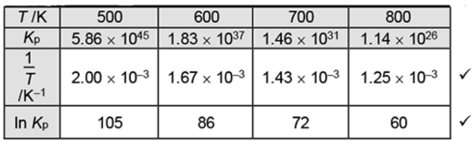
Mark scheme – How Far

Question			Answer/Indicative content	Marks	Guidance
1			**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer = 7.4 award 4 marks** -- **Initial moles of reactants 1 mark** $n(CH_3OH)_{initial} = \frac{9.6}{32} = 0.3$ (mol) **AND** $n(CH_3COOH)_{initial} = \frac{12}{60} = 0.2$ (mol) ✓ **Equilibrium moles 2 marks** $n(CH_3COOH)$ reacted = 0.2 – 0.03 = 0.17 (mol) **AND** $n(CH_3OH)_{equil}$ = 0.3 – 0.17 = 0.13 (mol) ✓ $n(CH_3COOCH_3)_{equil}$ = 0.17 (mol) **AND** $n(H_2O)_{equil}$ = 0.17 (mol) ✓ ***K*c calculation 1 marks** $K_c = \frac{0.17/V \times 0.17/V}{0.13/V \times 0.03/V} = 7.4$ ✓	4 (AO 1.2×1) (AO 2.8×3)	**ALLOW** minimum of **2SF** throughout **ALLOW ECF** from initial moles **ALLOW ECF** from equilibrium moles Use of V not required but Kc expression must be correct **ALLOW** up to calculator answer of 7.41025641 **Examiner's Comments** 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. 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.
			Total	**4**	
2			**FIRST CHECK THE ANSWER ON ANSWER LINE If answer =** 2.22×10^4 **award first 2 marks** -- $\ln K_p = -\Delta G/RT = \frac{2.48 \times 10^4}{8.314 \times 298} = 10.01$ ✓ $K_p = 2.22 \times 10^4$ (**3SF required**) ✓ Units = atm^{-2} ✓	3 (AO 3.1×2) (AO	**ALLOW ECF** for transcription errors in first sum **ALLOW** 10 up to calculator value of 10.00979992 **ALLOW** 22200 **ALLOW** 2.20×10^4 **OR** 22000 (use of 10) **ALLOW** alternatives (k)Pa^{-2} **OR** $N^{-2}\ m^4$ **OR** $mmHg^{-2}$ **OR** PSI^{-2} **OR** *bar*$^{-2}$

<table>
<tr><td></td><td></td><td></td><td></td><td>1.2×1)</td><td><i>Common errors for 1 mark:</i>
<i>22400 (use of 8.31)</i>
<i>4.50 x 10^{-5} (use of -10.01)</i>

<i><u>Examiner's Comments</u></i>

<i>This was an unfamiliar expression linking ΔG and K_p. Many candidates correctly calculated this number. Some candidates calculated ln K_p as 10.0 but then put a – in front for the e calculation. The question required the answer to 3 significant figures. Higher-attaining candidates were able to work out the units as any pressure unit $^{-2}$.</i></td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>3</td><td></td></tr>
<tr><td>3</td><td>a</td><td></td><td>
<table>
<tr><td>T /K</td><td>500</td><td>600</td><td>700</td><td>800</td><td></td></tr>
<tr><td>K_p</td><td>5.86×10^{45}</td><td>1.83×10^{37}</td><td>1.46×10^{31}</td><td>1.14×10^{26}</td><td></td></tr>
<tr><td>$\frac{1}{T}$ /K^{-1}</td><td>2.00×10^{-3}</td><td>1.67×10^{-3}</td><td>1.43×10^{-3}</td><td>1.25×10^{-3}</td><td>✓</td></tr>
<tr><td>ln K_p</td><td>105</td><td>86</td><td>72</td><td>60</td><td>✓</td></tr>
</table>
<i>Calculator values</i>
<table>
<tr><td>1/T /10^{-3}</td><td>2.00</td><td>1.66 recurring</td><td>1.428571429</td><td>1.25</td></tr>
<tr><td>ln K_p</td><td>105.3844788</td><td>85.79996441</td><td>71.75857432</td><td>59.99824068</td></tr>
</table></td><td>2
(AO 1.2×2)</td><td>Mark by row

ALLOW 2 SF or more for 1/T but ignore trailing zeroes

ALLOW whole numbers (±1) for ln Kp

ALLOW 1 small slip in each row.
e.g. 1.66 for 1.67; 71.7 for 71.8
<i>Check with calculator values below table</i>

BUT DO NOT ALLOW whole number errors, e.g. 85 for 86

<u>Examiner's Comments</u>

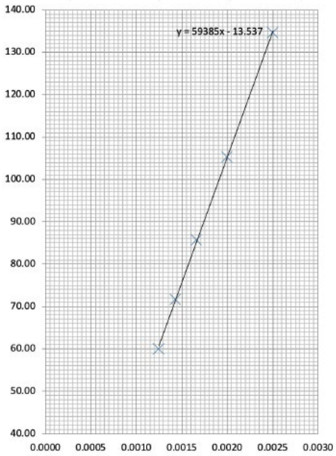
Candidates were expected to complete values for 1/T and ln K_p from supplied T and K_p values. Candidates were supplied with an example and this enabled most candidates to obtain both available marks.</td></tr>
<tr><td></td><td>b</td><td></td><td>Equilibrium (position) shifts to the left
AND
(forward) reaction is exothermic ✓</td><td>1
(AO 2.2)</td><td>ALLOW 'favours reverse reaction'
<i>Implies shift to left</i>

ALLOW 'shifts in endothermic direction' BUT only if (forward) reaction stated as exothermic

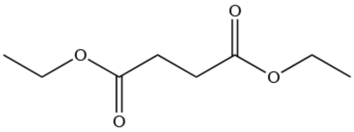
<u>Examiner's Comments</u>

Most candidates were aware that a decrease in K_p with increasing temperature signals that the forward reaction is exothermic.

The question also asked for the effect on the equilibrium position. A significant number of candidates omitted this part of the question. Candidates are advised to check back to all the requirements in a question.</td></tr>
</table>

	c		**Plotting of graph** **All** points correctly plotted **AND** best-fit straight line ✓ **Gradient** Correct gradient of best-fit straight line within the range ±57000 → ±63000 ✓ **Δ*H* calculation (subsumes mark for gradient)** ΔH = (–) gradient × 8.31(4) **OR** calculated value ✓ *e.g. from ±60000, ΔH = (+)498840* (J) **OR** ±498.840 (kJ) **Δ*H* in kJ mol^{-1}** ΔH correct in kJ mol^{-1} **AND 3SF** **AND** – sign ✓ *e.g. from ±498840, ΔH = –499 (kJ mol^{-1})*	4 (AO 3.1) (AO 3.1) (AO 3.2) (AO 3.2)	 **ALLOW** 4 points on graph Tolerance 1 small square **ALLOW** ΔH in range: –480 → –530 *(kJ mol^{-1})* **This mark subsumes gradient mark** **Examiner's Comments** 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 $1/T = 1.25 \times 10^{-3}$. 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. Significantly, nearly a third of candidates did not collect any of the four available marks. The question was an excellent discriminator.
	d		Extrapolate line to (y) intercept **OR** Measure/Use (y) intercept ✓ Intercept $= \frac{\Delta S}{R}$ **OR** $\Delta S = R \times (y)$ intercept ✓ *This statement automatically subsumes 1st mark* **NOTE**: If 'x' intercept, **DO NOT ALLOW** 1st mark but 2nd mark available for × R as **BOD**	2 (AO 3.1x2)	**ALLOW** substitute values of ln K_p, $1/T$ and gradient into **Equation 5.1** ✓ From provided values and gradient = 60000: $= \frac{\Delta S}{R}$ = ln K_p – gradient × $1/T$ **OR** $135 - 60000 \times 2.50 \times 10^{-3} = -15$ ✓ **Examiner's Comments**

					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. 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'.
			Total	**9**	
4			$p(O_2) = 0.21 \times 1.00 \times 10^5$ = **21,000 / 2.1 × 10^4** (Pa)✓	1 AO 2.2	**Examiner's Comments** 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. In calculations, candidates are advised to think about whether their answer is sensible, rather than relying just on the answer displayed on the calculator.
			Total	**1**	
5		i	Titration ✓	1	**IGNORE** type of titration **Examiner's Comments** Candidates found this part difficult and only higher ability candidates identified that a titration could easily determine the concentration of succinic acid. 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.
		ii	$(CH_2COOH)_2 + 2C_2H_5OH \rightleftharpoons (CH_2COOC_2H_5)_2 + 2H_2O$ ✓	1	**ALLOW** → instead of ⇌ sign **ALLOW** molecular formulae or hybrid formulae *Structures provided on* e.g. $C_4H_6O_4 + 2C_2H_6O \rightleftharpoons C_8H_{14}O_4 + 2H_2O$ **Examiner's Comments** Candidates were required to derive the equation

					from which the supplied K_c expression had been written. Overall, this part was answered well but some candidates struggled with the brackets or used CH_2COOH_2 for succinic acid.
		iii	 ✓	1	**IGNORE** displayed formulae **Examiner's Comments** 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. Even when incorrect, most attempted answers were skeletal formulae.
		iv	Volume cancels **OR** Same number of moles on each side of equation ✓	1	**ALLOW** units cancel **ALLOW** (sum of) balancing numbers/coefficients on each side of equation are the same **OR** same number of (moles of) reactants and products **IGNORE** volume is the same; K_c has no units **Examiner's Comments** 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. This challenging part discriminated very well. The best responses showed the units as n/V in the expression and showed that the volumes cancel.
		v	**Moles of equilibrium products** ***1 mark*** $n((CH_2COOC_2H_5)_2)$ = 0.0300 (mol) **AND** $n(H_2O)$ = 0.0600 (mol) ✓ **Moles of C_2H_5OH** ***1 mark*** $n(\mathbf{C_2H_5OH})$ = 0.150 − 0.060 = 0.0900 (mol) ✓	3	

			K_c calculated ***1 mark*** $= \frac{0.03 \times 0.06^2}{0.02 \times 0.09^2} = 0.667$ **OR** 0.67 ✓ **NOTE**: 0.02 must be used for *n*(succinic acid)		**ALLOW ECF** **ALLOW** 0.66, 0.666, etc. (**2 SF** and more) *Treated as meaning 0.6 recurring* **ALLOW** 2/3 **IGNORE** any units **Examiner's Comments** 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. 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.
			Total	**7**	
6	a		$K_c = \frac{[NO_2]^2}{[NO]^2\,[O_2]}$ ✓ Units = $dm^3\ mol^{-1}$ ✓	**2**	Must be square brackets **IGNORE** state symbols **ALLOW** $mol^{-1}\ dm^3$ **ALLOW** $mol\ dm^{-3}$ as ECF from inverted K_c expression **Examiner's Comments** The expression and the units were almost universally known by the candidates.
	b		**FIRST CHECK THE ANSWER ON THE ANSWER LINE IF answer = 1.2 (mol) award 4 marks** **Unless otherwise stated, marks are for correctly calculated values. Working shows how values have been derived.** $[NO] = \frac{0.40}{4.0} = 0.1(0)\ (mol\ dm^{-3})$ **AND** $[O_2] = \frac{0.80}{4.0} = 0.2(0)\ (mol\ dm^{-3})$ ✓ $[NO_2]^2 = 45 \times 0.102 \times 0.20$ **OR** = 0.09(0) ✓ $[NO_2] = \sqrt{(45 \times 0.10^2 \times 0.20)}$ **OR** = 0.3(0) $(mol\ dm^{-3})$ ✓ amount $NO_2 = 0.30 \times 4 = 1.2$ (mol) ✓	**4**	***ANNOTATIONS MUST BE USED*** For **all** parts, **ALLOW** numerical answers from 2 significant figures up to the calculator value Ignore rounding errors after second significant figure 1st mark is for realising that concentrations need to be calculated. **ALLOW ECF** **Correct numerical answer with no working would score all previous calculation marks** Making point 2 subsumes point 1

					Making point 3 subsumes points 2 and 1 Common errors 9.6 = 3 marks mol of NO and O_2 used 0.36 = 3 marks mol of NO_2 calculated from $[NO_2]^2$ 2.4 = 2 marks mol of NO and O_2 used and no mol of NO_2 calculated **Examiner's Comments** There were three steps to this calculation: Conversion of molar quantities of NO and O_2 to molar concentrations. Insertion into the K_c expression and determination (via a square root calculation) of the molar concentration of NO_2. Conversion of the molar concentration of NO_2 to a molar quantity. 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.
	c	i	Exothermic AND K_p decreases as temperature increases ✓	1	**ALLOW** K_c for K_p **ALLOW** Equilibrium shifts to left hand side as temperature increases **Examiner's Comments** Most candidates knew the forward reaction was exothermic due to K_p decreasing as temperature increased. A common error was to write vague responses such as 'K_p decreases with temperature'.
		ii	***Equilibrium shift*** (Equilibrium position) shifts to right / forward / towards products ✓ ***Effect of increased pressure on K_p expression*** Ratio (in Kp expression) decreases **OR**	3	**FULL ANNOTATIONS NEEDED** **ALLOW** K_c for K_p throughout the response. **ALLOW** K_p (initially) decreases for second marking point **IF** K_p is seen to be restored later in the process.

			Denominator/bottom of K_p expression increases more (than numerator/top) ✓ ***Equilibrium shift (K*$_p$ *expression)*** Ratio (in K_p expression) increases **to restore K_p** **OR** **Numerator/top of K_p expression increases to restore K_p** ✓		**ALLOW** more NO_2 / product formed to restore K_p **ALLOW** ratio adjusts to restore K_p **Examiner's Comments** Candidates almost universally secured the first mark for equilibrium shifting to the right. Many scored this by simple application of Le Chatelier's principle, and then went on to incorrectly explain K_p increased because of this shift. Very few realised that (a constant) K_p drives Le Chatelier's principle (and not the other way around). An increase of pressure will increase the value of the partial pressures in the bottom half of the K_p expression more than the top half, thus (initially) decreasing the K_p ratio. Therefore, to **restore** K_p, the amount of NO_2 present must increase; consequently, the equilibrium shifts to the right.
			Total	**10**	
7		i	$(K_c =)\ \frac{[SO_3]^2}{[SO_2]^2\,[O_2]}$ ✓ Units: $dm^3\ mol^{-1}$ S	2	**IGNORE** state symbols in K_c expression, even if wrong. For units, **ALLOW** $mol^{-1}\ dm^3$ **DO NOT ALLOW** dm^3/mol **NOTE:** If K_c upside down, units become $mol\ dm^{-3}$ by **ECF** No other **ECF** allowed for units. **Examiner's Comments** The expression and the units were almost universally known by the candidates.
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 2.45, Award **4 marks.** ……………………………………………………… **Equilibrium concentrations (moles x 2.5)** **1 MARK** $SO_2 = 0.135\ (mol\ dm^{-3})$ **AND** $O_2 = 0.0675\ (mol\ dm^{-3})$ ✓	4	**FULL ANNOTATIONS NEEDED** **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below ………………………………………………………. **ALLOW ECF** from incorrect concentrations of SO_2 and / or O_2

			Calculation of $[SO_3(g)]$ **2 MARKS** $[SO_3] = \sqrt{(K_c \times [SO_2]^2 \times O_2)}$ **OR** $\sqrt{((3.045 \times 10^4) \times 0.135^2 \times 0.0675)}$ ✓ = 6.12039291 (mol dm^{-3}) ✓ *Answer scores both $[SO_3]$ marks automatically* **Calculation of *n*(SO_3) in 400 cm^3** **1 MARK** *n*(SO_3) = 6.12039291/2.5 = 2.45 (mol) ✓ ***3SF required (Appropriate number)***		**ALLOW ECF** from incorrect $[SO_3]$ **ALLOW 3 SF,** 6.12, up to calculator value of 6.12039291 correctly rounded. **Common errors** **37.5** **1 mark** *No √for $[SO_3]^2$ and no scaling by 1/2.5* **15.0** **2 marks** *No √for $[SO_3]^2$* **0.619** **3 marks** *Use of mol of SO_2 and O_2* **1.55** **2 marks** *No conc used and Use of mol of SO_2 and O_2* **Examiner's Comments** There were three steps to this calculation: • Conversion of molar quantities of SO_2 and O_2 to molar concentrations. • Insertion into the K_c expression and determining of the molar concentration of SO_3. • Conversion of the molar concentration of SO_3 to a molar quantity including an appropriate number of significant figures. 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.
			Total	**6**	
8		i	(Species have) different states / phases ✓	1	**Examiner's Comments** All but a few candidates realised that the term heterogeneous equilibrium could be applied because carbon monoxide was in a different physical state to the other reactants and products.
		ii	(K_p =) $p(CO(g))^4$ ✓	1	Allow species without state symbols and without brackets, e.g. Pco^4, $ppCO^4$, PCO^4, $p(CO^4)$ etc.

					DO NOT ALLOW square brackets **Examiner's Comments** Marks were awarded for less than perfect versions of $K_p = p(CO(g))^4$. As long as a 'p' or a 'P' was seen and curved, rather than square, brackets, along with the correct power, the mark was awarded. This was to differentiate between the candidates who knew that only the partial pressures of gaseous species should feature in a K_p expression from the candidates who used all four species to write the expression.
		iii	*ΔG at 25 C* $\Delta G = \Delta H - T\Delta S = 676.4 - (298 \times 0.7031)$ = (+) 467 (kJ mol^{-1}) **OR** (+) 466876 (J mol^{-1}) ✓ *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** $-13.5 = (4 \times -393.5) - (-1118.5 + 4$	3	**For answer,** **ALLOW −111 (kJ mol^{-1})** …………………………………………………………….

<table>
<tr>
<td></td><td></td><td></td>
<td>× Δ_fH(CO)) ✓

Correct subtraction using ΔH and $\Delta_fH(Fe_3O_4)$
4 × Δ_fH(CO) = (4 × −393.5) − (−1118.5) + 13.5
= −442(.0) (kJ mol^{-1}) ✓

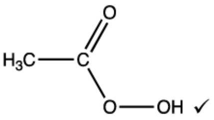
Calculation of Δ_fH(CO) formation
$\Delta_fH(\text{CO}) = -\frac{442}{4}$ = −110.5 (kJ mol^{-1}) ✓</td>
<td></td>
<td>NOTE: IF any values are omitted, DO NOT AWARD any marks. e.g. −393.5 OR −13.5 may be missing

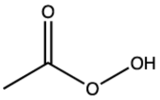
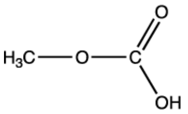
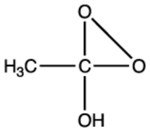
……………………………………………………….

Common errors

<table>
<tr><td>(+)110.5</td><td><i>wrong / omitted sign</i></td><td>2 marks</td></tr>
<tr><td>(+)184.625 / 184.63 / 184.6 / 185</td><td><i>No 4CO$_2$</i></td><td>2 marks</td></tr>
<tr><td>(+)738.5 / 739</td><td><i>No 4CO$_2$ and no CO/4</i></td><td>1 mark</td></tr>
<tr><td>−117.25 / −117.3 / −117</td><td><i>Wrong cycle</i></td><td>2 marks</td></tr>
<tr><td>−469</td><td><i>Wrong cycle, no CO/4</i></td><td>1 mark</td></tr>
<tr><td>(+)177.875 / 177.88 / 177.9 / 178</td><td><i>Wrong cycle, no 4CO2</i></td><td>1 mark</td></tr>
<tr><td>−360.5</td><td><i>Used 118.5</i></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 Δ_fH(CO) was known to most candidates, but many examples of avoidable errors were seen. For example, transcription errors in recording Δ_fH 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>
</tr>
<tr><td></td><td></td><td></td><td>Total</td><td>8</td><td></td></tr>
<tr>
<td>9</td><td></td><td>i</td>
<td>

ALLOW skeletal OR displayed formula
OR mixture of the above as long as non-ambiguous, e.g.
 </td>
<td>1</td>
<td>ALLOW
 OR 

Structure must include OH as part of COOOH group

ALLOW –O$^-$ H$^+$ in structure</td>
</tr>
</table>

					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. H_3C-O-COOH
		ii	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 0.023(125) (mol) award 3 marks for calculation ……………………………………………………… ***K_c expression*** $(K_c =) \frac{[CH_3COOOH]}{[H_2O_2]\,[CH_3COOH]}$ ✓ **[CH_3COOOH]** = 0.37 × 0.500 × 0.500 = 0.0925 (mol dm^{-3}) ✓ *Subsumes K_c expression* ***n*(CH_3COOOH)** $= 0.0925 \times \frac{250}{1000} = 0.023(125)$ (mol) ✓	**3**	**If there is an alternative answer, check for any ECF credit** …………………………………………………….…. **ALLOW** $0.37 = \frac{[CH_3COOOH]}{0.500 \times 0.500}$ **ALLOW ECF** but **ONLY** if 0.37 **AND** 0.5 × 0.5 have been used **Common errors** **0.076** **2 marks** *Use of [CH_3COOOH]^2* **0.675** **2 marks** *Use of 0.5 for [H_2O] on K_c* **0.169** **2 marks** *Inverted K_c* **0.338** **1 mark** *Inverted K_c AND 0.5 for [H_2O]* **5.78 × 10^{-3}** **2 marks** *$\times \frac{250}{1000}$ before [CH_3COOOH]* **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 CH_3COOH, unity, or even 55.6 from 1000/18.

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

					calculations of equilibrium constants. The correct numerical answer of 104 and units of $dm^3\ mol^{-1}$ were seen often. The commonest calculation error was use of the equilibrium moles, rather than concentrations, giving 521. 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 $dm^3\ mol^{-1}$
	b		Ag^+ / silver nitrate reacts with I^- to form AgI / silver iodide **OR** $Ag^+ + I^- \rightarrow AgI$ ✓ yellow precipitate / solid forms ✓ **Equilibrium 2** shifts to the left ✓ **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 ✓	4	***FULL ANNOTATIONS MUST BE USED*** .... **DO NOT ALLOW** cream **OR** cream73–yellow **ALLOW** just 'yellow' if supported by AgI(s) somewhere **Examiner's Comments** This question was about equilibrium, set in the context of the solubility of iodine. This part required candidates to apply their knowledge and understanding of equilibria to a novel situation. Candidates were expected to predict that $Ag^+(aq)$ and $I^-(aq)$ 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.
			Total	**8**	
11		i	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 57.6 $dm^3\ mol^{-1}$, award **6 marks** **IF** answer = 57.6 with incorrect units, award **5 mark** ……………………………………………………… **Equilibrium amounts in mol** **2 MARKS** $n(SO_2)$ = 0.180 (mol) **ALL 3** correct: ✓✓ $n(O_2)$ = 0.090 (mol) **ANY 2** correct: ✓ $n(SO_3)$ = 0.820 (mol) **Equilibrium concentrations (moles × 4)** **1 MARK** SO_2 = 0.720 (mol dm^{-3}) **AND** O_2 = 0.360 (mol dm^{-3}) **AND** SO_3 = 3.28 (mol dm^{-3}) ✓	6	**FULL ANNOTATIONS NEEDED** **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below ……………………………………………………… . **ALLOW ECF** from incorrect moles of SO_2, O_2 **AND** SO_2 **ALL three** concentrations required for this mark **ALLOW ECF** from incorrect concentrations **NO ECF** for numerical value with a square

			Calculation of K_c and units 3 MARKS $K_c = \frac{[SO_3]^2}{[SO_2]^2\ [O_2]}$ **OR** $\frac{3.28^2}{(0.720)^2 \times (0.360)}$ ✓ = 57.6 ✓ $dm^3\ mol^{-1}$ ✓ *At least 3SF is required*		missing For K_c, **ALLOW** 3 significant figures up to calculator value of 57.64746228 correctly rounded For units, **ALLOW** $mol^{-1}\ dm^3$ **DO NOT ALLOW** dm^3 / mol **ALLOW ECF** from incorrect K_c expression for both calculation and units **COMMON ERRORS** 0.0294 ***3 marks + units mark*** from SO_2 = 0.820, O_2 = 0.410, SO_3 = 0.180 (mol) **Examiner's Comments** 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 ÷ 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. Answer: K_c = 57.6 $dm^3\ mol^{-1}$
		ii	(Pressure) decreases **AND** fewer molecules / moles ✓	1	For fewer moles, **ALLOW** 3 mol → 2 mol **ALLOW** more moles of **reactants** **Examiner's Comments** 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

					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	**IGNORE** exothermic and endothermic **Examiner's Comments** 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.
		iv	**IGNORE** le Chatelier responses …………………………………………………… ***Each marking point is independent*** ***K_c*** K_c does not change (with pressure / concentration) ✓ ***Comparison of conc terms with more O_2*** $[O_2]$ / concentration of oxygen is greater **OR** denominator / bottom of K_c expression is greater ✓ ***QWC: yield of SO_3 linked to K_c*** (Yield of) SO_3 is greater / increases **AND**		**FULL ANNOTATIONS NEEDED** **ALLOW** K_c **only** changes with temperature **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. **IGNORE** O_2 is greater / increases **ALLOW** **(Yield of) SO_3 is greater / increases AND**
		iv	numerator / top of K_c expression is greater / increases ✓	3	to reach / restore K_c value ✓ **Examiner's Comments** Explaining shifts in equilibrium in terms of K_c is far more difficult that 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. This part discriminated extremely well and unfortunately weaker candidates often failed to score.
			Total	**11**	

12	a		$(K_c =)\ \frac{[C_2H_2]\,[H_2]^3}{[CH_4]^2}$ ✓	1	Square brackets are **essential** State symbols **not** required. **IGNORE** incorrect state symbols **Examiner's Comments** The K_c expression was shown correctly by almost all candidates, the only mistakes being the very occasional inverted expression or use of "+' within the denominator.
	b	i	amount of H_2 = 3 × 0.168 = 0.504 (mol) ✓	1	**Examiner's Comments** The correct answer of 0.504 mol was seen in the majority of scripts but examiners were also presented with many other responses. The key was use of the 1:3 molar ratio of C_2H_2 and H_2 formed in the equilibrium mixture, with simple multiplication of 0.168 by 3 giving the correct answer. The commonest incorrect answer was 0.1404 from 3/2 × 9.36 × 10^{-2}: from use the molar ratio of moles CH_4 formed and H_2 formed. Answer: 0.504 mol
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 0.153 $mol^2\ dm^{-6}$, award **3 marks** **IF** answer = 0.153 with incorrect units, award **2 marks** …………………………………… **IF answer from 3(b)(i) for $n(H_2) \neq 0.504$, mark by ECF.** **Equilibrium concentrations** (from $n(H_2)$ = 0.504 mol dm^{-3}) $[CH_4] = 2.34 \times 10^{-2}$ (mol dm^{-3}) **AND** $[C_2H_2] = 4.20 \times 10^{-2}$ (mol dm^{-3}) **AND** $[H_2]$ = 0.126 (mol dm^{-3}) ✓ **Calculation of K_c and units** $K_c = \frac{4.20\times10^{-2}\times(0.126)^3}{(2.34\times10^{-2})^2}$ = 0.153 ✓ $mol^2\ dm^{-6}$ ✓ **3 significant figures** are required	3	***FULL ANNOTATIONS MUST BE USED*** …………………………………… **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below …………………………………… **ALLOW** ÷ by 4 of equilibrium amounts in all expressions, i.e. **ALLOW** $[CH_4] = \frac{9.36\times10^{-2}}{4}$ mol dm^{-3} **AND** $[C_2H_2] = \frac{0.168}{4}$ mol dm^{-3} **AND** $[H_2] = \frac{0.504}{4}$ mol dm^{-3} ✓ **ALLOW ECF** from incorrect concentrations or from moles From moles: 9.36 × 10^{-2}, 0.168 and 0.504, K_c = 2.45 by **ECF** **ALLOW** $dm^{-6}\ mol^2$ **DO NOT ALLOW** mol^2/dm^6 **ALLOW ECF** from incorrect K_c expression for both calculation and units …………………………………… **COMMON ECF** From **3(b)(i)** answer of 0.1404, K_c = 3.32 x 10^{-3} 2 marks + units

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>K_c = 0.0531 No ÷ 4 throughout 1 mark + units

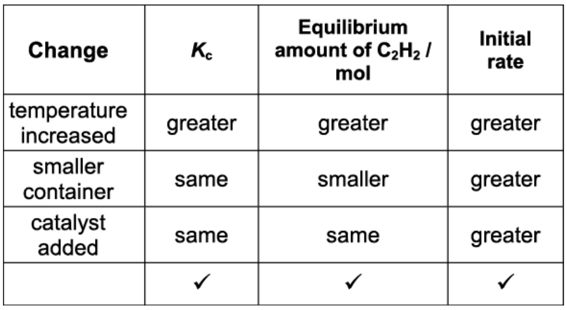
Examiner's Comments

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.

Answer: 0.153 $mol^2\ dm^{-6}$</td></tr>
<tr><td></td><td></td><td>iii</td><td>Initial amount of CH_4
amount of CH_4 = $9.36 \times 10^{-2} + 2 \times 0.168$
= 0.4296 OR 0.43(0) (mol) ✓</td><td>1</td><td>NO ECF possible (all data given in question)

Examiner's Comments

Although this part was more challenging than the initial molar ratio in (b)(i), many candidates were able to work out the amount of CH_4 that had reacted as $2 \times 9.36 \times 10^{-2}$ and to then add this to the remaining amount of CH_4: 9.36×10^{-2}. This part did cause a lot of difficult for weaker candidates with a range of incorrect numerical answers being seen.

Answer: 0.4296 mol</td></tr>
<tr><td></td><td>c</td><td></td><td>
<table>
<tr><th>Change</th><th>K_c</th><th>Equilibrium amount of C_2H_2 / mol</th><th>Initial rate</th></tr>
<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>
</table></td><td>3</td><td>Mark by COLUMN

ALLOW obvious alternatives for greater / smaller / same, e.g.
increases / decreases;
more / less

Examiner's Comments

This part tested candidates understanding of how three quantities would change from changes to experimental conditions. This was marked by column.
Of the three quantities, K_c and rate were correct more often than the equilibrium amount of C_2H_2. This question discriminated extremely well. Strangely, some candidates chose to use their own words instead of those provided and</td></tr>
</table>

					examiners often saw words such as 'increases' and 'decreases'. As the meaning was clear, such responses were still credited.
			Total	**9**	
13	a		**FIRST CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 0.812 dm^6 mol^{-2}, award **6 marks** **IF** answer = 0.812 with incorrect units, award **5 marks** …………………………………………………… **Equilibrium amounts in mol** **2 MARKS** $n(N_2)$ = 0.62(0) $n(N_2)$ = 1.86 **Equilibrium concentrations in mol dm^{-3} (mol ÷ 5)** **1 MARK** N_2 = 0.124 **AND** H_2 = 0.372 **AND** NH_3 = 0.072 **Calculation of K_c and units** **3 MARKS** $K_c = \frac{[NH_3(g)]^2}{[N_2(g)] \times [H_2(g)]^3}$ **OR** $\frac{0.072^2}{0.124 \times 0.372^3}$ = 0.812 dm^6 mol^{-2} *At least 3SF is required*	6	**FULL ANNOTATIONS NEEDED** **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below ………………………………………………………. **ALLOW ECF** from incorrect moles of N_2, H_2 **AND / OR** NH_3 **ALL three** concentrations required for mark **ALLOW ECF** from incorrect concentrations **OR** use of moles (omitting conc stage) **NO ECF** for numerical value with a square **AND / OR** cube missing For K_c, **ALLOW** 3 significant figures up to calculator value of 0.8121093077 correctly rounded For units, **ALLOW** mol^{-2} dm^6 **DO NOT ALLOW** dm^6/mol^{-2} ………………………………………………………. **COMMON ERRORS** 0.0325 ***3 marks + units mark*** from N_2 = 0.620, H_2 = 1.86, NH_3 = 0.360 (mol)
	b	i	**IGNORE** le Chatelier responses …………………………………………………… ***Each marking point is independent*** ***K_c*** K_c does not change (with pressure / concentration) ***Comparison of conc terms with more N_2*** [N_2] increases	3	**FULL ANNOTATIONS NEEDED** **ALLOW** K_c **only** changes with temperature **IF** 1st marking point has been awarded, **IGNORE** comments about 'K_c decreasing' or 'K_c

			OR denominator / bottom of K_c expression increases ***yield of NH_3 linked to K_c*** Chemist is correct **AND** denominator decreases **OR** numerator increases to restore equilibrium K_c		increasing' and assume that this refers to how the ratio subsequently changes. i.e. **DO NOT CON** 1st marking point.
		ii	N_2 obtained from the air **AND** H_2 must be manufactured / does not occur naturally	1	N_2 is more readily available **not** insufficient. **ALLOW** an example of H_2 manufacture, e.g. from oil / gas / water **BOTH** responses required for mark.
			Total	**10**	
14	a		The forward reaction is exothermic, so an increase in temperature favours the backward reaction *(owtte)* … (1) … 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 *(owtte)* (1)	2	**allow** names of compounds **allow** reactants / product instead of compounds 2nd mark only available if deduced from 1st mark **allow ecf** for 2nd mark
	b		**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 2.37×10^{-6} kPa^{-2} award 5 marks **IF** answer = 2.37×10^{-6} with incorrect units award 4 marks At equilibrium, $n(H_2) = 0.300$ (mol) **AND** $n(NH_3) = 0.100$ (mol) (1) $p(N_2) = \frac{0.400}{0.800} \times 500 = 250$ kPa **AND** $p(H_2) = \frac{0.300}{0.800} \times 500 = 187.5$ kPa **AND** $p(NH_3) = \frac{0.100}{0.800} \times 500 = 62.5$ kPa (1) $K_p = \frac{p(NH_3)^2}{p(N_2) \times p(H_2)^3} = \frac{62.5^2}{250 \times 187.}$ (1) $= 2.37 \times 10^{-6}$ (1) kPa^{-2} (1)	5	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. **If there is an alternative answer, check to see if there is any ECF credit possible using working below** Correct values substituted into correct expression for K_p gains first three marks.
			Total	**7**	