



A-Level Chemistry

K_p Equilibrium Constant

Mark Scheme

Time available: 64 minutes

Marks available: 57 marks

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Mark schemes

1.

- (a) M1 decreases yield

1

M2 So equilibrium shifts to side with more moles/molecules or more moles/molecules on LHS

Allow M2 independent of M1

1

M3 So equilibrium shifts (to left side) to oppose decrease in pressure **OR** to increase pressure

Must refer to equilibrium shifting to gain maximum marks

1

- (b) M1 amount SO_2 ($= 0.46 - 0.18$) = 0.28 mol

1

M2 amount O_2 ($= 0.25 - 0.09$) = 0.16 mol

1

M3 total amount ($= 0.28 + 0.16 + 0.18$) = 0.62 mol

1

M4 partial pressure of $\text{SO}_2 = \frac{0.28}{0.62} \times 215 = 97(.1)$ (kPa)

$$M4 = \frac{M1}{M3} \times 215$$

1

- (c) M1 $K_p = \frac{(\text{pp SO}_3)^2}{(\text{pp SO}_2)^2 \times \text{pp O}_2}$

Penalise square brackets in M1

1

M2 = $1.2(0) \times 10^{-2}$

1

M3 = kPa^{-1}

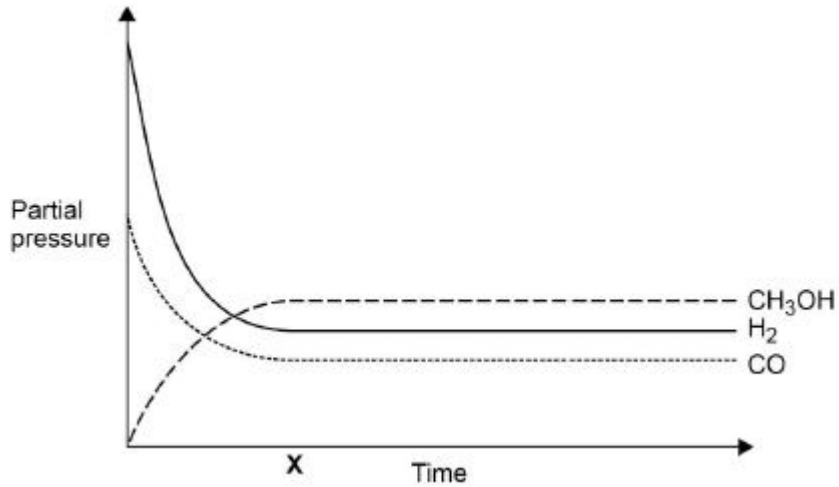
1

- (d) Stays the same

1

[11]

2. (a)



X must be on or just below line of x axis

1

(b) **M1** Equilibrium $n(\text{H}_2) = \underline{0.24}$

1

M2 Total number of moles = 0.47

1

M3 Mole fraction of $\text{H}_2 = 0.51(1)$ or $\frac{0.24}{0.47}$

M3 Allow mole fraction of $\text{H}_2 = \frac{\text{M1}}{\text{M2}}$

1

M4 Partial pressure of hydrogen = 5310 or 5.31×10^3 kPa

M4 Allow Partial pressure of hydrogen = M3 $\times 1.04 \times 10^4$

1

(c) **M1** $K_p = \frac{pp\text{CH}_3\text{OH}}{pp\text{H}_2^2 \times pp\text{CO}}$ OR $\frac{p\text{CH}_3\text{OH}}{p\text{H}_2^2 \times p\text{CO}}$

Do not allow square brackets

1

Pa^{-2} or kPa^{-2}

Allow any pressure to power of -2

1

(d) **M1** Increases

1

M2 No effect

1

(e) **M1** No effect

1

M2 Increases rate of forward and backward reaction equally/by the same amount OR catalyst does not affect position of equilibrium

M2 Allow Catalyst does not appear in the K_p expression

M2 Allow Only temperature affects K_p

Ignore Catalysts increase the rate of reaction or rate at which equilibrium is reached 1

1

[11]

3.

(a) Moles SO_2 eqbm (=6.08/64.1 = 0.0949) so moles O_2 eqbm = 0.0474

1

Mass of oxygen (= 0.0474 x 32(.0)) = 1.52 g

Allow 0.0475

Allow **M1** x 32

1

(b) **M1**: Mole fraction SO_3 = 0.15

Mole fraction SO_2 = 0.57

Mole fraction O_2 = 0.28

Accept fractions for **M1**

1

$$\mathbf{M2} \quad K_p = \frac{(p\text{SO}_2)^2 \times (p\text{O}_2)}{(p\text{SO}_3)^2} \quad \left(= \frac{(\lambda\text{SO}_2)^2 P^2 \times (\lambda\text{O}_2) P}{(\lambda\text{SO}_3)^2 P^2} \right)$$

Do not accept []

λ = mole fraction

1

$$\mathbf{M3} \quad P = \frac{K_p \times (\lambda\text{SO}_3)^2}{(\lambda\text{SO}_2)^2 \times (\lambda\text{O}_2)} \quad \text{or} \quad \frac{K_p \times (0.15)^2}{(0.57)^2 \times (0.28)}$$

M3 is for rearrangement with or without numbers

If incorrect rearrangement allow correct **M1** and **M2** only

1

M4 $P = 1.91 \times 10^5$ (Pa) Allow range 1.88×10^5 to 1.94×10^5

1

(c) **M1** K_p is higher at higher temperature or converse

1

M2 At higher temperature more dissociation occurs / more products are formed / equilibrium shifts to the right/forward direction

M2: Allow converse arguments

M2 dependent on **M1**

1

(d) $(\sqrt{3.94 \times 10^4 \text{ Pa}}) = 198.5$

1

Pa^{1/2} or Pa^{0.5}

Allow 198 – 198.5 (answer is 198.49)

If $\sqrt{7.62 \times 10^5} = 873$ then lose **M1** but allow **M2**

1

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4.

(a) pp nitrogen = $0.25 \times 30 = \underline{7.5}$ kPa

1

pp hydrogen = $0.75 \times 30 = \underline{22.5 \text{ or } 23}$ kPa

1

pp of ammonia = $0.8 \times 150 = \underline{120}$ kPa

1

(pp hydrogen + nitrogen = $150 - 120 = 30$ kPa)

Alternative method

pp hydrogen = $0.15 \times 150 = \underline{22.5 \text{ or } 23}$ kPa

pp nitrogen = $0.05 \times 150 = \underline{7.5}$ kPa

(b) $K_p = \frac{(\text{ppNH}_3)^2}{(\text{ppN}_2) \times (\text{ppH}_2)^3}$

Penalise []

1

(c) $K_p = \frac{(1.10 \times 10^3)^2}{(1.50 \times 10^2)^3 \times 1.20 \times 10^2}$

No mark for this expression

1

= 0.0029 to 0.003(0) or 2.9×10^{-3} to $3(.0) \times 10^{-3}$
kPa⁻²

If expression inverted in 02.2 allow 1 mark for kPa²

Allow 2.9 to $3(.0) \times 10^{-9} \text{ Pa}^{-2}$

1

(d) decrease/smaller/lower

If increase or no change, 0 marks

If blank, mark on

1

(Reaction/equilibrium) shifts/moves/goes in the endothermic direction (which is to the left)

Allow reaction is exothermic so equilibrium moves to the left side

1

to reduce the temperature OR oppose the increase in temperature

1

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5.

(a) Bonds broken = $2(\text{C}=\text{O}) + 3(\text{H}-\text{H}) = 2 \times 743 + 3 \times \text{H}-\text{H}$

Bonds formed = $3(\text{C}-\text{H}) + (\text{C}-\text{O}) + 3(\text{O}-\text{H}) = 3 \times 412 + 360 + 3 \times 463$

Both required

1

$$-49 = [2 \times 743 + 3 \times (\text{H}-\text{H})] - [3 \times 412 + 360 + 3 \times 463]$$

$$3(\text{H}-\text{H}) = -49 - 2 \times 743 + [3 \times 412 + 360 + 3 \times 463] = 1450$$

Both required

1

$$\text{H}-\text{H} = 483 \text{ (kJ mol}^{-1}\text{)}$$

Allow 483.3(3)

1

- (b) Mean bond enthalpies are not the same as the actual bond enthalpies in CO_2 (and / or methanol and / or water)

1

- (c) The carbon dioxide (produced on burning methanol) is used up in this reaction

1

- (d) 4 mol of gas form 2 mol

1

At high pressure the position of equilibrium moves to the right to lower the pressure / oppose the high pressure

1

This increases the yield of methanol

1

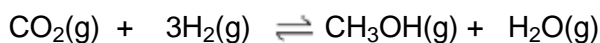
- (e) Impurities (or sulfur compounds) block the active sites

Allow catalyst poisoned

1

- (f) Stage 1: moles of components in the equilibrium mixture

Extended response question



| | | | | |
|---------------|------------------------|---------------------------------|------|------|
| Initial moles | 1.0 | 3.0 | 0 | 0 |
| Eqm moles | $(1-0.86)$ $= 0.14$ | $(3-3 \times 0.86)$ $= 0.42$ | 0.86 | 0.86 |

1

Stage 2: Partial pressure calculations

Total moles of gas = 2.28

Partial pressures = mol fraction \times p_{total}

1

$$p_{\text{CO}_2} = \text{mol fraction} \times p_{\text{total}} = 0.14 \times 500 / 2.28 = 30.7 \text{ kPa}$$

$$p_{\text{H}_2} = \text{mol fraction} \times p_{\text{total}} = 0.42 \times 500 / 2.28 = 92.1 \text{ kPa}$$

M3 is for partial pressures of both reactants

Alternative M3 =

$$pp_{\text{CO}_2} = 0.0614 \times 500$$

$$pp_{\text{H}_2} = 0.1842 \times 500$$

1

$$p_{\text{CH}_3\text{OH}} = \text{mol fraction} \times p_{\text{total}} = 0.86 \times 500 / 2.28 = 188.6 \text{ kPa}$$

$$p_{\text{H}_2\text{O}} = \text{mol fraction} \times p_{\text{total}} = 0.86 \times 500 / 2.28 = 188.6 \text{ kPa}$$

M4 is for partial pressures of both products

Alternative M4 =

$$pp_{\text{CH}_3\text{OH}} = 0.3772 \times 500$$

$$pp_{\text{H}_2\text{O}} = 0.3772 \times 500$$

1

Stage 3: Equilibrium constant calculation

$$K_p = p_{\text{CH}_3\text{OH}} \times p_{\text{H}_2\text{O}} / p_{\text{CO}_2} \times (p_{\text{H}_2})^3$$

1

$$\text{Hence } K_p = 188.6 \times 188.6 / 30.7 \times (92.1)^3 = 1.483 \times 10^{-3} = 1.5 \times 10^{-3}$$

Answer must be to 2 significant figures

1

$$\text{Units} = \underline{\text{kPa}}^{-2}$$

1

[16]