QQ4 Equalibria

AQA 2017-2023

Do not write outside the box

0 9 . 2 The equation shows the final stage in the production of methanol.

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

20.1 mol of carbon monoxide and 24.2 mol of hydrogen were placed in a sealed container. An equilibrium was established at 600 K. The equilibrium mixture contained 2.16 mol of methanol.

Calculate the amount, in moles, of carbon monoxide and of hydrogen in the equilibrium mixture.

[2 marks]

Amount of carbon monoxide _____ mol

Amount of hydrogen _____ mol

Question 9 continues on the next page

Do not write outside the box

0 9 . 3 A different mixture of carbon monoxide and hydrogen was allowed to reach equilibrium at 600 K

At equilibrium, the mixture contained 2.76 mol of carbon monoxide, 4.51 mol of hydrogen and 0.360 mol of methanol. The total pressure was 630 kPa

Calculate a value for the equilibrium constant, K_p, for this reaction at 600 K and state its units.

[6 marks]

Value of K_p _____ Units _____

14

	Level 0 0 marks	Insufficient correct chemistry to gain a mark.		

Question	Answers	Mark	Additional Comments/Guidance
09.2	Moles of carbon monoxide 17.9 Moles of hydrogen 19.9	1 1	Allow 17.94 Allow 19.88
09.3	$K_p = \frac{pp(CH^3OH)}{pp(CO)\times pp(H_2)2}$ ignore brackets Total moles of gas = (2.76 + 4.51 + 0.36) = 7.63 $pp(CO) = \frac{2.76}{7.63}$ x 630 (kPa) (= 228 (kPa)) $pp(H_2) = \frac{4.51}{7.63}$ x 630 (kPa) (= 372 (kPa)) $pp(CH_3OH) = \frac{0.36}{7.63}$ x 630 (kPa) (= 29.7 (kPa)) $K_p = \frac{29.7}{228x(372)2}$ = 9.4(1) x 10^{-7} or 9.4(1) x 10^{-13} if *pp* in Pa can also score M1 from this expression $\underline{kPa^{-2}}$ or $\underline{Pa^{-2}}$ (if converted to 630 000)	1 1 2 1 1	If K_p expression incorrect can only score M2 & M3 & M4 If CE in M2 allow ecf for M3, M4 and M6 If no total moles calculated then can only score M1 and M6 All 3 pp of CO, H_2 and CH_3OH = 2 marks 2 pp correct = 1 mark Allow 9.39 to 9.50 x 10^{-7} (kPa^{-2}) If no marks awarded allow M6 only for $\underline{kPa^{-2}}$ or $\underline{Pa^{-2}}$
Total		**14**	

Do not write outside the box

0 2 Nitrogen and hydrogen were mixed in a 1:3 mole ratio and left to reach equilibrium in a flask at a temperature of 550 K. The equation for the reaction between nitrogen and hydrogen is shown.

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

0 2 . 1 When equilibrium was reached, the total pressure in the flask was 150 kPa and the mole fraction of $NH_3(g)$ in the mixture was 0.80

Calculate the partial pressure of each gas in this equilibrium mixture.

[3 marks]

Partial pressure of nitrogen _____ kPa

Partial pressure of hydrogen _____ kPa

Partial pressure of ammonia _____ kPa

0 2 . 2 Give an expression for the equilibrium constant (K_p) for this reaction.

[1 mark]

K_p

Do not write outside the box

0 2 . 3 In a different equilibrium mixture, under different conditions, the partial pressures of the gases are shown in **Table 2**.

Table 2

Gas	Partial pressure / kPa
N_2	1.20×10^2
H_2	1.50×10^2
NH_3	1.10×10^3

Calculate the value of the equilibrium constant (K_p) for this reaction and give its units.

[2 marks]

K_p _____ Units _____

0 2 . 4 The enthalpy change for the reaction is –92 kJ mol^{-1}

State the effect, if any, of an increase in temperature on the value of K_p for this reaction.
Justify your answer.

[3 marks]

Effect on K_p _____

Justification _____

_____

_____

_____

_____

9

Question	Answers	Additional Comments/Guidance	Mark
02.1	pp nitrogen = 0.25 x 30 = 7.5 kPa pp hydrogen = 0.75 x 30 = 22.5 or 23 kPa pp of ammonia = 0.8 x 150 = 120 kPa	(pp hydrogen + nitrogen = 150-120 = 30 kPa) Alternative method pp hydrogen = 0.15 x 150 = 22.5 or 23 kPa pp nitrogen = 0.05 x 150 = 7.5 kPa	1 1 1
02.2	$K_p = \frac{(ppNH_3)^2}{(ppN_2) \times (ppH_2)^3}$	Penalise [ ]	1
02.3	$K_p = \frac{(1.10 \times 10^3)^2}{(1.50 \times 10^2)^3 \times 1.20 \times 10^2}$ $= 0.0029$ to $0.003(0)$ or 2.9×10^{-3} to $3(.0) \times 10^{-3}$ kPa^{-2}	No mark for this expression If expression inverted in 02.2 allow 1 mark for kPa^2 Allow 2.9 to $3(.0) \times 10^{-9}$ Pa^{-2}	1 1
02.4	decrease/smaller/lower (Reaction/equilibrium) shifts/moves/goes in the endothermic direction (which is to the left) to reduce the temperature OR oppose the increase in temperature	If increase or no change, 0 marks If blank, mark on Allow reaction is exothermic so equilibrium moves to the left side	1 1 1
Total			9

Do not write outside the box

0 7 Sulfur trioxide decomposes on heating to form an equilibrium mixture containing sulfur dioxide and oxygen.

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$$

0 7 . 1 A sample of sulfur trioxide was heated and allowed to reach equilibrium at a given temperature.
The equilibrium mixture contained 6.08 g of sulfur dioxide.

Calculate the mass, in g, of oxygen gas in the equilibrium mixture.

[2 marks]

Mass _____ g

Question 7 continues on the next page

Do not write outside the box

0 7 . 2 A different mass of sulfur trioxide was heated and allowed to reach equilibrium at 1050 K

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$$

The amounts of each substance in the equilibrium mixture are shown in **Table 4**.

Table 4

Substance	**Amount at equilibrium / mol**
sulfur trioxide	0.320
sulfur dioxide	1.20
oxygen	0.600

For this reaction at 1050 K the equilibrium constant, $K_p = 7.62 \times 10^5$ Pa

Calculate the mole fraction of each substance at equilibrium.
Give the expression for the equilibrium constant, K_p
Calculate the total pressure, in Pa, of this equilibrium mixture.

[4 marks]

Mole fraction SO_3 _____

Mole fraction SO_2 _____

Mole fraction O_2 _____

K_p

Total pressure _____ Pa

Do not write outside the box

0 7 . 3 For this reaction at 1050 K the equilibrium constant, K_p = 7.62 x 10^5 Pa
For this reaction at 500 K the equilibrium constant, K_p = 3.94 x 10^4 Pa

Explain how this information can be used to deduce that the forward reaction is endothermic.

[2 marks]

0 7 . 4 Use data from Question **07.3** to calculate the value of K_p, at 500 K, for the equilibrium represented by this equation.
Deduce the units of K_p

$$SO_3(g) \rightleftharpoons SO_2(g) + \tfrac{1}{2}O_2(g)$$

[2 marks]

K_p _____

Units _____

10

Turn over for the next question

Question	Answers	Additional Comments/Guidelines	Mark
07.1	Moles SO_2 eqbm (=6.08/64.1 = 0.0949) so moles O_2 eqbm = 0.0474 Mass of oxygen (= 0.0474 x 32(.0)) = 1.52 g	Allow 0.0475 Allow M1 x 32	1 1
07.2	M1: Mole fraction SO_3 = 0.15 Mole fraction SO_2 = 0.57 Mole fraction O_2 = 0.28 M2: $K_p = \frac{(pSO_2)^2 \times (pO_2)}{(pSO_3)^2}$ (= $\frac{(\lambda SO_2)^2 P^2 \times (\lambda O_2) P}{(\lambda SO_3)^2 P^2}$) M3: $P = \frac{K_p \times (\lambda SO_3)^2}{(\lambda SO_2)^2 \times (\lambda O_2)}$ or $\frac{K_p \times (0.15)^2}{(0.57)^2 \times (0.28)}$ M4 P = 1.91 x 10^5 (Pa) Allow range 1.88 x 10^5 to 1.94 x 10^5	Accept fractions for M1 Do not accept [ ] λ = mole fraction M3 is for rearrangement with or without numbers If incorrect rearrangement allow correct M1 and M2 only	1 1 1 1
07.3	M1 Kp is higher at higher temperature or converse 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 1
07.4	(√3.94 x 10^4 Pa) = 198.5 $Pa^{1/2}$ or $Pa^{0.5}$	Allow 198 – 198.5 (answer is 198.49) If √7.62 x 10^5 = 873 then lose M1 but allow M2	1 1

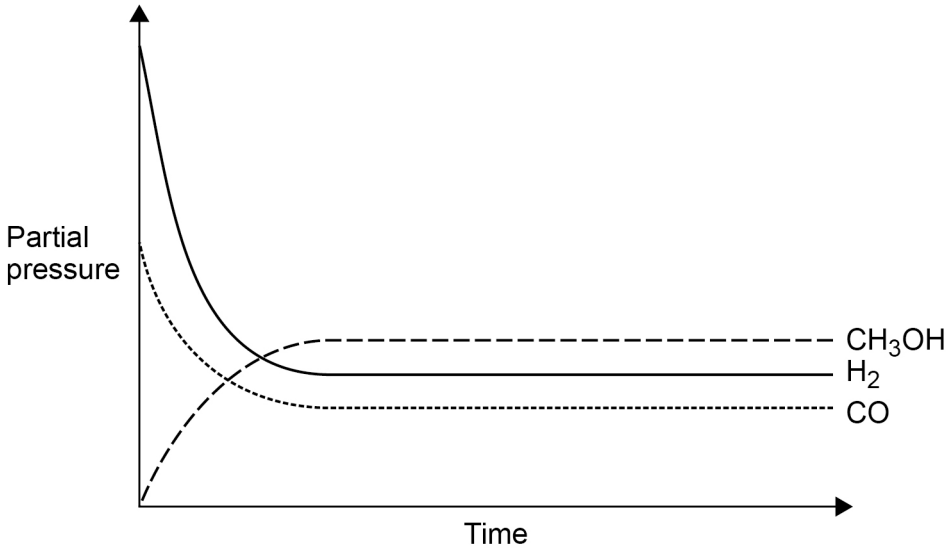
Do not write outside the box

0 6 Methanol can be manufactured in a reversible reaction as shown.

$$CO(g) + 2\,H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H^{\ominus} = -91 \text{ kJ mol}^{-1}$$

Figure 3 shows how the partial pressures change with time at a constant temperature.

Figure 3



0 6 . 1 Draw a cross (x) on the appropriate axis of **Figure 3** when the mixture reaches equilibrium.

[1 mark]

0 6 . 2 A 0.230 mol sample of carbon monoxide is mixed with hydrogen in a 1:2 mol ratio and allowed to reach equilibrium in a sealed flask at temperature *T*.
At equilibrium the mixture contains 0.120 mol of carbon monoxide.
The total pressure of this mixture is 1.04×10^4 kPa

Calculate the partial pressure, in kPa, of hydrogen in the equilibrium mixture.

[4 marks]

Partial pressure of hydrogen _____ kPa

Do not write outside the box

0 6 . 3 Give an expression for the equilibrium constant (K_p) for this reaction.

State the units.

[2 marks]

K_p

Units _____

0 6 . 4 Some more carbon monoxide is added to the mixture in Question **06.2**. The new mixture is allowed to reach equilibrium at temperature *T*.

State the effect, if any, on the partial pressure of methanol and on the value of K_p

[2 marks]

Effect on partial pressure of methanol _____

Effect on value of K_p _____

0 6 . 5 State the effect, if any, of the addition of a catalyst on the value of K_p for this equilibrium.
Explain your answer.

[2 marks]

Effect on value of K_p _____

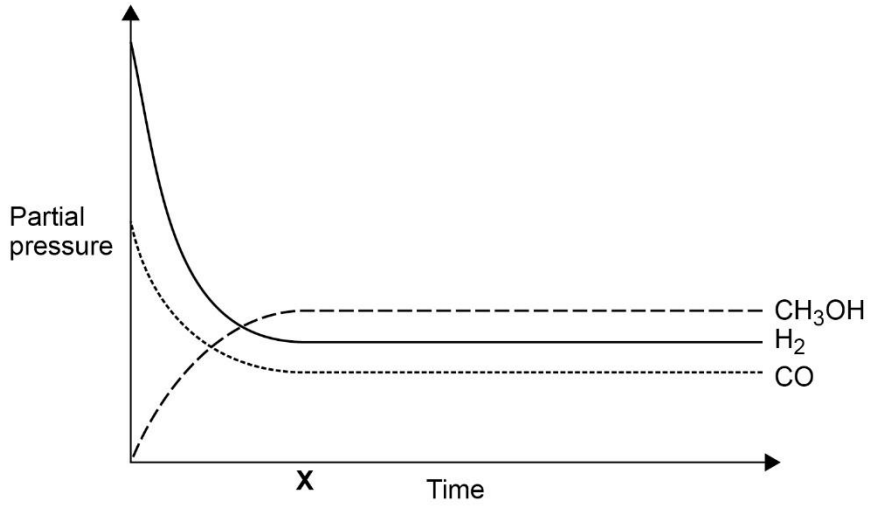
Explanation _____

_____

_____

11

Turn over for the next question

Question	Answers	Additional comments/Guidelines	Mark
06.1		X must be on or just below line of x axis	1
06.2	M1 Equilibrium $n(H_2) = \underline{0.24}$ M2 Total number of moles = $\underline{0.47}$ M3 Mole fraction of H_2 = 0.51(1) or $\frac{\underline{0.24}}{0.47}$ M4 Partial pressure of hydrogen = 5310 or 5.31×10^3 kPa	M3 Allow mole fraction of H_2 = $\frac{\underline{M1}}{M2}$ M4 Allow Partial pressure of hydrogen = M3 $\underline{\times 1.04 \times 10^4}$	1 1 1 1

06.3	M1 K_p = $\frac{ppCH_3OH}{ppH_2^2 \times ppCO}$ OR $\frac{pCH_3OH}{pH_2^2 \times pCO}$ Pa^{-2} or kPa^{-2}	Do not allow square brackets Allow any pressure to power of $^{-2}$	1 1
06.4	M1 Increases M2 No effect		1 1
06.5	M1 No effect M2 Increases <u>rate</u> 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 Kp Ignore Catalysts increase the rate of reaction or rate at which equilibrium is reached	1 1

Do not write outside the box

0 5 This question is about the equilibrium

$$2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g)$$

0 5 . 1 State and explain the effect, if any, of a decrease in overall pressure on the equilibrium yield of SO_3

[3 marks]

Effect _____

Explanation _____

_____

_____

0 5 . 2 A 0.460 mol sample of SO_2 is mixed with a 0.250 mol sample of O_2 in a sealed container at a constant temperature.
When equilibrium is reached at a pressure of 215 kPa, the mixture contains 0.180 mol of SO_3

Calculate the partial pressure, in kPa, of SO_2 in this equilibrium mixture.

[4 marks]

Partial pressure of SO_2 _____ kPa

Do not write outside the box

0 5 . 3 A different mixture of SO_2 and O_2 reaches equilibrium at a different temperature.

Table 4 shows the partial pressures of the gases at equilibrium.

Table 4

Gas	Partial pressure / kPa
SO_2	1.67×10^2
O_2	1.02×10^2
SO_3	1.85×10^2

Give an expression for the equilibrium constant (K_p) for this reaction.

Calculate the value of the equilibrium constant for this reaction and give its units.

[3 marks]

K_p

K_p _____

Units _____

Do not write outside the box

0 5 . 4 What is the effect on the value of K_p if the pressure of this equilibrium mixture is increased at a constant temperature?

$$2\,SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g)$$

[1 mark]

Tick (✓) **one** box.

The value of K_p

increases. ☐

stays the same. ☐

decreases. ☐

11

Turn over for the next question

Question	Answers	Additional comments/Guidelines	Mark
05.1	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

Question	Answers	Additional comments/Guidelines	Mark
05.2	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 SO_2 = $\frac{0.28}{0.62}$ x 215 = 97(.1) (kPa)	M4 = $\frac{M1}{M3}$ x 215	1

Question	Answers	Additional comments/Guidelines	Mark
05.3	M1 K_p = $\frac{(pp\ SO_3)^2}{(pp\ SO_2)^2 \times pp\ O_2}$	Penalise square brackets in M1	1
	M2 = $1.2(0) \times 10^{-2}$		1
	M3 = kPa^{-1}		1

Question	Answers	Additional comments/Guidelines	Mark
05.4	Stays the same		1

Answer **all** questions in the spaces provided.

Do not write outside the box

0 1 This question is about equilibria.

0 1 . 1 Give **two** features of a reaction in dynamic equilibrium.

[2 marks]

Feature 1 _____

_____

Feature 2 _____

_____

0 1 . 2 A gas-phase reaction is at equilibrium.
When the pressure is increased the yield of product decreases.

State what can be deduced about the chemical equation for this equilibrium.

[1 mark]

_____

_____

Question 1 continues on the next page

Do not write outside the box

0 1 . 3 Carbon monoxide and hydrogen react to form methanol.

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

0.430 mol of carbon monoxide is mixed with 0.860 mol of hydrogen.
At equilibrium, the total pressure in the flask is 250 kPa and the mixture contains 0.110 mol of methanol.

Calculate the amount, in moles, of carbon monoxide present at equilibrium.

Calculate the partial pressure, in kPa, of carbon monoxide in this equilibrium mixture.

[3 marks]

Amount of carbon monoxide _____ mol

Partial pressure _____ kPa

0 1 . 4 Give an expression for the equilibrium constant (K_p) for this reaction.

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

[1 mark]

K_p

Do not write outside the box

0 1 . 5 A different mixture of carbon monoxide and hydrogen is left to reach equilibrium at a temperature *T*.

Some data for this equilibrium are shown in **Table 1**.

Table 1

Partial pressure of CO	125 kPa
Partial pressure of CH_3OH	5.45 kPa
K_p	1.15×10^{-6} kPa^{-2}

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

Calculate the partial pressure, in kPa, of hydrogen in this equilibrium mixture.

[3 marks]

Partial pressure _____ kPa

0 1 . 6 Use the K_p value from **Table 1** to calculate a value for K_p for the following reaction at temperature *T*.

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

Give the units for K_p

[2 marks]

K_p _____

Units _____

12

Turn over ►

Question	Answers	Additional Comments/Guidelines	Mark
01.1	forward and reverse reactions proceed at equal <u>rates</u>	allow answers in either order	1
	concentrations (of reactants and products) remain constant **or** concentrations (of reactants and products) stay the same	do **not** accept equal concentrations do **not** accept concentrations are the same ignore closed system	1 AO1

Question	Answers	Additional Comments/Guidelines	Mark
01.2	more moles of (gaseous) products (than (gaseous) reactants) **or** more moles on the RHS (than LHS)	allow molecules do **not** accept atoms	1 AO3

Question	Answers	Additional Comments/Guidelines	Mark
01.3	M1 (at equilibrium) n(CO) = 0.32 (mol) M2 total number of moles (at equilibrium) = 1.07 (mol) **or** mole fraction (CO) = 0.299 M3 $p(CO)\left(= \frac{0.320 \times 250}{1.07}\right) = 74.8$ (kPa)	M3 = $\frac{M1 \times 250}{M2}$ allow 75 (kPa) an answer of 67.8 (kPa) = **2** marks max	1 1 1 AO2

Question	Answers	Additional Comments/Guidelines	Mark
01.4	$K_p = \frac{p(CH_3OH)}{p(H_2)^2\, p(CO)}$	do **not** accept square brackets	1 AO1

Do not write outside the box

0 4 Nitrogen dioxide decomposes at a high temperature.

$$2\,NO_2(g) \rightleftharpoons 2\,NO(g) + O_2(g) \qquad \Delta H = +113\ kJ\ mol^{-1}$$

0 4 . 1 A 0.317 mol sample of nitrogen dioxide is placed in a sealed flask and heated at a constant temperature until equilibrium is reached.

At equilibrium, the flask contains 0.120 mol of oxygen.

Calculate the mole fraction of each substance at equilibrium.

[3 marks]

Mole fraction of NO_2 _____

Mole fraction of NO _____

Mole fraction of O_2 _____

0 4 . 2 The total pressure in the flask in Question **04.1** is 120 kPa at equilibrium.

Calculate the partial pressure, in kPa, of NO_2

If you were unable to answer Question **04.1** you should assume that the mole fraction of NO_2 is 0.380. This is **not** the correct answer.

[1 mark]

Partial pressure _____ kPa

Do not write outside the box

0 4 . 4 The equilibrium mixture in Question **04.3** is compressed into a smaller volume.

Deduce the effect, if any, of this change on the equilibrium yield of oxygen and on the value of K_p

[2 marks]

Effect on yield of oxygen _____

Effect on K_p _____

0 4 . 5 The equilibrium mixture in Question **04.3** is allowed to reach equilibrium at a lower temperature.

Explain why the equilibrium yield of oxygen decreases.

[2 marks]

_____

_____

_____

_____

11

Turn over for the next question

Do not write outside the box

0 4 . 3 **Table 1** shows the mole fractions of the three gases in a different equilibrium mixture.

$$2\,NO_2(g) \rightleftharpoons 2\,NO(g) + O_2(g) \qquad \Delta H = +113\ kJ\ mol^{-1}$$

Table 1

Gas	Mole fraction
NO_2	0.310
NO	0.460
O_2	0.230

For this equilibrium mixture, $K_p = 59.7$ kPa

Give an expression for K_p for this reaction.

Use your expression and the data in **Table 1** to calculate the total pressure, in kPa, in the flask.

[3 marks]

K_p

Total pressure _____ kPa

Question	Answers	Additional comments/Guidelines	Mark
04.1	M1 0.176 M2 0.549 M3 0.275	Allow answers to 2 significant figures	3 (3 x AO2)

Question	Answers	Additional comments/Guidelines	Mark
04.2	21.1 (kPa)	Allow answer to question **04.1** x 120 and answer in kPa Allow 21.6 (kPa) Answer using given value of 0.380 mol = 45.6(kPa)	1 (AO2)

Question	Answers	Additional comments/Guidelines	Mark
04.3	M1 $K_p = \frac{p(NO)^2 p(O_2)}{p(NO_2)^2}$ M2 = $\frac{K_p \times \text{mol frac } (NO_2)^2}{\text{mol frac } (NO)^2 \times \text{mol frac } (O_2)}$ OR $\frac{59.7 \times (0.31)^2}{(0.46)^2 \times (0.23)}$ M3 = 117.9 (kPa) or 118 (kPa)	Do **not** allow square brackets Rearrangement	3 (1 x AO1, 2 x AO2)

Question	Answers	Additional comments/Guidelines	Mark
04.4	Decrease No change		2 (1 x AO1, 1 x AO3)

Question	Answers	Additional comments/Guidelines	Mark
04.5	M1 Reaction is endothermic OR exothermic in backwards direction M2 Equilibrium shifts/moves in backwards direction/to the left to raise the temp/oppose the decrease in temp		2 (2 x AO3)