Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			** 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**	
2	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	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

			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 ✓□		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.
	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 × 2.00^2 × 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 **<u>Examiner's Comments</u>** 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**	
3		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**	
4			D	1	
			Total	**1**	
5			**B**	1 (AO1.1)	
			Total	**1**	
6			$p(O_2) = 0.21 \times 1.00 \times 10^5$ = **21,000 / 2.1 × 10**	1 AO 2.2	**<u>Examiner's Comments</u>** 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**	
7			**B**	**1 (AO 1.3)**	**<u>Examiner's Comments</u>** This was a very successful multiple choice question for nearly all candidates.

			Total	**1**	
8			**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 5184/5180 atm^2 award 7 marks **IF** answer = 5184/5180 with incorrect units award 6 marks **Equilibrium amounts in mol 2 MARKS** 3 correct ✓✓ 2 correct ✓ $n(H_2O)$ = 0.600 mol $n(H_2)$ = 2.40 mol n(CO) = 0.800 mol **Partial pressures** Total moles = 4.(00) (mol) ✓ $p(CH_4) = \frac{0.200}{4.00} \times 30.0$ = 1.50 atm **AND** $p(H_2O) = \frac{0.600}{4.00} \times 30.0$ = 4.50 atm **AND** $p(H_2) = \frac{2.40}{4.00} \times 30.0$ = 18.0 atm **AND** $p(CO) = \frac{0.800}{4.00} \times 30.0$ = 6.00 atm ✓ **K_p calculation** $k_p = \frac{p(H_2)^3 \times p(CO)}{p(CH_4) \times p(H_2O)}$ **OR** $\frac{18.0^3 \times 6.00}{1.50 \times 4.50}$ ✓ k_p = 5184 **OR** 5180 atm^2 ✓ units = atm^2 ✓	7	Final answer must be correct and have the correct units to score all seven marks **If there is an alternative answer, check to see if there is any ECF credit possible using working below** **ALLOW ECF** from equilibrium amounts **OR/AND** incorrect total number of moles Correct values substituted into correct expression for K_p gains first five marks. **ALLOW ECF** with answer 3 or more **SF** up to calculator value, correctly rounded
			Total	**7**	
9			**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)	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**

			$K_p = \frac{p(NH_3)^2}{p(N_2) \times p(H_2)^3} = \frac{62.5^2}{250 \times 187.5^3}$ (1) = 2.37×10^{-6} (1) kPa^{-2} (1)		Correct values substituted into correct expression for K_p gains first three marks.
			Total	**5**	
10		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** 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 **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	**4**	

11		i	Rate of the forward reaction is equal to the rate of the reverse reaction ✓ **OR** concentrations do not change✓	1	**ALLOW** both reaction**s** 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.
		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**	
12		i	**Pressure:** Right-hand side has fewer (gaseous) moles / molecules **OR** left-hand side has more (gaseous)	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **DO NOT ALLOW** fewer atoms on right-hand side **OR** more atoms on left-hand side.

			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 ✓		**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.
		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**	
13			**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** $\frac{0.26}{0.31 \times 0.24^2}$ **OR** 14.56 …… ✓	**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

			Answer to 3 SF 14.6 (dm^6 mol^{-2}) ✓		**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**	