

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1		i	<p>Two (✓ ✓) from:</p> <ul style="list-style-type: none"> • rate of forward reaction = rate of reverse reaction • Concentrations (of reactants and products) do not change/are constant • In a closed system/environment 	2	<p>IGNORE reactions take place together/reversible reaction</p> <p>ALLOW backward for reverse</p> <p>DO NOT ALLOW concentration of reactants = concentration of products</p> <p>ALLOW 'nothing can leave/enter'</p> <p><u>Examiner's Comments</u></p> <p>Most candidates identified at least one feature of a dynamic equilibrium. 'In a closed system' was given marks most often, and other mark-worthy features were 'the same rate for forward and reverse reactions' and 'concentrations do not change'. Less successful responses that were not given marks included 'reversible reaction' and 'concentrations are the same'.</p>
		ii	<p>Temperature:</p> <p>(Forward) reaction is exothermic/ΔH is negative/ (Forward) reaction gives out heat AND Low temperature ✓</p> <p>Pressure:</p> <p>Right-hand side has fewer (gaseous) moles/ 4 (gaseous) moles form 2 (gaseous) moles AND High pressure ✓</p> <p>Equilibrium shift:</p>	3	<p><u>FULL ANNOTATIONS MUST BE USED</u></p> <p>ALLOW reverse reaction is endothermic / ΔH is positive OR reverse reaction takes in heat</p> <p>ALLOW decrease temperature for low temperature</p> <p>For moles, ALLOW molecules/particles ORA for reverse reaction DO NOT ALLOW gaseous atoms</p> <p>ALLOW increase pressure for high pressure</p> <p>For shifts, ALLOW 'shifts/moves/pushes' towards right'/NH₃/products OR in favours the forward direction OR favours the right</p>

			Equilibrium/system/equation shift expressed correctly seen at least once ✓		<p><u>Examiner's Comments</u></p> <p>This long-response question was approached very well and there were some excellent and concise responses.</p> <p>Only the less successful responses did not identify the main trends.</p> <p>Candidates are well-versed with tackling this type of question and most were able to write sensible explanations. However, marks could not be given for insufficiently specific responses. For example, some candidates stated that increased pressure would shift the equilibrium in the direction with fewer moles, without stating what that direction was for this equilibrium. It was also common to see explanations that contradicted earlier statements.</p> <p>Responses could be improved if candidates read through what they write to see if it makes cohesive sense. Nearly half of the scripts were given the full 3 marks, the question proving to be a good discriminator.</p>
			Total	5	
2			B	1	<p><u>Examiner's Comments</u></p> <p>Almost all candidates were aware of how to express the K_c expression for an equilibrium, choosing the correct option B.</p>
			Total	1	
3		i	<p>FIRST CHECK THE ANSWER ON ANSWER LINE IF answer = 0.455 award 4 marks AND IF units = $\text{atm}^{1/2}$ award 5 marks</p> <p>----- -----</p> <p>Equilibrium moles ✓ $N \text{ SO}_3 = 1.35$, $n \text{ O}_2 = 0.45(0)$ AND $n \text{ total} = 2.7(0)$</p>	5	<p>IF there is an alternative answer, check for any ECF credit possible using working below.</p> <p>----- -----</p> <p>ALLOW 3SF or more unless there is a trailing zero e.g. ALLOW $p(\text{SO}_3) = 1.4$, $n \text{ total} = 2.7$</p>

Partial pressures ✓

$p(\text{SO}_3)$	$\frac{1.35}{2.7(0)} \times 2.80$ OR $1.4(0)$
$p(\text{SO}_2)$	$\frac{0.900}{2.7(0)} \times 2.80$ OR 0.933
$p(\text{O}_2)$	$\frac{0.450}{2.7(0)} \times 2.80$ OR 0.467

$$(K_p) = \frac{p(\text{SO}_2) \cdot p(\text{O}_2)^{1/2}}{p(\text{SO}_3)}$$

$$\text{OR } (K_p) = \frac{(0.933) \times (0.467)^{1/2}}{(1.40)} \checkmark \checkmark$$

Answer to 3 SF

$$K_p = 0.455 \checkmark$$

Units

Substitution of units into correct K_p expression

$$\frac{\text{atm}^1 \times \text{atm}^{1/2}}{\text{atm}^1} = \text{atm}^{1/2} \checkmark \checkmark$$

ALLOW all marks to be awarded if atmospheres are converted into other pressure units e.g. to kPa.

ALLOW use of fractions for intermediate working

$$\text{ALLOW } (K_p) = \frac{p(\text{SO}_2) \cdot p^{1/2}(\text{O}_2)}{p(\text{SO}_3)}$$

ALLOW

$$K_p^2 = \frac{p(\text{SO}_2)^2 \times p(\text{O}_2)}{p(\text{SO}_3)^2}$$

IGNORE [] (we are just looking for the calculation)

ALLOW ECF for units of an incorrect K_p expression

ALLOW $\text{atm}^{0.5}$

DO NOT ALLOW $\sqrt{\text{atm}}$

Common errors

4 marks

(3 marks for calculation + unit mark)


$$0.207 \text{ (from expression } \frac{p(\text{SO}_2)^2 \times p(\text{O}_2)}{p(\text{SO}_3)^2} \text{) Unit: atm}$$


$$2.20 \text{ (from inverted expression) Unit: atm}^{-1/2}$$

Examiner's Comments

Candidates tend to find K_p calculations difficult and so a strategy to work their way through them could include:

- Write the K_p expression using the molar ratio given in the question. Care should be taken not to change the molar ratio to help an easier calculation. Square brackets should not be used as these represent concentration.
- Calculation of initial moles present, with careful consideration of the use of appropriate significant figures
- Calculation of the change in moles present
- Deduction of the number of moles present at equilibrium


					<ul style="list-style-type: none">Determination of total moles present at equilibrium <p>These steps are often best completed as RICE tables (Ratio, Initial, Change, Equilibrium) and should look to use the appropriate amount of significant figures to avoid having a rounding error in the final answer.</p> <p> Misconception</p> <p>K_p values are for the equation as stated. Candidates should recognise that changing the stoichiometry of the equation changes the K_p value.</p>								
		ii	<p>ΔH is +ve / endothermic (in forward direction).</p> <p>AND</p> <p>(At higher temperature,) equilibrium shifts to right hand side ✓</p> <p>(T_2) has greater K_p value</p> <p>OR $7.7 \times 10^{-2} > 3.3 \times 10^{-5}$ ✓</p>	2	<p>ORA throughout</p> <p>ALLOW towards the products for right hand side</p> <p>ALLOW increases yield of products</p> <p>DO NOT ALLOW T_1 has greater K_p value</p> <p><u>Examiner's Comments</u></p> <p>Candidates performed well with this question and many stated that K_p would increase. Some identified the forward reaction as endothermic but did not link this to equilibrium being shifted to the right, thus increasing the ratio within the K_p expression. A few candidates sought to incorrectly explain the effect by using Le Chatelier effect on pressure.</p>								
		iii	<p>One mark per correct row ✓ ✓</p> <table border="1"><tr><td>Change</td><td>Decrease</td><td>No change</td><td>Increase</td></tr><tr><td>No catalyst</td><td></td><td>✓</td><td></td></tr></table>	Change	Decrease	No change	Increase	No catalyst		✓		2	<p><u>Examiner's Comments</u></p> <p>This proved a challenging question where candidates did not stick to the principle that K_p (or K_a) values only change due to temperature changes. Only a few candidates scored both</p>
Change	Decrease	No change	Increase										
No catalyst		✓											

			<div>Increased pressure</div> <div></div> <div>✓</div> <div></div>		marks with many having the K_p value changing due to increased pressure.
			Total	9	
4			C	1	<p><u>Examiner's Comments</u></p> <p>The correct answer was C. This was a well answered question with most candidates gaining the mark. The most common error was B, where reactants and product concentration became equal. It is important that candidates can apply definitions and theory to diagrams.</p> <p> Misconception</p> <p>Dynamic equilibrium exists in a closed system when the rate of the forward reaction is equal to the rate of the reverse reaction and the concentrations of reactants and products <u>do not change</u>. It is a misconception that equilibrium is at the point where reactants and product concentration became <u>equal</u>.</p>
			Total	1	
5	a	i	$(K_p) = \frac{p(\text{N}_2\text{O}_4(\text{g}))}{p(\text{NO}_2(\text{g}))^2} \checkmark$ <p>Units $\text{atm}^{-1} \checkmark$</p> <p>CHECK THE ANSWER ON ANSWER LINE if answer = 1.17×10^{-2} OR 1.18×10^{-2} award 3 calculation marks</p> <hr/> <p>Calculation</p> <ul style="list-style-type: none"> $n_{\text{N}_2\text{O}_4} = 0.3(00) \text{ (mol)}$ AND $n_{\text{total}} = 5.7(0) \text{ (mol)} \checkmark$ $p_{\text{NO}_2} = \frac{5.4(0)}{5.7(0)} \times 5.00 = 4.74 \text{ (atm)}$ 	5 (AO 1.2 × 1) (AO 1.2 × 1) (AO 2.6 × 3)	<p>ALLOW species without state symbols and without brackets. e.g., $p\text{SO}_3^2$, $pp\text{SO}_3^2$, PSO_3^2, $p(\text{SO}_3)^2$, $(p\text{SO}_3)^2$ etc. DO NOT ALLOW square brackets</p> <p>ALLOW atm as ECF if K_p is upside down</p> <p>ALLOW ECF throughout ALLOW 3 SF up to the calculated value. IGNORE RE after 3SF</p> <p><i>Calculator value</i> $p_{\text{NO}_2} = 4.7368 \dots$</p>

			<p>AND $p\text{N}_2\text{O}_4 = \frac{0.3(00)}{5.7(0)} \times 5.00 =$ $0.263 \text{ (atm)} \checkmark$</p> <ul style="list-style-type: none"> K_p to 3 SF $(K_p = \frac{0.263}{4.74^2} =) 1.17 \times 10^{-2} \checkmark$ 		<p>$p\text{N}_2\text{O}_4 = 0.26315\dots$</p> <p>Mark use of 2SF in working as incorrect once and then allow ECF Answer MUST be 3 SF</p> <p>Common error for 2 calculation marks: 2.47×10^{-2} (using 0.6 mol N_2O_4)</p> <p><u>Examiner's Comments</u></p> <p>Candidates tend to find K_p calculations difficult and so a strategy to work their way through them could include:</p> <ul style="list-style-type: none"> write the K_p expression, with units, ensuring square brackets are not used. Common mistakes with units included $\text{atm}^{-1} \text{ mol}^{-1}$, $\text{mol}^{-1} \text{ dm}^3$, kPa^{-1} calculation of initial moles present, with careful consideration of the use of appropriate significant figures calculation of the change in moles present deduction of the number of moles present at equilibrium determination of total moles present at equilibrium. <p>These steps are often best completed as RICE tables (Ratio, Initial, Change, Equilibrium) and should look to use the appropriate amount of significant figures:</p> <ul style="list-style-type: none"> calculation of mole fractions at equilibrium calculation of partial pressures at equilibrium inserting partial pressure values into the K_p expression and avoiding any unnecessary unit conversions writing an answer to the required number of significant figures.
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		ii	<p>Higher temperature ΔH is negative / exothermic (for forward reaction) AND equilibrium shifts to left/to LHS/decreases yield ✓</p> <p>Higher pressure 2 (gaseous) moles form 1 (gaseous) mole/ to side with fewer moles AND Equilibrium shifts to right /RHS/increases yield ✓</p> <p>Comparison Difficult to predict relative contributions of two opposing factors ✓</p>	<p>3 (AO 2.1 × 2) (AO 3.1 × 1)</p>	<p>ORA</p> <p>ALLOW correct equilibrium shifts without explanations for 1 mark</p> <p>ALLOW opposing effects may not be the same size ALLOW effects could cancel each other out ALLOW effects oppose one another</p> <p>DO NOT ALLOW if both equilibrium shifts are in the same direction DO NOT ALLOW just 'it is difficult to predict equilibrium position' (in question) For the 3rd mark, we are assessing the idea that we don't know which factor is dominant</p> <p>Examiner's Comments</p> <p>This question was answered for the most part correctly with many candidates scoring 2 marks for the explanations of the effect on the equilibrium position by the changing of the temperature and pressure. Most candidates were able to recognise the changes had opposite effects but could not score the final mark, as their response needed the concept of opposing factors, or 'we don't know which factor is dominant'. Some did not write anything about equilibrium and attempted answers based on rate, or loss of energy/chemicals to the surroundings.</p>
	b		<p>Rearranging ideal gas equation $n = \frac{pV}{RT}$ ✓</p> <p>Unit conversion AND substitution into $n = \frac{pV}{RT}$:</p> <ul style="list-style-type: none"> • $R = 8.314$ OR 8.31 • V in $\text{m}^3 = 74 \times 10^{-6}$ • T in $K = 348$ 	<p>5 (AO 2.1 × 1) (AO 2.6 × 3) (AO 3.2 × 1)</p>	<p>FULL ANNOTATIONS MUST BE USED</p> <p>-----</p> <p>ALLOW ECF throughout if all values have been used to calculate n</p> <p>IF $n = \frac{pV}{RT}$ is omitted, ALLOW when values are substituted into rearranged ideal gas equation</p>


		<ul style="list-style-type: none"> $P \text{ in Pa} = 101 \times 10^3$ <p>e.g. $\frac{101 \times 10^3 \times 74.0 \times 10^{-6}}{8.314 \times 348} \checkmark$</p> <p>Calculation of n $n = 2.58 \dots \times 10^{-3} \text{ (mol)} \checkmark$</p> <p>Calculation of M $M = (0.28 \div 2.58 \dots \times 10^{-3}) = 108(\dots) \checkmark$</p> <p>Molecular formula that is the closest to the calculated M_r value. e.g. $M_r 108 = \text{N}_2\text{O}_5 \checkmark$</p>	<p>CARE: Correct n value subsumes first marking point only as two incorrect unit conversions can lead to correct n</p> <p>Calculator value: from 8.314 $n = 2.583234483 \times 10^{-3}$ from 8.31 $n = 2.584477917 \times 10^{-3}$</p> <p>Calculator value: M from 8.314 = 108.3912443 M from 8.31 = 108.3390955 M from $0.28 \div 2.58 \times 10^{-3} = 108.5$ OR 109</p> <p>ALLOW ECF from calculation of n provided formula of oxide contains at least one N i.e. NO ($M_r = 30$)</p> <p>-----</p> <p>Use of 24 dm³: Final 2 marks possible by ECF e.g. $n = \frac{74.0}{24000} = 3.08 \times 10^{-3}$ No mark (calculation much simpler)</p> <p>$M = \frac{0.28}{3.08 \times 10^{-3}} = 90(.8)$ ECF N_3O_3 ECF</p> <p>DO NOT ALLOW N_2O_4 (in question)</p> <p>ALLOW ECF matching calculated M</p> <p><u>Examiner's Comments</u></p> <p>This question was well answered by nearly all candidates and many scored all 5 marks. A number used the wrong units for the pressure and the volume so used both kPa and dm³. This resulted in the correct number of moles and scored 4 marks as error carried forward. Most candidates were able to find the formula from the molar mass and very few used the incorrect molar volume route.</p>
		Total	13

6		B	1 (AO 2.1)	<p>Examiner's Comments</p> <p>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.</p> <p> Assessment for learning</p> <p>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.</p> <p>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.</p>
		Total	1	
7		<p>Level 3 (5–6 marks)</p> <p>ALL 3 correct orders linked to explanations AND rate equation AND rate constant</p> <p><i>There is a well-developed line of reasoning which is clear and logically structured.</i></p> <p>Level 2 (3–4 marks)</p> <p>Three correct orders AND two out of: some evidence of an explanation linked to an order rate equation rate constant</p>	6 (AO 3.1 × 3) (AO 3.2 × 3)	<p>Indicative scientific points may include Orders</p> <ul style="list-style-type: none"> • 1st order wrt Br⁻ • 1st order wrt BrO₃⁻ • 2nd order wrt H⁺ <p>Rate equation</p> <ul style="list-style-type: none"> • rate = k[Br⁻] [BrO₃⁻] [H⁺]² <p>Calculation of k from any row of data, e.g.</p> $k = \frac{\text{Rate}}{[\text{Br}^-][\text{BrO}_3^-][\text{H}^+]^2}$ $k = \frac{2.52 \times 10^{-4}}{0.020 \times 0.120 \times (0.080)^2} = 16.4(0625)$ <hr/> <p>Explanations from results e.g.</p>

			<p>OR</p> <p>Three correct orders with an attempt at: Some evidence of an explanation link to an order rate equation rate constant</p> <p>OR</p> <p>Two correct orders linked to explanations AND rate equation AND rate constant consistent with the candidate's orders</p> <p><i>There is a line of reasoning with some structure and supported by some evidence.</i></p> <p>Level 1 (1–2 marks)</p> <p>Two correct orders</p> <p>OR</p> <p>One correct order AND attempts to determine rate equation OR rate constant.</p> <p>OR</p> <p>One correct order AND attempts an explanation.</p> <p><i>There is an attempt at a logical structure with a reasoned conclusion from the evidence.</i></p> <p>0 mark No response worthy of credit.</p>	<p>Br⁻ $[\text{Br}^-] \times 3$ rate $\times 3$ Expts 1 and 2</p> <p>BrO₃⁻ $[\text{Br}^-] \times 2$ AND $[\text{BrO}_3^-] \div 2$</p> <p>rate: no change Expts 1 and 3</p> <p>OR</p> <p>$[\text{Br}^-] \times 2/3$ AND $[\text{BrO}_3^-] \div 2$</p> <p>rate: $\times 1/3$ Expts 2 and 3</p> <p>H⁺ $[\text{BrO}_3^-] \div 2$ AND $[\text{H}^+] \times 5$</p> <p>rate $\times 12.5$ Expts 1 and 4</p> <p>OR</p> <p>$[\text{Br}^-] \div 3$ and $[\text{BrO}_3^-] \div 2$ and $[\text{H}^+] \times 5$</p> <p>rate $\times 4.17$ Expts 2 and 4</p> <p>OR</p> <p>$[\text{Br}^-] \div 2$ and $[\text{H}^+] \times 5$</p> <p>rate $\times 12.5$ Expts 3 and 4</p> <p>ALLOW a sequential approach where they apply known orders first</p> <p>ALLOW minor slips as we are looking for an holistic approach to LoR marking</p> <p>NOTE: A clear and logically structured response would link orders to the experiment and experimental results provided. They could provide units</p> <p>Units $\text{dm}^9 \text{ mol}^{-3} \text{ s}^{-1}$ ALLOW any order, e.g. $\text{mol}^{-3} \text{ dm}^9 \text{ s}^{-1}$</p> <p><u>Examiner's Comments</u></p> <p>The first Level of Response question in the paper was answered well. Almost all candidates were able to conclude that the experimental results showed that they were consistent with first order with respect to Br⁻. Some candidates were able to use a sequential approach to determine the orders with respect to BrO₃⁻ and H⁺, reaching a Level 3, but others found this more problematic. Some did not</p>
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					<p>notice that more than one concentration had been changed between experiments. This led to many determining the rate to be 0 order with respect to $[\text{BrO}_3^-]$ and $[\text{H}^+]$. Candidates should focus on the quality of their descriptions when linking data to their conclusions with some candidates creating their own data set to fit their explanations. Having determined orders, nearly all candidates were able to give a corresponding rate equation and could calculate a value for the rate constant, albeit with frequent omission of units. Some candidates confused the rate equation with a K_c expression.</p>
			Total	6	
8	a		<p>All reaction species have same state/phase OR Reactants AND products has same state ✓</p>	<p>1 (AO1.1)</p>	<p>ALLOW SO_2 AND O_2 AND SO_3 for all species OR reactants and products are gases OR the molecules are all gases</p> <p>IGNORE reactants and catalyst have same state</p> <p><u>Examiner's Comments</u></p> <p>Only about half the candidates obtained this mark suggesting that this term had not been recalled by many. A common error stated that the catalyst and reactants were in the same state. Responses from lower-attaining candidates sometimes had the appearance of guesses.</p>
	b		<p>Throughout,</p> <p>ALLOW suitable alternatives for right-hand side, e.g. towards SO_3/products OR forward direction</p> <p>-----</p> <p>--</p> <p>Pressure 2 marks</p> <p>Increased pressure shifts equilibrium to right</p>	<p>5 (AO1.1) (AO1.2) (AO1.2) (AO1.1) (AO1.2) (AO1.2)</p>	<p><i>FULL ANNOTATIONS MUST BE USED</i></p> <p>-----</p> <p>---</p> <p>ORA for reverse reaction e.g. decreased pressure shifts equilibrium to left</p> <p>For moles, ALLOW molecules/particles</p> <p>ORA for reverse reaction</p>

			<p>OR favours the right OR increases yield (of SO₃) ✓</p> <p>Right-hand side has fewer (gaseous) moles OR 3 (gaseous) moles → 2 (gaseous) moles ✓</p> <p>Temperature 2 marks</p> <p>Increased temperature shifts equilibrium to left</p> <p>OR favours the left OR decreases yield (of SO₃) ✓</p> <p>(Forward) reaction is exothermic/ΔH is negative OR (Forward) reaction gives out heat ✓</p> <p>Catalyst 1 mark</p> <p>No shift in equilibrium OR no effect on yield (of SO₃) ✓</p>		<p>e.g. decreased temperature shifts equilibrium to right</p> <p>ALLOW reverse reaction is endothermic ΔH is positive/takes in heat</p> <p>ALLOW rates of forward and reverse reaction increase by same amount</p> <p>IGNORE 'no increase in yield' <i>Yield could still decrease</i></p> <p><u>Examiner's Comments</u></p> <p>This long-answer question was approached very well and there were some excellent and concise answers.</p> <p>Only the less successful responses did not identify the main trends.</p> <p>Marks were often lost for responses in general terms, rather than related to the scenario in the question. For example, some candidates stated that the equilibrium would shift in the direction with fewer moles, without stating what that direction was for this equilibrium.</p> <p>Some candidates contradicted themselves due to a lack of fully understanding how Le Chatelier's Principle should be applied. It was also common to see lengthy responses in which candidates discussed the effect of rate and compromise (not asked for in this question) and then confused equilibrium yield with overall yield.</p>
	c	i	<p>FIRST CHECK THE ANSWER ON ANSWER LINE IF answer = 7.9×10^4 award 2 marks</p> <p>----- ----</p> <p>K_c expression</p> <p>$(K_c =) \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2 [\text{O}_2]}$ OR $\frac{(5.0 \times 10^{-2})^2}{(3.0 \times 10^{-3})^2 \times (3.5 \times 10^{-3})}$</p>	<p>2 (AO2.6 ×2)</p>	<p>IF there is an alternative answer, check for any ECF credit possible using working below.</p> <p>----- -----</p> <p>Square brackets required for K_c expression</p> <p>ALLOW ECF to 2 SF and standard</p>

			<p>OR 79365. ✓</p> <p>Answer to 2 SF and in standard form</p> <p>$K_c = 7.9 \times 10^4$ ✓</p>		<p>form ONLY from inverted K_c expression → 1.3×10^{-5}</p> <p>DO NOT ALLOW $\frac{[\text{SO}_3]^2}{[\text{SO}_2]^2 + [\text{O}_2]}$ (no marks)</p> <p>IGNORE attempts at units</p> <p><u>Examiner's Comments</u></p> <p>The K_c expression was written well by many inverted the expression or added rather than multiplying the values. Indices were usually included.</p> <p>Many candidates gave responses to more than 2 significant figures (2SF) and some did not give the response in standard form.</p> <p>Candidates should be made aware that the term in the question of 'most appropriate' means that the final response should be shown to the least number of significant figures in the supplied data. In this scenario, all values were provided to 2SF and so the final response should also be expressed to 2SF.</p> <p> OCR support</p> <p>The Mathematical Skills Handbook provides guidance on the use of significant figures which can be shared with students.</p>
		ii	<p>Equilibrium shifts to the right/towards products/SO_3 ✓</p>	<p>1 (AO3.1)</p>	<p>ALLOW equilibrium favours the right</p> <p><u>Examiner's Comments</u></p> <p>Few candidates successfully answered this difficult application question.</p> <p>Some candidates considered ensuring complete combustion, or not wasting reactants, or various environmental reasons.</p> <p>The question did supply a hint: 'in</p>


					terms of equilibrium' but this was ignored by most candidates. The idea of equilibrium shift to the right was essential.
			Total	9	
9			D	1(AO1.1)	<u>Examiner's Comments</u> Candidates produced a variety of responses with just over half choosing the correct option D. Option C was the main distractor.
			Total	1	
10			A	1(AO2.6)	<u>Examiner's Comments</u> This question discriminated very well. Evidence from annotations showed that the successful candidates substituted the 0.1 mol dm^{-3} concentration into the K_c expression for each equilibrium and calculated K_c by calculator. This method should guarantee the correct answer.
			Total	1	
11	a		<p>Level 3 (5–6 marks) Uses correct method to calculate K_c AND explains why most operational condition is different with few omissions in the explanation.</p> <p><i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i></p> <p>Level 2 (3–4 marks) Uses correct method to calculate K_c with few errors OR Derives a correct expression for K_c with an attempt at the K_c calculation AND explains why an operational condition is different with some omissions.</p> <p><i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i></p>	6(AO2.4×4 AO1.2×2)	<p>Indicative scientific points may include: IGNORE trailing zeroes</p> <p>Equilibrium amounts $n(\text{N}_2): 1.20 - 0.08 = 1.12$, $n(\text{H}_2): 3.60 - 0.24 = 3.36$</p> <p>Equilibrium concentrations $[\text{N}_2] = \frac{1.12}{8.00} = 0.140 \text{ (mol dm}^{-3}\text{)}$ $[\text{H}_2] = \frac{3.36}{8.00} = 0.420 \text{ (mol dm}^{-3}\text{)}$ $[\text{NH}_3] = \frac{0.160}{8.00} = 0.0200 \text{ (mol dm}^{-3}\text{)}$</p> <p>Equilibrium expression and K_c value with units $K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2] \times [\text{H}_2]^3}$ $K_c = \frac{0.0200^2}{0.140 \times 0.420^3} = 0.0386$</p> <p>Calculator: 0.03856417851 Units: $\text{dm}^6 \text{ mol}^{-2}$</p>


		<p>Level 1 (1–2 marks) Derives a correct expression for K_c AND explains why one operational condition is different with some omissions. OR explains why most operational conditions are different</p> <p><i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i></p> <p>0 marks <i>No response or no response worthy of credit.</i></p>		<p>Explanation for operational differences. Temperature</p> <ul style="list-style-type: none"> • Low temperature for maximum yield: (ΔH –ve \ exothermic) • High temperature to increase rate <p>Pressure</p> <p>High pressure for maximum yield</p> <ul style="list-style-type: none"> • (fewer (gaseous) moles/molecules of products) <p>High pressure expensive to</p> <ul style="list-style-type: none"> • generate OR high pressure is a safety hazard <p>Catalyst</p> <ul style="list-style-type: none"> • Allows a lower temperature to be used for maximum yield. • Reducing fuel expense OR increasing rate <p><u>Examiner's Comments</u></p> <p>This Level of Response question was generally well answered with many candidates achieving maximum marks by simply considering what was required in the question. Responses were often split between a calculation on the main paper and the conditions explanation on extra pages. The calculation errors included no shift or incorrect shift in the equilibrium values. Not calculating the concentration or incorrectly multiplying by 8 rather than dividing by 8. Some candidates attempted a 'hybrid' calculation of K_p by trying to calculate a mole fraction and partial pressures. There was a number of candidates who confidently worked out the value of K_c. There were also some very good analyses of the operational conditions. Many of those who had done well on the calculation treated the explanation as an afterthought, not giving it enough attention to give them an answer that would access Level 3.</p> <p>Exemplar 2</p>
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					 <p>An example of a complete answer, showing a good level of communication in the description and the calculation layout, achieving Level 3 (6 marks) is shown above.</p> <p>This candidate gave a clear method using an "ICE" table to calculate the number of moles at equilibrium. The calculation of the new concentrations can be seen by the use of [] and division by 8. The candidate then shows the Kc expression and substitutes the numerical values before successfully calculating the value and includes the units. This is followed by a concise explanation of the conditions used by industry.</p>
	b	i	Equilibrium (position) shifts to the left (as T is decreased) AND (forward) reaction is endothermic ✓	1(AO1.2)	<p>ALLOW 'favours backward reaction' <i>Implies shift to left</i></p> <p>ALLOW 'shifts in exothermic direction' BUT only if (forward) reaction stated as endothermic</p> <p><u>Examiner's Comments</u></p> <p>Candidates coped well with this question, but many candidates did not gain the mark due to ambiguous statements. Some identified the forward reaction as endothermic, but stated that Kp decreased which was given in the question. Others simply stated that the forward reaction was endothermic as the reverse reaction was exothermic.</p>
		ii	Student 2 is correct AND same number of gas particles/	1(AO3.2)	<p>ALLOW AW that suggests student 2 is correct</p> <p><u>Examiner's Comments</u></p>

			gas(eous) molecules/moles of gas on each side (of equation) ✓		Many candidates gave the correct reason to agree with student 2. Those who agreed with student 1 did not see the equation as a heterogeneous equilibrium system. There were a small number of responses agreeing with student 2 but for the wrong reason – such as a confusion about how the position of equilibrium can change when the value of K_p stays constant. Candidates are advised to read through and address all parts of the question as a minority of students didn't identify which student was correct but gave a correct explanation.
			Total	8	
12	i		<p>Level 3 (5-6 marks) A comprehensive explanation of effect of temperature AND pressure on equilibrium is given with some details about rate AND operating conditions</p> <p><i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i></p> <p>Level 2 (3–4 marks) The candidate attempts three scientific points, but explanations are incomplete.</p> <p><i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i></p> <p>Level 1 (1–2 marks) A simple description based on at least two of the main scientific points.</p> <p><i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i></p>	<p>6 (AO 1.2 × 3) (AO 2.5 × 3)</p>	<p>Indicative scientific points may include: ALLOW reverse arguments throughout</p> <p><u>Effect of Temperature on equilibrium position</u></p> <ul style="list-style-type: none"> • (Forward) reaction is endothermic/ΔH is +ve • High temperature shifts equilibrium to right <p><u>Effect of Pressure on equilibrium position</u></p> <ul style="list-style-type: none"> • Left-hand side has fewer (gaseous) moles • OR 2 (gaseous) moles form 4 (gaseous) moles • Low pressure shifts equilibrium to right <p><u>Effect on rate of reaction</u></p> <ul style="list-style-type: none"> • High temp increases rate • Low pressure reduces rate • Catalyst increases rate • Catalyst lowers activation energy • Discussion using collision theory to support arguments

			<p>0 marks No response or no response worthy of credit.</p>	<p><u>Operating conditions (not inclusive)</u></p> <ul style="list-style-type: none"> • Compromise conditions needed • High temperatures increase energy demand/costs • Slightly higher pressure used than optimum • Higher pressures unsafe • Catalyst reduces need for higher temperatures • Catalyst doesn't effect the position of equilibrium • Excess steam shifts equilibrium to right <p><u>Examiner's Comments</u></p> <p>Only a small number of candidates were given all 6 marks for their response. Many responses made little or no reference to equilibrium, considering only the rate of reaction. A clear understanding of the difference between rate and equilibrium was essential to scoring highly on this question.</p> <p>Excellent descriptions were given regarding the role of the catalyst on the rate of reaction, possibly influenced by the previous question. Some gave detailed responses in terms of the impact of both pressure and temperature on the equilibrium position but then did not give the changes made by industry such as reducing temperature due to energy demand or increasing pressure to increase rate.</p> <p>Some candidates indicated that 15atm was a low pressure including reference to it being "lower than normal atmospheric pressure" which suggested that they did not understand either the measurement in atmospheres and/or scale of pressure. A common incorrect response was to</p>
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				<p>suggest that a higher pressure gives increased yield as more moles on right/products.</p> <p>Some stated that the reaction was exothermic, clearly confusing the enthalpy change signs. Some also described the “endothermic side” demonstrating a lack of understanding that enthalpy changes require a difference between products and reactants. Many did not correctly consider the use of excess of steam to increase concentration of reactant and shift equilibrium to products/right but talked in terms of limiting reagents, e.g. “This is used so all of the methane is reacted” or increased collisions.</p> <p>Many were prone generalisations, e.g. “These conditions are used industrially to achieve the most hydrogen efficiently with the least amount of undesired (waste) products”. Candidates need to be encouraged to plan their answers, even using subheadings to organise information and follow the key approach: point, evidence, explain. Candidates should also be encouraged to re-read their answers to check communication is clear and accurate without any contradictory statements.</p> <p>Many included irrelevant or inaccurate information such as describing the toxicity of carbon monoxide, so reducing yield of that being beneficial, or “using a catalyst improves atom economy”.</p> <p> OCR support</p> <p>This question was good at highlighting candidates understanding of the impact of different conditions on equilibrium reactions. We have produced a delivery guide to help with teaching about equilibrium: https://www.ocr.org.uk/Images/261544-equilibrium.pdf</p>
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				<p>Exemplar 2</p>  <p>This exemplar shows a candidate who achieved L3 with all 6 marks given. They have considered both the effect of temperature and pressure on equilibrium and potential compromises used industrially. They have also considered the impact of using a catalyst. Their response is logically structured and has a clear line of reasoning.</p>
		ii	<p>FIRST CHECK THE ANSWER ON ANSWER LINE IF answer = 24.1, award 2 marks</p> <p>-----</p> <p>-----</p> <p>K_c expression</p> $(K_c =) \frac{[\text{CO}][\text{H}_2]^3}{[\text{CH}_4][\text{H}_2\text{O}]} \text{ OR } \frac{(0.510)(1.53)^3}{(0.111)(0.682)}$ <p>OR 24.12..... ✓</p> <p>Answer to 3 SF K_c = 24.1 ✓</p>	<p>IF there is an alternative answer, check for any ECF credit possible using working below.</p> <p>-----</p> <p>-----</p> <p>ALLOW calculated value 24.12887731 correctly rounded to 3 or more SF for 1st marking point</p> <p>ALLOW ECF to 3 SF ONLY from inverted K_c expression → 0.0414</p> <p>DO NOT ALLOW $\frac{[\text{CO}] + [\text{H}_2]^3}{[\text{CH}_4] + [\text{H}_2\text{O}]}$ (no marks)</p> <p>IGNORE attempts at units</p> <p><u>Examiner's Comments</u></p> <p>This question was well answered with most candidates scoring both marks. Common errors seen included: inverse K_c expression, final answer</p>

					not to 3 significant figures, adding rather than multiplying concentrations, calculator error ($[\text{H}_2]^2$ instead of $[\text{H}_2]^3$) or transcription errors (e.g. using 0.11 rather than 0.111).
			Total	8	
13	a		<p>At 90 °C/higher temperature</p> <ul style="list-style-type: none"> Faster rate AND more frequent collisions ✓ More particles have the activation energy/E_a or greater ✓ $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ is lower ✓ (forward reaction) ΔH -ve OR exothermic ✓ 	<p>4 (1 ×AO2.7) (1 ×AO1.2) (1 ×AO2.3) (1 ×AO1.2)</p>	<p>ORA for 50 °C IGNORE more successful collisions ALLOW more molecules have enough energy to react ALLOW atoms/molecules/ions ALLOW decreases</p> <p><u>Examiner's Comments</u></p> <p>This question asked candidates to explain the different rates from a novel experiment carried out at 50°C and 90°C, and to predict the ΔH sign for the forward reaction. Candidate explanations for the rates were often superficial, solely in terms of greater energy at 90°C. Many responses referred neither to the different frequency of collisions nor the greater number of particles exceeding the activation energy at 90°C. Most candidates predicted that ΔH would have a negative sign.</p> <p>Candidates were expected to link the evidence from the absorbance data in the graph to less $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ being present at 90°C. When experimental information has been presented, candidates are advised to look for the evidence responsible in their explanations.</p>
	b	i	<p>Cl^- /It/They react with AgNO_3 / Ag^+ /silver ions OR AgCl formed OR $\text{Ag}^+ + \text{Cl}^- \rightarrow \text{AgCl}$ ✓</p>	<p>1 (AO3.2)</p>	<p>IGNORE chlorine/Cl^- for chloride ion IGNORE AgCl_2</p> <p><u>Examiner's Comments</u></p> <p>Almost all candidates realised that Cl^- ions would react with the added AgNO_3 at time = t_1.</p>
		ii	<p>$[\text{CoC}_4^{2-}]$ decreases AND $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ increases ✓</p> <p>Cl^- increase is 4 × change in $[\text{CoC}_4^{2-}]$ / $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ ✓</p>	<p>3 (2 ×AO3.1) (1 ×AO3.2)</p>	<p>IGNORE missing charges and small slips in formulae, e.g. CoCl_4 missing bracket, etc IGNORE Cl^- for changes in concentration</p>

			Equilibrium shifts to right ✓		<p>ALLOW suitable alternatives for 'shifts to right', e.g. towards products OR in forward direction OR 'favours the right'</p> <p><u>Examiner's Comments</u></p> <p>In contrast with Question 4 (a), most candidates did interpret the graphical information provided and related this to the reduced concentration of CoCl_4^{2-} ions and the increased concentration of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ ions. Most candidates also referred to Equilibrium 4.1 to conclude that the equilibrium shifts to the right. Only the very best candidates recognised that the increase in Cl^- concentration following the initial addition of AgNO_3 was 4 times greater than the increase in the concentration of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$, arising from the 4 : 1 ratio in the stoichiometry in the equation.</p>
			Total	8	