted this stage whilst other just divided by 250 or multiplied instead of dividing. Throughout, the examiners marked consequentially so that an individual error was not repeatedly penalised. Consequently the majority of candidates scored 4–6 marks for this part.</p> <p>Answer: $K_c = 57.6 \text{ dm}^3 \text{ mol}^{-1}$</p>
	ii	(Pressure) decreases AND fewer molecules / moles \checkmark	<p>1</p> <p>For fewer moles, ALLOW 3 mol \rightarrow 2 mol ALLOW more moles of reactants</p> <p>Examiner's Comments</p> <p>Surprisingly this part presented problems to many candidates. The examiners were expecting to see a response in terms of a decreased pressure from the presence of fewer gas molecules. However, many candidates</p>

5.1.2 How Far

					responded with an increase or even the same pressure. This question discriminated extremely well.
		iii	ΔH is negative / '- ' / -ve AND yield of SO_3 decreases ✓	1	<p>IGNORE exothermic and endothermic</p> <p>Examiner's Comments</p> <p>Candidates had far more success with this part, with the vast majority responding with a negative ΔH value and decreased yield of SO_3. Weaker candidates often used exothermic (or even endothermic) instead and obtained the incorrect effect.</p>
		i v	<p>IGNORE le Chatelier responses</p> <p>.....</p> <p>Each marking point is independent</p> <p>K_c K_c does not change (with pressure / concentration) ✓</p> <p>Comparison of conc terms with more O_2 [O_2] / concentration of oxygen is greater OR denominator / bottom of K_c expression is greater ✓</p> <p>QWC: yield of SO_3 linked to K_c (Yield of) SO_3 is greater / increases AND</p>		<p>FULL ANNOTATIONS NEEDED</p> <p>ALLOW K_c only changes with temperature</p> <p>IF 1st marking point has been awarded, IGNORE comments about 'K_c decreasing' or 'K_c increasing' and assume that this refers to how the ratio subsequently changes. i.e DO NOT CON 1st marking point.</p> <p>IGNORE O_2 is greater / increases</p> <p>ALLOW (Yield of) SO_3 is greater / increases AND</p>
		i v	numerator / top of K_c expression is greater / increases ✓	3	<p>to reach / restore K_c value ✓</p> <p>Examiner's Comments</p> <p>Explaining shifts in equilibrium in terms of K_c is far more difficult than the simpler le Chatelier approach. The examiners were impressed by the responses from able candidates with some excellent explanations comparing the values of the denominator and numerator between the two experiments and the consequential effect on the concentration of SO_3. Many responses did state that K_c is unaffected by changes in concentration or pressure but the explanation then used le Chatelier's principle.</p> <p>This part discriminated extremely well and unfortunately weaker candidates often failed to score.</p>
			Total	11	

5.1.2 How Far

				<p>$K_c = 0.0531$ No $\div 4$ throughout 1 mark + units</p> <p>Examiner's Comments</p> <p>Many candidates are well-rehearsed for this type of question. Candidates were expected to use the equilibrium amounts, convert to concentrations by dividing by 4 and to use these values to obtain the K_c value. A common mistake was omission of the concentration stage, leading to a value of 2.45. More calculator errors were seen than in the past, perhaps caused by the cubed power within the numerator. Candidates without a cubed function key on the calculator can simply multiply a value with itself three times. Few candidates failed to express their numerical value for K_c to three significant figures. The units caused few problems although some inverted units were seen.</p> <p>Answer: $0.153 \text{ mol}^2 \text{ dm}^{-6}$</p>																				
		<p>Initial amount of CH₄</p> <p>iii amount of CH₄ = $9.36 \times 10^{-2} + 2 \times 0.168$ = 0.4296 OR 0.43(0) (mol) ✓</p>	1	<p>NO ECF possible (all data given in question)</p> <p>Examiner's Comments</p> <p>Although this part was more challenging than the initial molar ratio in (b)(i), many candidates were able to work out the amount of CH₄ that had reacted as $2 \times 9.36 \times 10^{-2}$ and to then add this to the remaining amount of CH₄: 9.36×10^{-2}. This part did cause a lot of difficulty for weaker candidates with a range of incorrect numerical answers being seen.</p> <p>Answer: 0.4296 mol</p>																				
	c	<table border="1"> <thead> <tr> <th>Change</th> <th>K_c</th> <th>Equilibrium amount of C₂H₂ / mol</th> <th>Initial rate</th> </tr> </thead> <tbody> <tr> <td>temperature increased</td> <td>greater</td> <td>greater</td> <td>greater</td> </tr> <tr> <td>smaller container</td> <td>same</td> <td>smaller</td> <td>greater</td> </tr> <tr> <td>catalyst added</td> <td>same</td> <td>same</td> <td>greater</td> </tr> <tr> <td></td> <td>✓</td> <td>✓</td> <td>✓</td> </tr> </tbody> </table>	Change	K_c	Equilibrium amount of C ₂ H ₂ / mol	Initial rate	temperature increased	greater	greater	greater	smaller container	same	smaller	greater	catalyst added	same	same	greater		✓	✓	✓	3	<p>Mark by COLUMN</p> <p>ALLOW obvious alternatives for greater / smaller / same, e.g. increases / decreases; more / less</p> <p>Examiner's Comments</p> <p>This part tested candidates understanding of how three quantities would change from changes to experimental conditions. This was marked by column.</p> <p>Of the three quantities, K_c and rate were correct more often than the equilibrium amount of C₂H₂. This question discriminated extremely well. Strangely, some candidates chose to use their own words instead of those provided and</p>
Change	K_c	Equilibrium amount of C ₂ H ₂ / mol	Initial rate																					
temperature increased	greater	greater	greater																					
smaller container	same	smaller	greater																					
catalyst added	same	same	greater																					
	✓	✓	✓																					

5.1.2 How Far

				examiners often saw words such as 'increases' and 'decreases'. As the meaning was clear, such responses were still credited.
			Total	9
1 3	a	<p>FIRST CHECK THE ANSWER ON ANSWER LINE IF answer = 0.812 dm⁶ mol⁻², award 6 marks IF answer = 0.812 with incorrect units, award 5 marks</p> <p>.....</p> <p>Equilibrium amounts in mol 2 MARKS</p> <p style="text-align:right">$n(\text{N}_2) = 0.62(0)$ $n(\text{N}_2) = 1.86$</p> <p>Equilibrium concentrations in mol dm⁻³ (mol ÷ 5) 1 MARK</p> <p style="text-align:right">$\text{N}_2 = 0.124$ AND $\text{H}_2 = 0.372$ AND $\text{NH}_3 = 0.072$</p> <p>Calculation of K_c and units 3 MARKS</p> <p>$K_c = \frac{[\text{NH}_3(\text{g})]^2}{[\text{N}_2(\text{g})] \times [\text{H}_2(\text{g})]^3}$ OR $\frac{0.072^2}{0.124 \times 0.372^3}$</p> <p>= 0.812 dm⁶ mol⁻²</p> <p><i>At least 3SF is required</i></p>	6	<p>FULL ANNOTATIONS NEEDED IF there is an alternative answer, check to see if there is any ECF credit possible using working below</p> <p>.....</p> <p>.</p> <p>ALLOW ECF from incorrect moles of N₂, H₂ AND / OR NH₃ ALL three concentrations required for mark</p> <p>ALLOW ECF from incorrect concentrations OR use of moles (omitting conc stage)</p> <p>NO ECF for numerical value with a square AND / OR cube missing</p> <p>For K_c, ALLOW 3 significant figures up to calculator value of 0.8121093077 correctly rounded</p> <p>For units, ALLOW mol⁻² dm⁶ DO NOT ALLOW dm⁶/mol⁻²</p> <p>.....</p> <p>.</p> <p>COMMON ERRORS 0.0325 3 marks + units mark from N₂ = 0.620, H₂ = 1.86, NH₃ = 0.360 (mol)</p>
	b i	<p>IGNORE le Chatelier responses</p> <p>.....</p> <p>Each marking point is independent</p> <p>K_c K_c does not change (with pressure / concentration)</p> <p>Comparison of conc terms with more N₂ [N₂] increases</p>	3	<p>FULL ANNOTATIONS NEEDED</p> <p>ALLOW K_c only changes with temperature</p> <p>IF 1st marking point has been awarded, IGNORE comments about 'K_c decreasing' or 'K_c</p>

5.1.2 How Far

		<p>OR denominator / bottom of K_c expression increases</p> <p>yield of NH_3 linked to K_c Chemist is correct AND denominator decreases OR numerator increases to restore equilibrium K_c</p>		<p>increasing' and assume that this refers to how the ratio subsequently changes. i.e. DO NOT CON 1st marking point.</p>
	ii	<p>N_2 obtained from the air AND H_2 must be manufactured / does not occur naturally</p>	1	<p>N_2 is more readily available not insufficient.</p> <p>ALLOW an example of H_2 manufacture, e.g. from oil / gas / water</p> <p>BOTH responses required for mark.</p>
		Total	10	
1 4	a	<p>The forward reaction is exothermic, so an increase in temperature favours the backward reaction (<i>owtte</i>) ... (1)</p> <p>... therefore there will be more N_2 and H_2 OR less NH_3 in the equilibrium mixture, AND therefore the value of the equilibrium constant will decrease (<i>owtte</i>) (1)</p>	2	<p>allow names of compounds allow reactants / product instead of compounds 2nd mark only available if deduced from 1st mark allow ecf for 2nd mark</p>
	b	<p>FIRST CHECK THE ANSWER ON THE ANSWER LINE IF answer = $2.37 \times 10^{-6} \text{ kPa}^{-2}$ award 5 marks IF answer = 2.37×10^{-6} with incorrect units award 4 marks</p> <p>At equilibrium, $n(H_2) = 0.300 \text{ (mol)}$ AND $n(NH_3) = 0.100 \text{ (mol)}$ (1)</p> <p style="text-align: center;"><u>0.400</u></p> <p>$p(N_2) = 0.800 \times 500 = 250 \text{ kPa}$ AND</p> <p style="text-align: center;"><u>0.300</u></p> <p>$p(H_2) = 0.800 \times 500 = 187.5 \text{ kPa}$ AND</p> <p style="text-align: center;"><u>0.100</u></p> <p>$p(NH_3) = 0.800 \times 500 = 62.5 \text{ kPa}$ (1)</p> $K_p = \frac{p(NH_3)^2}{p(N_2) \times p(H_2)^3} = \frac{62.5^2}{250 \times 187.5}$ <p>(1)</p> <p>= 2.37×10^{-6} (1) kPa^{-2} (1)</p>	5	<p>Final answer must be correct and have the correct units to score all five marks allow calculator value for K_p correctly rounded to three or more significant figures.</p> <p>If there is an alternative answer, check to see if there is any ECF credit possible using working below</p> <p>Correct values substituted into correct expression for K_p gains first three marks.</p>
		Total	7	