CHEMICAL EQUILIBRIUM (3.2.3)

1. A student mixes hydrogen and iodine at room temperature and pressure and allows the mixture to reach dynamic equilibrium.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = -9 \text{ kJ mol}^{-1}$$ **equilibrium 3.1**

(i) A closed system is required for dynamic equilibrium to be established.

State **one** other feature of this dynamic equilibrium.

---[1]

(ii) The student heats the equilibrium mixture keeping the volume constant.

Predict how the composition of the equilibrium mixture changes on heating.

Explain your answer.

---[2]

(iii) Predict and explain what effect, if any, an increase in the pressure would have on the position of the equilibrium.

effect _____

explanation _____

---[1]

2. State le Chatelier's principle.

---[1]

3. Which statement is **not** correct for a system in dynamic equilibrium?

A The concentrations of products and reactants are the same.
B The equilibrium can be achieved from both sides.
C The rate of the forward reaction is equal to the rate of the reverse reaction.
D The system is closed.

Your answer ☐

[1]

4. Carbon monoxide reacts with steam in the following reaction equation:

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H = -40 \text{ kJ mol}^{-1}$$

Which change will shift the position of equilibrium to the right hand side of the equation?

A decrease in pressure
B increase in pressure
C decrease in temperature
D increase in temperature

Your answer ☐

[1]

5. Methanol, CH_3OH, is an important feedstock for the chemical industry.

In the manufacture of methanol, carbon dioxide and hydrogen are reacted together in the reversible reaction shown below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \quad \Delta H = -49 \text{ kJ mol}^{-1}$$

High pressures and low temperatures would give a maximum equilibrium yield of methanol.

(i) Explain this statement in terms of le Chatelier's principle.

---[3]

(ii) Explain why the actual conditions used by the chemical industry might be different.

---[2]

6. The following reaction is used in industry to make sulfur trioxide gas, SO_3.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \ \Delta H^{\circ} = -196 \text{ kJ mol}^{-1}$$

This preparation is carried out in the presence of a catalyst.

* Explain the conditions of temperature and pressure that could be used to obtain the maximum equilibrium yield of sulfur trioxide.

Discuss the importance of a compromise between equilibrium yield and reaction rate when deciding the operational conditions for this process.

[6]

7(a). Sulfur trioxide, SO_3, is used for the industrial manufacture of sulfuric acid.

SO_3 is produced by reacting sulfur dioxide, SO_2, and oxygen, O_2, as shown in **equilibrium 25.1** below.

Equilibrium 25.1 $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta H = -197$ kJ mol^{-1}

Le Chatelier' s principle can be used to predict how different conditions affect the equilibrium position.

- Using le Chatelier' s principle, show that a low temperature and a high pressure should be used to obtain a maximum **equilibrium** yield of SO_3.
- Explain why the actual conditions used in industry may be different from the conditions needed for a maximum equilibrium yield.

---

[5]

(b). Under certain conditions, K_c for **equilibrium 25.1** is 0.160 dm^3 mol^{-1}.

The equilibrium mixture under these conditions has the following concentrations of SO_2 and O_2.

Species	Equilibrium concentration / mol dm^{-3}
SO_2	2.00
O_2	1.20

- Using the value of K_c, explain whether the equilibrium position will be towards the right or towards the left under these conditions.
- Calculate the concentration of SO_3 in the equilibrium mixture.

---

[4]

8. This question is about equilibrium and catalysts.

The equilibrium between NO_2 and N_2O_4 gases is set up in a gas syringe at room temperature.
The two gases are different in appearance.

$$\underset{\text{brown}}{2NO_2(g)} \rightleftharpoons \underset{\text{colourless}}{N_2O_4(g)} \qquad \Delta H = -58\,\text{kJ mol}^{-1}$$

Using le Chatelier's principle, predict and explain how the following changes would affect the appearance of the equilibrium mixture.

(i) The gas mixture is compressed by pushing in the plunger of the gas syringe.

--- [2]

(ii) The gas syringe is placed in a warm water bath.

--- [2]

9. The reversible reaction below is allowed to reach equilibrium.

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = -9.4\ \text{kJ mol}^{-1}$

Which change in conditions would be expected to shift the equilibrium position towards the products?

A decrease the pressure
B decrease the temperature
C increase the pressure
D increase the temperature

Your answer ☐ [1]

10. The reaction of ammonia, NH_3, with oxygen to form nitrogen monoxide, NO, is an important industrial process.

The equation for this reaction is shown in **equilibrium 4.1** below.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H = -905 \text{ kJ mol}^{-1}$$ **Equilibrium 4.1**

Predict the conditions of temperature and pressure for a maximum equilibrium yield of nitrogen monoxide in **equilibrium 4.1**.

- Explain your prediction in terms of le Chatelier's principle.
- State and explain how these conditions could be changed to achieve a compromise between equilibrium yield, rate and other operational factors.

---[5]

11. The reversible reaction below is at equilibrium.

$$2SO_2(g) + O_2(g) \leftrightharpoons 2SO_3(g) \qquad \Delta H = -197 \text{ kJ mol}^{-1}$$

Which changes in pressure and temperature would shift the equilibrium position towards the products?

	Pressure	Temperature
A	Decrease	Decrease
B	Decrease	Increase
C	Increase	Decrease
D	Increase	Increase

Your answer ☐ [1]

12. The reversible reaction below is at equilibrium.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

What is the expression for K_c?

A $\dfrac{[N_2(g)]\,[H_2(g)]^3}{[NH_3(g)]^2}$

B $\dfrac{[NH_3(g)]^2}{[N_2(g)]\,[H_2(g)]^3}$

C $\dfrac{[N_2(g)] + 3[H_2(g)]}{2[NH_3(g)]}$

D $\dfrac{2[NH_3(g)]}{[N_2(g)] + 3[H_2(g)]}$

Your answer ☐ [1]

13. The reaction of ammonia, NH_3, with oxygen to form nitrogen monoxide, NO, is an important industrial process.

The equation for this reaction is shown in **equilibrium 4.1** below.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \quad \Delta H = -905 \text{ kJ mol}^{-1}$$ **Equilibrium 4.1**

Write an expression for the equilibrium constant, K_c, in **equilibrium 4.1**.

[1]

14. A chemist investigates the equilibrium that produces methanol:

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH\ (g)$

The chemist mixes CO(g) with $H_2(g)$ and leaves the mixture to react until equilibrium is reached.
The equilibrium mixture is analysed and found to contain the following concentrations.

Substance	Concentration/mol dm^{-3}
CO (g)	0.310
$H_2(g)$	0.240
$CH_3OH(g)$	0.260

Calculate the numerical value of K_c for this equilibrium.

Give your answer to an **appropriate** number of significant figures.

K_c = _____ $dm^6\ mol^{-2}$ **[2]**

15. Ammonia is used in the manufacture of nitric acid. The first stage of this process is a dynamic equilibrium.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$$

(i) When the temperature is increased, K_c for this reaction decreases.

State the effect, if any, on the equilibrium yield of NO in this reaction.

Explain your answer.

---

[1]

(ii) Which element has been oxidised and which element has been reduced in the reaction?

Include signs with the oxidation numbers.

Oxidised _____ Oxidation number change from _____ to _____

Reduced _____ Oxidation number change from _____ to _____

[2]

16. Nitrogen can be reacted with hydrogen in the presence of a catalyst to make ammonia in the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H = -92 \text{ kJ mol}^{-1}$$

A mixture of N_2 and H_2 was left to react until it reached equilibrium. The equilibrium mixture had the following composition:

N_2	1.20 mol dm^{-3}
H_2	2.00 mol dm^{-3}
NH_3	0.877 mol dm^{-3}

(i) Calculate a value for K_c for this equilibrium.

K_c = _____ dm^6 mol^{-2} **[3]**

(ii) Explain how the following changes would affect the amount of NH_3 present in the equilibrium mixture.

Use of a catalyst:

A higher temperature:

---

[3]

17. This question looks at equilibrium reactions used by industry for preparing important chemicals.

Methanol can be manufactured by reacting carbon monoxide with hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

An equilibrium mixture contains 3.10×10^{-3} mol dm^{-3} CO, 2.40×10^{-3} mol dm^{-3} H_2 and an unknown concentration of CH_3OH.

(i) Write an expression for the equilibrium constant, K_c.

[1]

(ii) The value of K_c for this equilibrium is 14.6 dm^6 mol^{-2}.

Determine the equilibrium concentration methanol, $CH_3OH(g)$.

Give your answer to **three** significant figures.

equilibrium concentration of $CH_3OH(g)$ = _____ dm^6 mol^{-2} **[2]**

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1		i	Rate of the forward reaction is equal to the rate of the reverse reaction ✓ OR concentrations do not change✓	1	ALLOW both reactions occur at same rate IGNORE conc. of reactants = conc. of products **Examiner's Comments** A good proportion of candidates recognised the need to provide one of the key features of a dynamic equilibrium as outlined in the specification.
		ii	More H_2 and I_2 OR less HI ✓ (equilibrium position shifts) to the left AND (Forward) reaction is exothermic OR reverse reaction is endothermic OR in the endothermic direction✓	2	**Mark each point independently** ALLOW more reactants OR less products Note: ALLOW suitable alternatives for to the left e.g. towards reactants OR towards H_2 / I_2 OR in reverse direction OR favours the left. ALLOW gives out heat for exothermic ALLOW takes in heat for endothermic IGNORE responses in terms of rate **Examiner's Comments** This question required candidates to apply le Chatelier's Principle to the equilibrium and in addition predict the effect it would have on the composition of the mixture. Most candidates were able to predict and explain the shift in the position of equilibrium and the most able stated the effect on the composition of the mixture. Candidates should be encouraged to read questions carefully to ensure they address all aspects in their response.

Question			Answer/Indicative content	Marks	Guidance
		iii	No effect **AND** Same number of (gaseous) moles on both sides ✓	1	**ALLOW** same number of molecules on each side **Examiner's Comments** This question was answered very well and most candidates picked up this mark.
			Total	**4**	
2			The (position of a dynamic) equilibrium shifts to minimise (the effect of) any change ✓	1	**ALLOW** suitable alternatives for 'shifts' and 'minimises' **IGNORE** 'reaction shifts' **Examiner's Comments** Most candidates were able to describe le Chatelier's principle.
			Total	**1**	
3			A	1	
			Total	**1**	
4			C	1	
			Total	**1**	

CHEMICAL EQUILIBRIUM (3.2.3)

Question			Answer/Indicative content	Marks	Guidance
5		i	**Pressure:** Right-hand side has fewer (gaseous) moles / molecules **OR** left-hand side has more (gaseous) moles / molecules ✓ **Temperature**: Statement that: (Forward) reaction is exothermic **OR** (forward) reaction gives out heat **OR** reverse reaction is endothermic **OR** reverse reaction takes in heat ✓ **Equilibrium** Lower temperature / cooling **AND** increasing pressure shifts (equilibrium position) to the right ✓	3	ANNOTATE ANSWER WITH TICKS AND CROSSES ETC **DO NOT ALLOW** fewer atoms on right-hand side **OR** more atoms on left-hand side. **IGNORE** comments about the 'exothermic side' or 'endothermic side' **Equilibrium mark** is for stating that **BOTH** low temperature and high pressure shift equilibrium to the right (Could be separate statements) **Note: ALLOW** suitable alternatives for 'to right' , e.g.: towards products **OR** towards CH_3OH / H_2O **OR** in forward direction **OR** favours the right **IGNORE** Increases yield of CH_3OH / products (*in question*) **IGNORE** responses in terms of rate **Examiner's Comments** A good discrimination was achieved by this question. The most able candidates gave succinct responses which related the low temperature and high pressure to the change in equilibrium position. Candidates are encouraged to write as accurately as possible in this type of question. For example, the effect of pressure is best explained by reference the relative number of moles on each side of the equation. A statement about the nature of the forward reaction, in this case exothermic, is appropriate to explain the effect of temperature.

Question			Answer/Indicative content	Marks	Guidance
		ii	Low temperature gives a slow rate **OR** high temperatures needed to increase rate ✓ High pressure is expensive (to generate) **OR** high pressure provides a safety risk ✓	2	**ALLOW** high pressure is dangerous **IGNORE** high pressure is explosive **Examiner's Comments** Most candidates identified high pressures as either dangerous or requiring expensive equipment. The strongest responses linked low temperature with a slow rate of reaction.
			Total	5	

Question			Answer/Indicative content	Marks	Guidance
6			* *Please refer to the marking instruction point 10 for guidance on how to mark this question.* **(Level 3)** All/most points covered and clearly linked. Must have points taken across all of the headings in the indicative points for Level 3. *The explanations show a well-developed line of reasoning linked to appropriate suggestions which is clear and logically structured. The compromises are relevant and well thought out and clearly linked to the explanations.* (5–6 marks) **(Level 2)** Suggests correct conditions with explanations **OR** comments on compromises with reference to yield **AND** rate effect. *The explanations are linked to appropriate suggestions and show a line of reasoning with some structure. The compromises are relevant but may not be clearly linked to the explanation.* (3–4 marks) **(Level 1)** Comments on conditions with some explanation **OR** comments on compromise with reference to yield **OR** rate. *The comments about yield / rate with explanation are basic and communicated in an unstructured way. The compromises may not be relevant with lack of reasoning.* (1–2 marks) No response or no response worthy of credit. (0 marks)	6	**Indicative scientific points may include** Yield • Increasing pressure increases yield of SO_3 • Decreasing temperature increases yield of SO_3 Explanation • (pressure) more moles / molecules on the reactant side **ORA** • (temp.) the forward reaction is exothermic **ORA** Rate • Increasing pressure increases rate • Increasing temperature increases rate Compromise • Choose a higher temperature which creates a reduced yield but in a shorter space of time **ignore** reference to increase pressure leading to safety / cost issues
			Total	6	

CHEMICAL EQUILIBRIUM (3.2.3)

Question			Answer/Indicative content	Marks	Guidance
7	a		*EQUILIBRIUM CONDITIONS 3 MAX* 4 marking points ☐ 3 max ✓✓✓ *Mark first three **CORRECT** responses seen* **Temperature:** (Forward) reaction is exothermic/Δ*H* is negative **OR** (Forward) reaction gives out heat ✓ **Pressure:** Right-hand side has fewer (gaseous) moles **OR** 3 (gaseous) moles form 2 (gaseous) moles ✓ **Equilibrium shift** Correct equilibrium shift in terms of **temperature** ✓ Correct equilibrium shift in terms of **pressure** ✓ _____ *INDUSTRIAL CONDITIONS* Low temperature gives a slow rate/slower reaction **OR** high temperatures needed to increase rate ✓☐ (High) pressure provides a safety risk **OR** (High) pressure is expensive (to generate) /uses a lot of energy ✓☐	5	*FULL ANNOTATIONS MUST BE USED* _____ **ALLOW** suitable alternatives for 'towards right', e.g.: towards SO_3/products **OR** in forward direction **OR** 'favours the right' **ALLOW reverse** reaction is endothermic /Δ*H* is positive/takes in heat For moles, **ALLOW** molecules/particles **ORA for** reverse reaction **IGNORE** responses in terms of activation energy **ALLOW** high pressure is dangerous/explosive **ALLOW** 'These conditions are expensive' *Statement subsumes **pressure** as 'these' will apply to **pressure** (required for this mark) and temperature* **ALLOW ORA** e.g. Lower pressure → less danger/uses less energy **IGNORE** 'It's expensive *Link with pressure required*
					Examiner's Comments This longer answer was answered very well with the majority of candidates able to score 4 or 5 marks. Most candidates explained how the position of equilibrium shifts in response to low temperature and high pressure. The commonest omission was the link between low temperature and a slow reaction rate.

Question			Answer/Indicative content	Marks	Guidance
	b		*Value of K_c 1 mark* K_c is small **OR** $K_c < 1$ **AND** equilibrium (position) is towards left ✓ *Calculation:* FIRST CHECK ANSWER IF $[SO_3] = 0.876$ OR 0.88 (mol dm^{-3}) award all 3 marks available for calculation K_c expression 1 mark $\frac{[SO_3]^2}{[SO_2]^2[O_2]}$ **OR** $\frac{[SO_3]^2}{2.00^2 \times 1.20}$ ✓ Evaluation of K_c $[SO_2]^2[O_2]$ 1 mark $Kc[SO_2]^2[O_2] = 0.160 \times 2.00^2 \times 1.20$ $= 0.768$ ✓ Calculation of $[SO_3]$ *ONLY available from **correct** evaluation for 2nd mark* $[SO_3] = \sqrt{(0.160 \times 2.00^2 \times 1.20)}$ $= 0.876$ (mol dm^{-3}) ✓	4	*FULL ANNOTATIONS MUST BE USED* **ALLOW** suitable alternatives for 'towards left, e.g.: towards SO_2/O_2 **OR** towards reactants **OR** in reverse direction **OR** 'favours the left Square brackets required in K_c expression **ALLOW ECF** from $\frac{[SO_3]}{[SO_2]^2[O_2]}$, i.e. no $[SO_3]^2$ ALLOW 0.77 (2 SF) **ALLOW** 0.88 (2 SF) up to calculator value of 0.876356092 correctly rounded IF K_c expression is inverted 2nd and 3rd marks are available by ECF: $[SO_3]^2 = \frac{2.00^2 \times 1.20}{0.160}$ **OR** 30 ✓ $[SO_3] = \sqrt{30} = 5.48$ **OR** 5.5 ✓ Any other K_c expression → **NO MARKS**, e.g. $\frac{[SO_3]^2}{[SO_2]^2 + [O_2]} \rightarrow \sqrt{0.832} \rightarrow 0.912$ **NO** Marks Examiner's Comments Given that K_c is new to AS level in the reformed specification, this part was attempted well. However, writing a correct K_c did cause problems for weaker candidates, who sometimes inverted the expression, used the + sign from the equation, obtaining a denominator of $[SO_2]^2 + [O_2]$, or omitted the square from $[SO_2]^2$ and $[SO_3]^2$. Some excellent answers were seen and this part differentiated very well between candidates of different abilities. Answer: $[SO_3] = 0.876$ mol dm^{-3}
			Total	9	

CHEMICAL EQUILIBRIUM (3.2.3)

Question			Answer/Indicative content	Marks	Guidance
8		i	Equilibrium (position) shifts to right **AND** turns paler (brown) ✓ Right-hand side has fewer (gaseous) moles / molecules **OR** left-hand side has more (gaseous) moles / molecules ✓	2	**ALLOW** turns colourless **IGNORE** initially goes darker (brown) **Note: ALLOW** suitable alternatives for 'to right', e.g.: towards products **OR** towards N_2O_4 **OR** in forward direction **OR** favours the right **IGNORE** responses in terms of rate **Examiner's Comments** The effect of pressure on the position of an equilibrium is well known by candidates. Most were able to apply le Chatelier's principle accurately stating the equilibrium shifted to the right as that was the side with fewest moles of gas. However a significant proportion of the cohort did not comment on the effect on the appearance of the equilibrium mixture.

Question			Answer/Indicative content	Marks	Guidance
		ii	Equilibrium (position) shifts to left **AND** turns darker / deeper (brown) ✓ (Forward) reaction is exothermic **OR** (forward) reaction gives out heat **OR** reverse reaction is endothermic **OR** reverse reaction takes in heat ✓	2	**ALLOW** turns brown **Note: ALLOW** suitable alternatives for 'to left', e.g.: towards reactants **OR** towards NO_2 **OR** in reverse direction **OR** favours the left **IGNORE** comments about the 'exothermic side' or 'endothermic side' **ALLOW** 'equilibrium (position) shifts left **AND** in the endothermic direction' for second marking point **IGNORE** responses in terms of rate **Examiner's Comments** As with part (a)(i), candidates demonstrated an excellent grasp of le Chatelier's principle but it was only the most able candidates who referred to the appearance of the equilibrium mixture. Candidates should be encouraged to read questions carefully to ensure they include all the required information in their responses.
			Total	4	
9			B	1	**Examiner's Comments** This question discriminated very well with most able candidates obtaining the correct answer.
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
10			*EQUILIBRIUM CONDITIONS* **Temperature: 1 mark** (Forward) reaction is exothermic/ΔH is negative **OR** (Forward) reaction gives out heat ✓ **Pressure: 1 mark** Left-hand side has fewer (gaseous) moles **OR** 9 (gaseous) moles form 10 (gaseous) moles ✓ *OPTIMUM EQUILIBRIUM CONDITIONS:* **1 mark** (for maximum yield of NO) Low temperature **AND** low pressure ✓ *RATE:* **1 mark** Low temperature/pressure gives a slow rate/slower reaction so high temperatures / higher pressure needed to increase **rate OR frequency of collisions** ✓ *INDUSTRIAL CONDITIONS /* OPERATIONAL FACTORS: **1 mark** High pressure provides a safety risk **OR** Higher temperatures increase energy costs / reduce yield / shift equilibrium to left **OR** (High) pressure is expensive (to generate) / uses a lot of energy ✓	5	ANNOTATE ANSWER WITH TICKS AND CROSSES ETC **ALLOW reverse arguments** Answer **MUST** relate temp/pressure to rate / frequency of collisions **ALLOW** Temperature / pressure not too high because yield reduced **IGNORE** stated temperatures and pressures **IGNORE** catalyst **Examiner's Comments** Most candidates answered this question very well, with the most common mark being 4/5. Many candidates put a lot of effort into explaining, in depth, Le Chatelier's principle, which was not required. The first three marking points were credited to most candidates. Responses were confident in their descriptions of equilibrium shifts and many candidates then went on to qualify their answers with operational factor considerations and/or rate. The explanation for pressure was described less commonly than temperature and many candidates did not appreciated that increased rate would lead to a decreased equilibrium yield. **Exemplar 3**

Question			Answer/Indicative content	Marks	Guidance
					(c) Predict the conditions of temperature and pressure for a maximum equilibrium yield of nitrogen monoxide in equilibrium 4.1. • Explain your prediction in terms of le Chatelier's principle. • State and explain how these conditions could be changed to achieve a compromise between equilibrium yield, rate and other operational factors. low temperature so as to shift the position of equilibrium to the right while favouring forward reaction. This is because forward reaction is endothermic (ΔH = +ve). low pressure so as to shift position of equilibrium to the right, as a decrease in pressure causes the equilibrium to move towards the direction with more gas molecules (right). These two conditions will minimise the change caused so maximum product (i.e. NO and H_2O) are formed. A higher temperature is used so as to increase the rate of reaction. Otherwise reaction is too slow. A slightly higher pressure is also used to increase reaction rate but not too high pressure as it is dangerous and doesn't promote safety for workers. This candidate scored all five marks for this well-reasoned approach to the question.
			Total	5	
11			C	1	Examiner's Comments This question was a good discriminator with well-prepared candidates usually selecting the correct option of C. Incorrect responses were reasonably evenly split across the other options, suggesting guesses and poor preparation.
			Total	1	
12			B	1	Examiner's Comments Most candidates responded with the correct response of B. The most common incorrect response was the inverse expression shown in A.
			Total	1	
13			$(K_c =) \frac{[NO(g)]^4 [H_2O(g)]^6}{[NH_3(g)]^4 [O_2(g)]^5}$ ✓	1	Square brackets required IGNORE state symbols Examiner's Comments Generally, this question was well answered with only a small proportion of candidates adding the values together instead of multiplying.
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
14			FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = 14.6 (dm^2 mol^{-6}) award 2 marks --- K_c expression (K_c =) $\frac{[CH_3OH]}{[CO]\,[H_2]^2}$ **OR** $\frac{0.26}{0.31 \square 0.24^2}$ **OR** 14.56 ..... ✓ Answer to 3 SF 14.6 (dm^6 mol^{-2}) ✓	2	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** calculated value 14.5609319 correctly rounded to 3 or more SF for 1st marking point **ALLOW ECF to 3 SF ONLY** from inverted K_c expression → 0.0687 **DO NOT ALLOW** $\frac{[CH_3OH]}{[CO] + [H_2]^2}$ = 0.707 (no marks) **Examiner's Comments** Most candidates were able to obtain a value of 14.56 using a correct K_c expression, but a significant number of candidates were unable to give their answer to an appropriate number of significant figures. Candidates should use the least accurate data provided, here three significant figures, and to indicate the appropriate number of significant figures in the final answer. Other common errors included the inverted K_c expressions and use of [CO] + [$2H_2$], rather than [CO] $[H_2]^2$, as the denominator. Answer = 14.6 dm^6 mol^{-2}
			Total	**2**	
15		i	Yield decreases **AND** Equilibrium (position) has moved to the left	1	**allow** moved towards reactants **OR** moved towards CO and H_2
		ii	Oxidised Nitrogen **AND** –3 **AND** +2 (1) Reduced Oxygen **AND** 0 **AND** –2 (1)	2	
			Total	**3**	

Question			Answer/Indicative content	Marks	Guidance
16		i	*Expression:* $K_c = [NH_3]^2 / [H_2]^3[N_2]$ (1) *Calculation:* $= (0.877)^2/(2.00)^3(1.20)$ (1)	3	square brackets required
		i	$= 0.0801$ ✓ ($dm^6\ mol^{-2}$)		**allow** from 1 sig fig up to calculator display correct answer alone scores all marks
		ii	*Catalyst:* No effect, it only changes the rate of reaction (1) *Higher temperature:* Forward reaction is exothermic (1) so position of equilibrium moves to the left and there will be less NH_3 (1)	3	
			Total	6	
17		i	$K_c = \frac{[CH_3OH]}{[CO][H_2]^2}$	1	
		ii	$[CH_3OH] = 14.6 \times (3.10 \times 10^{-3}) \times (2.40 \times 10^{-3})^2$ (1) $= 2.61 \times 10^{-7}$ ($mol\ dm^{-3}$) (1)	2	
			Total	3	