

Question	Answer	Marks	Guidance
1	B	1	ALLOW 0.426 in the box

Question			Answer	Marks	Guidance
2	(a)	(i)	(Species have) different states/phases ✓	1	
		(ii)	$(K_p =) p(\text{CO(g)})^4$ ✓	1	Allow species without state symbols and without brackets, e.g. p_{CO}^4 , $pp\text{CO}^4$, PCO^4 , $p(\text{CO}^4)$ etc. DO NOT ALLOW square brackets

Question			Answer	Marks	Guidance
3	(a)		Conditions Low/decreased pressure AND high/increased temperature ✓ Pressure: Right-hand/product side has more (gaseous) moles/molecules OR left-hand side/reactant side has fewer (gaseous) moles/molecules ✓ Temperature: (Forward) reaction is endothermic / takes in heat OR reverse reaction is exothermic / gives out heat ✓	4	ANNOTATE ANSWER WITH TICKS AND CROSSES ETC DO NOT ALLOW more atoms on right-hand side OR fewer atoms on left-hand side. DO NOT ALLOW incorrect shift direction
			Low pressure gives a slow rate OR High temperature uses a large amount of energy/fuel ✓		ORA IGNORE 'expensive' IGNORE use of catalyst
	(b)	(i)	$(K_c =) \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2 [\text{O}_2]} \quad \checkmark$ Units: $\text{dm}^3 \text{mol}^{-1}$ ✓	2	IGNORE state symbols in K_c expression, even if wrong. For units, ALLOW $\text{mol}^{-1} \text{dm}^3$ 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.

Question			Answer	Marks	Guidance
3	(b)	(ii)	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = 2.45, Award 4 marks. ----- Equilibrium concentrations (moles $\times$ 2.5) 1 MARK $\text{SO}_2 = 0.135 \text{ (mol dm}^{-3}\text{)}$ AND $\text{O}_2 = 0.0675 \text{ (mol dm}^{-3}\text{)}$ ✓ Calculation of $[\text{SO}_3(\text{g})]$ 2 MARKS $[\text{SO}_3] = \sqrt{(K_c \times [\text{SO}_2]^2 \times \text{O}_2)}$ OR $\sqrt{(3.045 \times 10^4 \times 0.135^2 \times 0.0675)}$ ✓ $= 6.12039291 \text{ (mol dm}^{-3}\text{)}$ ✓ <i>Answer scores both $[\text{SO}_3]$ marks automatically</i> Calculation of $n(\text{SO}_3)$ in 400 cm^3 1 MARK $n(\text{SO}_3) = 6.12039291/2.5 = 2.45 \text{ (mol)}$ ✓ 3SF required (Appropriate number)	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 ALLOW ECF from incorrect $[\text{SO}_3]$ ALLOW 3 SF, 6.12, up to calculator value of 6.12039291 correctly rounded. Common errors 37.5 1 mark <i>No $\sqrt{\text{for } [\text{SO}_3]^2}$ and no scaling by 1/2.5</i> 15.0 2 marks <i>No $\sqrt{\text{for } [\text{SO}_3]^2}$</i> 0.619 3 marks <i>Use of mol of SO_2 and O_2</i> 1.55 2 marks <i>No conc used and Use of mol of SO_2 and O_2</i>
			Total	11	

Question	Answer	Marks	AO element	Guidance
4	B	1	AO1.2	

Question			Answer	Marks	Guidance
5	(a)		$K_c = \frac{[\text{NO}_2]^2}{[\text{NO}]^2 [\text{O}_2]} \checkmark$ Units = $\text{dm}^3 \text{mol}^{-1} \checkmark$	2	Must be square brackets IGNORE state symbols ALLOW $\text{mol}^{-1} \text{dm}^3$ ALLOW mol dm^{-3} as ECF from inverted K_c expression
	(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. $[\text{NO}] = \frac{0.40}{4.0} = 0.1(0) (\text{mol dm}^{-3})$ AND $[\text{O}_2] = \frac{0.80}{4.0} = 0.2(0) (\text{mol dm}^{-3}) \checkmark$ $[\text{NO}_2]^2 = 45 \times 0.10^2 \times 0.20$ OR $= 0.09(0) \checkmark$ $[\text{NO}_2] = \sqrt{(45 \times 0.10^2 \times 0.20)}$ OR $= 0.3(0) (\text{mol dm}^{-3}) \checkmark$ amount $\text{NO}_2 = 0.30 \times 4 = 1.2 (\text{mol}) \checkmark$	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 O₂ used 0.36 = 3 marks mol of NO₂ calculated from $[\text{NO}_2]^2$ 2.4 = 2 marks mol of NO and O₂ used and no mol of NO₂ calculated

Question			Answer	Marks	Guidance
5	(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
	(c)	(ii)	Equilibrium shift (Equilibrium position) shifts to right / forward / towards products ✓ Effect of increased pressure on K_p expression Ratio (in K_p expression) decreases OR 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 ✓	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. ALLOW more NO_2 / product formed to restore K_p ALLOW ratio adjusts to restore K_p
			Total	10	

Question			Answer	Marks	AO	Guidance
6	(a)	(i)	$(K_p) = \frac{p(\text{SO}_3)^2(\text{g})}{p(\text{SO}_2(\text{g}))^2 \times p(\text{O}_2(\text{g}))} \checkmark$ $\text{atm}^{-1} \checkmark$	2	1.2 x2	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 ALLOW atm as ECF if K_p is upside down ALLOW use of any pressure unit eg Pa^{-1} or kPa^{-1}

Question			Answer	Marks	AO element	Guidance
6	(a)	(ii)	FIRST CHECK THE ANSWER ON ANSWER LINE if answer = 27.2 award 5 marks ----- Initial amounts $n(\text{SO}_2) = \frac{10.2}{24.0} = 0.425 \text{ (mol) AND}$ $n(\text{O}_2) = \frac{12}{32.0} = 0.375 \text{ (mol) ✓}$ Equilibrium amounts in moles $n(\text{SO}_2) = (0.425 - 0.350) = 0.075 \text{ (mol) AND}$ $n(\text{O}_2) = (0.375 - 0.350/2) = 0.200 \text{ (mol) ✓}$ Total moles $n_{\text{tot}} = 0.625 \text{ (mol) ✓}$ Partial pressures $p\text{SO}_2 = \left(\frac{0.075}{0.625} \times 2.50\right) = 0.3 \text{ (atm) AND}$ $p\text{O}_2 = \left(\frac{0.2}{0.625} \times 2.50\right) = 0.8 \text{ (atm) AND}$ $p\text{SO}_3 = \left(\frac{0.350}{0.625} \times 2.50\right) = 1.4 \text{ (atm) ✓}$ K_p to 3 SF $(K_p = \frac{1.4^2}{0.3^2 \times 0.8}) = 27.2 \text{ (atm}^{-1}\text{) ✓}$	5	2.6 x5	IF there is an alternative answer, check to see if there is any ECF credit possible using working below. <i>Common errors</i> Allow 4 marks for 1.45/1.46 (depending upon rounding) <i>Initial amounts</i> $n(\text{SO}_2) = 2 \times n(\text{O}_2)$ $n(\text{O}_2) = 0.375$ and $n(\text{SO}_2) = 0.75(0)$ <i>Equilibrium moles</i> $n(\text{SO}_2) = 0.75 - 0.350 = 0.4(0)$ $n(\text{O}_2) = 0.2(0)$ <i>total moles</i> $n_{\text{tot}} = 0.95$ <i>partial pressures</i> $p\text{SO}_2 = 1.05$ $p\text{O}_2 = 0.526$ $p\text{SO}_3 = 0.921$ Allow 4 marks for 15.1/15.0 <i>Initial amounts</i> $n(\text{O}_2) = 12/16 = 0.75$ <i>Equilibrium moles</i> $n(\text{O}_2) = 0.575$ <i>total moles</i> $n_{\text{tot}} = 1.00$ <i>partial pressures</i> $p\text{SO}_2 = 0.188$ $p\text{O}_2 = 1.438$ $p\text{SO}_3 = 0.88$ IGNORE units

Question			Answer	Marks	AO element	Guidance
6	(a)	(iii)	(greater K_p value means) equilibrium position shifted to right/RHS ✓ Lower temperature because (forward) reaction is exothermic ✓	2	3.2 x2	ALLOW greater/higher amount of SO_3 /product ALLOW greater K_p means larger numerator
		(iv)	equilibrium position (far) to the right ✓	1	3.2	ALLOW (very) high yield of products or of SO_3 ALLOW reaction is nearly complete / irreversible ALLOW Forward reaction is (greatly) favored ALLOW (far) more product(s) than reactant(s) or

Question	Answer	Marks	AO	Guidance
7	B	1	2.6	

Question	Answer	Marks	AO	Guidance
8	B	1	1.1	

Question			Answer	Marks	AO element	Guidance
9	(a)		High pressure AND low temperature ✓ Right-hand side has fewer (gaseous) moles/molecules OR left-hand side has more (gaseous) moles/molecules ✓ (Forward) reaction is exothermic/gives out heat OR reverse reaction is endothermic/takes in heat ✓	3	1.2×1 1.1×2	Marks are independent ORA throughout ALLOW RHS ALLOW suitable alternatives for RHS e.g. product side

Question			Answer	Marks	element	Guidance
10	(a)		FIRST CHECK THE ANSWER ON ANSWER LINE If answer = 7.4 award 4 marks Initial moles of reactants 1 mark $n(\text{CH}_3\text{OH})_{\text{initial}} = \frac{9.6}{32} = 0.3 \text{ (mol)}$ AND $n(\text{CH}_3\text{COOH})_{\text{initial}} = \frac{12}{60} = 0.2 \text{ (mol)} \checkmark$ Equilibrium moles 2 marks $n(\text{CH}_3\text{COOH})_{\text{reacted}} = 0.2 - 0.03 = 0.17 \text{ (mol)}$ AND $n(\text{CH}_3\text{OH})_{\text{equil}} = 0.3 - 0.17 = 0.13 \text{ (mol)} \checkmark$ $n(\text{CH}_3\text{COOCH}_3)_{\text{equil}} = 0.17 \text{ (mol)}$ AND $n(\text{H}_2\text{O})_{\text{equil}} = 0.17 \text{ (mol)} \checkmark$ K_c calculation 1 mark $K_c = \frac{0.17/V \times 0.17/V}{0.13/V \times 0.03/V} = 7.4 \checkmark$	4	1.2×1 2.8×3	ALLOW minimum of 2SF throughout ALLOW ECF from initial moles ALLOW ECF from equilibrium moles Use of V not required but K_c expression must be correct ALLOW up to calculator answer of 7.41025641
			Total	9		

Question	Answer	Marks	AO element	Guidance
11	B	1	AO2.2	

Question			Answer	Marks	element	Guidance
12	(a)		rate of forwards reaction = rate of backwards reaction OR concentrations/pressure/temperature are constant /do not change ✓	1	AO1.1	DO NOT ALLOW “are the same”

12	(b)	(i)	FIRST, CHECK FOR VALUE OF K_p. IF answer = 20.7 (MPa⁻¹), award 4 marks <i>Equilibrium amounts</i> $n(\text{NO}) = 0.4 \text{ (mol)}$ AND $n(\text{O}_2) = 0.9 \text{ (mol)}$ AND $n(\text{NO}_2) = 1.2 \text{ (mol)}$ ✓ <i>Total moles at equilibrium</i> $n_{\text{tot}} = 2.5 \text{ (mol)}$ ✓ <i>Partial pressures</i> $p(\text{NO}) = \frac{0.4}{2.5} \times 1.21 = 0.1936 \text{ (MPa)}$ AND $p(\text{O}_2) = \frac{0.9}{2.5} \times 1.21 = 0.4356 \text{ (MPa)}$ AND $p(\text{NO}_2) = \frac{1.2}{2.5} \times 1.21 = 0.5808 \text{ (MPa)}$ ✓ <i>K_p value</i> $K_p = \frac{0.5808^2}{0.1936^2 \times 0.4356} = 20.7 \text{ to 3 SF (MPa}^{-1}\text{)}$ ✓	4	AO2.4 ×4	FULL ANNOTATIONS MUST BE USED ALLOW ECF throughout ALLOW 20.6 from 3 SF partial pressures, 0.194, 0.436 and 0.581 IF there is an alternative answer, check to see if there is any ECF credit possible using working below Look for values to 3 SF here: 0.194, 0.436 and 0.581 ALLOW 25.0 as ECF (from omission of partial pressures for 3 marks)
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12	(b)	(ii)	<table><tr><th>Change</th><th>K_p</th><th>Equilibrium amount of NO₂</th><th>Initial rate</th></tr><tr><td>Temperature increased</td><td>smaller</td><td>smaller</td><td>greater</td></tr><tr><td>Pressure increase</td><td>same</td><td>greater</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>	Change	K_p	Equilibrium amount of NO ₂	Initial rate	Temperature increased	smaller	smaller	greater	Pressure increase	same	greater	greater	Catalyst added	same	same	greater		✓	✓	✓	3	AO1.2 ×3	Mark by COLUMN ALLOW obvious alternatives for greater/smaller/same, e.g. increases/decreases/more/less
Change	K_p	Equilibrium amount of NO ₂	Initial rate																							
Temperature increased	smaller	smaller	greater																							
Pressure increase	same	greater	greater																							
Catalyst added	same	same	greater																							
	✓	✓	✓																							
			Total	11																						

Question		Answer	Marks	AO element	Guidance
13	(a)	Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question. 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. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> 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. <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i> 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 <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i>	6	AO2.4 ×4 AO1.2 ×2	Indicative scientific points may include: IGNORE trailing zeroes <u>Equilibrium amounts</u> $n(\text{N}_2): 1.20 - 0.08 = 1.12$, $n(\text{H}_2): 3.60 - 0.24 = 3.36$ <u>Equilibrium concentrations</u> $[\text{N}_2] = \frac{1.12}{8.00} = 0.140 \text{ (mol dm}^{-3}\text{)}$ $[\text{H}_2] = \frac{3.36}{8.00} = 0.420 \text{ (mol dm}^{-3}\text{)}$ $[\text{NH}_3] = \frac{0.160}{8.00} = 0.0200 \text{ (mol dm}^{-3}\text{)}$ <u>Equilibrium expression and K_c value with units</u> $K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2] \times [\text{H}_2]^3}$ $K_c = \frac{0.0200^2}{0.140 \times 0.420^3} = 0.0386$ Calculator: 0.03856417851 Units: $\text{dm}^6 \text{ mol}^{-2}$ <u>Explanation for operational differences.</u> <u>Temperature</u> • Low temperature for maximum yield: (ΔH –ve \ exothermic) • High temperature to increase rate <u>Pressure</u> • High pressure for maximum yield (fewer (gaseous) moles/molecules of products) • High pressure expensive to generate OR high pressure is a safety hazard

					AO	
13	(b)	(i)	Equilibrium (position) shifts to the left (as T is decreased) AND (forward) reaction is endothermic ✓	1	AO1.2	ALLOW 'favours backward reaction' <i>Implies shift to left</i> ALLOW 'shifts in exothermic direction' BUT only if (forward) reaction stated as endothermic
		(ii)	Student 2 is correct AND same number of gas particles/ gas(eous) molecules/moles of gas on each side (of equation) ✓	1	AO3.2	ALLOW AW that suggests student 2 is correct
			Total	8		

[illegible]

Question			Answer	Marks	AO element	Guidance
14	(a)	(ii)	Higher temperature ΔH is negative / exothermic (for forward reaction) AND equilibrium shifts to left/to LHS/decreases yield ✓ Higher pressure 2 (gaseous) moles form 1 (gaseous) mole/ to side with fewer moles AND Equilibrium shifts to right /RHS/increases yield ✓ Comparison Difficult to predict relative contributions of two opposing factors ✓	3	AO2.1 ×2 AO3.1 ×1	ORA ALLOW correct equilibrium shifts without explanations for 1 mark ALLOW opposing effects may not be the same size ALLOW effects could cancel each other out ALLOW effects oppose one another 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

Question	Answer	Marks	Guidance
15	C	1	

Question			Answer	Marks	Guidance						
16	(a)	(i)	FIRST CHECK THE ANSWER ON ANSWER LINE IF answer = 0.455 award 4 marks AND IF units = atm^{1/2} award 5 marks Equilibrium moles ✓ $N \text{ SO}_3 = 1.35$, $n \text{ O}_2 = 0.45(0)$ AND $n \text{ total} = 2.7(0)$ Partial pressures ✓ <table><tr><td>$p(\text{SO}_3)$</td><td>$\frac{1.35}{2.7(0)} \times 2.80$ OR $1.4(0)$</td></tr><tr><td>$p(\text{SO}_2)$</td><td>$\frac{0.900}{2.7(0)} \times 2.80$ OR 0.933</td></tr><tr><td>$p(\text{O}_2)$</td><td>$\frac{0.450}{2.7(0)} \times 2.80$ OR 0.467</td></tr></table> $(K_p) = \frac{p(\text{SO}_2) p(\text{O}_2)^{1/2}}{p(\text{SO}_3)}$ OR $(K_p) = \frac{(0.933) \times (0.467)^{1/2}}{(1.40)} \checkmark$ Answer to 3 SF $K_p = 0.455 \checkmark$ Units Substitution of units into correct K_p expression $\frac{\text{atm}^1 \times \text{atm}^{1/2}}{\text{atm}^1} = \text{atm}^{1/2} \checkmark$	$p(\text{SO}_3)$	$\frac{1.35}{2.7(0)} \times 2.80$ 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	5	IF there is an alternative answer, check for any ECF credit possible using working below. ----- ALLOW 3SF or more unless there is a trailing zero e.g. ALLOW $p(\text{SO}_3) = 1.4$, $n \text{ total} = 2.7$ 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 ALLOW $(K_p) = \frac{p(\text{SO}_2) p^{1/2}(\text{O}_2)}{p(\text{SO}_3)}$ 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 $\sqrt{\text{atm}}$
$p(\text{SO}_3)$	$\frac{1.35}{2.7(0)} \times 2.80$ 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										

Question			Answer	Marks	Guidance												
16	(a)				Common errors 4 marks (3 marks for calculation + unit mark) 0.207 (from expression $\frac{p(\text{SO}_2)^2 \times p(\text{O}_2)}{p(\text{SO}_3)^2}$) Unit: atm 2.20 (from inverted expression) Unit: atm ^{-1/2}												
		(ii)	ΔH is +ve / endothermic (in forward direction). AND (At higher temperature,) equilibrium shifts to right hand side ✓ (T_2) has greater K_p value OR $7.7 \times 10^{-2} > 3.3 \times 10^{-5}$ ✓	2	ORA throughout ALLOW towards the products for right hand side ALLOW increases yield of products DO NOT ALLOW T_1 has greater K_p value												
		(iii)	One mark per correct row ✓✓ <table border="1"><tr><th>Change</th><th>Decrease</th><th>No change</th><th>Increase</th></tr><tr><td>No catalyst</td><td></td><td>✓</td><td></td></tr><tr><td>Increased pressure</td><td></td><td>✓</td><td></td></tr></table>	Change	Decrease	No change	Increase	No catalyst		✓		Increased pressure		✓		2	
Change	Decrease	No change	Increase														
No catalyst		✓															
Increased pressure		✓															

Question			Answer	Mark	Guidance
17	(a)	(i)	Equal number of (gaseous) reactant and product molecules/moles OR (pressure) units cancel ✓	1	ALLOW equal number of terms in numerator and denominator ALLOW units cancelling as shown in an equation DO NOT ALLOW references to concentration IGNORE same number of reactants and products (need moles/molecules)

Question			Answer	Mark	Guidance
17	(a)	(ii)	FIRST CHECK ANSWERS ON THE ANSWER LINES IF answer = 74(kPa) <u>for both</u> award 3 marks $p(\text{H}_2\text{O}) p(\text{CO}) = \frac{p(\text{H}_2) \times p(\text{CO}_2)}{K_p}$ $= \frac{211 \times 211}{8.13}$ $= 5476.(137761) \checkmark$ (At equilibrium) $p(\text{H}_2\text{O}) = p(\text{CO})$ / the same value on both partial pressure answer lines $\checkmark$ $p(\text{H}_2\text{O})$ AND $p(\text{CO}) = \sqrt{5476.(137761)}$ $= 74(.0) \text{ (kPa)} \checkmark$	3	ALLOW ECF from incorrect x^2 ALLOW $p(\text{H}_2\text{O}) = p(\text{CO}) = x$ So $x^2 = \frac{p(\text{H}_2) \times p(\text{CO}_2)}{K_p} = 5476.138$ scores first 2 marks
		(iii)	Lower temperature AND (forward reaction) is exothermic / reverse reaction is endothermic $\checkmark$ K_p (has increased and) equilibrium position shifted to the right $\checkmark$	2	ALLOW ORA ALLOW shifts to the products/increases yield or AW ALLOW value of $p(\text{H}_2\text{O}) p(\text{CO})$ decreased / $p(\text{H}_2) p(\text{CO}_2)$ increased