

1 Explain what you understand by the term *dynamic equilibrium*.

All concentrations remain constant/macroscopic properties constant

Rate of forward reaction = rate of reverse reaction

2 Explain what is meant by a *closed system*.

No exchange of matter with surroundings

3 Describe, on a molecular level, how equilibrium is established when a liquid is placed in a closed container.

Rate of evaporation = rate of condensation

4 Write expressions for the equilibrium constant, K_c , for

$K_c = \frac{[\text{CO}_2(\text{g})][\text{H}_2(\text{g})]^4}{[\text{CH}_4(\text{g})][\text{H}_2\text{O}(\text{g})]^2}$
$K_c = \frac{[\text{NH}_3(\text{g})]^2}{[\text{N}_2(\text{g})][\text{H}_2(\text{g})]^3}$
$K_c = \frac{[\text{SO}_3(\text{g})]^2}{[\text{SO}_2(\text{g})]^2[\text{O}_2(\text{g})]}$

$\text{CH}_4(\text{g}) + 2\text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}_2(\text{g}) + 4\text{H}_2(\text{g})$
$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$
$2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$

5 Write expressions for the equilibrium constant, K_{c1} , for the reactions shown and state the relationship between the values of K_{c1} and K_c in 4

$K_c = \frac{[\text{CO}_2(\text{g})][\text{H}_2(\text{g})]^4}{[\text{CH}_4(\text{g})][\text{H}_2\text{O}(\text{g})]^2}$	$K_{c1} = \frac{[\text{CH}_4(\text{g})][\text{H}_2\text{O}(\text{g})]^2}{[\text{CO}_2(\text{g})][\text{H}_2(\text{g})]^4}$	$K_{c1} = 1/K_c$
$K_c = \frac{[\text{NH}_3(\text{g})]^2}{[\text{N}_2(\text{g})][\text{H}_2(\text{g})]^3}$	$K_{c1} = \frac{[\text{NH}_3(\text{g})]}{[\text{N}_2(\text{g})]^{1/2}[\text{H}_2(\text{g})]^{3/2}}$	$K_{c1} = \sqrt{K_c}$
$K_c = \frac{[\text{SO}_3(\text{g})]^2}{[\text{SO}_2(\text{g})]^2[\text{O}_2(\text{g})]}$	$K_{c1} = \frac{[\text{SO}_2(\text{g})][\text{O}_2(\text{g})]^{1/2}}{[\text{SO}_3(\text{g})]}$	$K_{c1} = 1/\sqrt{K_c}$

$\text{CO}_2(\text{g}) + 4\text{H}_2(\text{g}) \rightleftharpoons \text{CH}_4(\text{g}) + 2\text{H}_2\text{O}(\text{g})$
$1/2\text{N}_2(\text{g}) + 3/2\text{H}_2(\text{g}) \rightleftharpoons \text{NH}_3(\text{g})$
$\text{SO}_3(\text{g}) \rightleftharpoons \text{SO}_2(\text{g}) + 1/2\text{O}_2(\text{g})$

6 Explain the connection between the value of the equilibrium constant and the position of equilibrium.

Bigger value of K_c – more the position of equilibrium lies towards the right

$K_c \gg 1$ position of equilibrium long way to right

$K_c \ll 1$ position of equilibrium long way to left

7 Predict, for each of the reactions shown, the effect of the changes below on the position of equilibrium and the value of the equilibrium constant

$\text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + 3\text{H}_2(\text{g})$	$\Delta H = +206 \text{ kJ mol}^{-1}$
$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$	$\Delta H = -92 \text{ kJ mol}^{-1}$
$\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$	$\Delta H = +52 \text{ kJ mol}^{-1}$

increasing the pressure decreasing the temperature adding hydrogen adding a catalyst

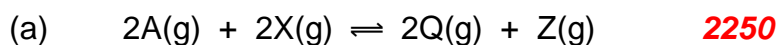
$\text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + 3\text{H}_2(\text{g})$	Increase P	Decrease T	Add H ₂	Catalyst
Effect on position of equilibrium	To left	To left	To left	No change
Effect on K_c	No change	decreases	No change	No change
$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$	Increase P	Decrease T	Add H ₂	Catalyst
Effect on position of equilibrium	To right	To right	To right	No change
Effect on K_c	No change	increases	No change	No change
$\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$	Increase P	Decrease T	Add H ₂	Catalyst
Effect on position of equilibrium	No change	To left	To right	No change
Effect on K_c	No change	decreases	No change	No change

- 8 Explain whether the reaction $A \rightleftharpoons B$ is endothermic or exothermic from the values of the equilibrium constant.

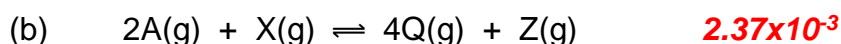
$$K_c = 1.2 \times 10^4 \text{ at } 500 \text{ K and } K_c = 5.6 \times 10^5 \text{ at } 1000 \text{ K}$$

Endothermic

- 9 Calculate K_c for each of the following reactions:



Initial number of moles of A = 0.200 mol	initial number of moles of X = 0.200 mol
initial number of moles of Q = 0.200 mol	initial number of moles of Z = 0.200 mol
number of moles of X at equilibrium = 0.100 mol	Volume of container = 10.0 dm ³

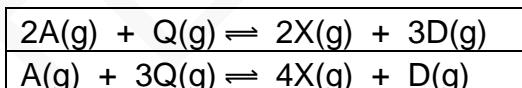


Initial number of moles of A = 0.800 mol	initial number of moles of X = 0.400 mol
initial number of moles of Q = 0.000 mol	initial number of moles of Z = 0.000 mol
number of moles of Z at equilibrium = 0.100 mol	Volume of container = 10.0 dm ³

- 10 Write expressions for the reaction quotient, Q , for the following reactions

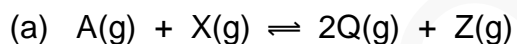
$$Q = \frac{[X]^2[D]^3}{[A]^2[Q]}$$

$$Q = \frac{[X]^4[D]}{[A][Q]^3}$$



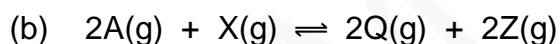
- 11 Given the data shown and the value of K_c work out the value of Q and whether

- A the system is at equilibrium
 B proceeds to the right towards equilibrium
 C proceeds to the left towards equilibrium



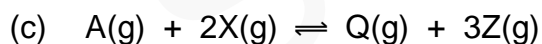
$Q=0.0200$ therefore to the right

moles of A = 0.200 mol	moles of X = 0.200 mol
moles of Q = 0.200 mol	moles of Z = 0.200 mol
Value of $K_c = 0.0300$	container volume = 10.0 dm ³



$Q=0.0400$ therefore to the left

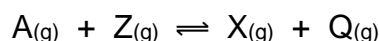
moles of A = 0.100 mol	moles of X = 0.400 mol
moles of Q = 0.200 mol	moles of Z = 0.200 mol
Value of $K_c = 0.0200$	container volume = 10.0 dm ³



$Q=0.160$ therefore at equilibrium

moles of A = 0.100 mol	moles of X = 0.200 mol
moles of Q = 0.100 mol	moles of Z = 0.400 mol
Value of $K_c = 0.160$	container volume = 10.0 dm ³

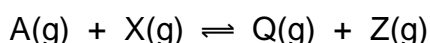
- 12 Calculate the number of moles present at equilibrium given the value of the equilibrium constant.



At a certain temperature, 0.100 mol of A and 0.100 mol of Z are placed in a container of volume 1.00 dm³ and allowed to come to equilibrium. The value of the equilibrium constant at this temperature is 9.00. Calculate the number of moles of X at equilibrium.

0.0750 mol

- 13 Use Q and K_c to explain Le Chatelier's principle for changes in concentration.



The system at equilibrium contains the following number of moles in a vessel of volume 1.00 dm^3 .

Moles of A / mol	Moles of X / mol	Moles of Q / mol	Moles of Z / mol
0.100	0.100	0.200	0.200

Explain what happens (using the values of Q and K_c) when another 0.100 mol of A is introduced into the container.

$K_c = 4$ when 0.100 mol A introduced $Q = 2$

$Q < K_c$ therefore the reaction is not at equilibrium and must proceed to right to reach equilibrium. New equilibrium will contain more than 0.200 mol of Q and Z , therefore the position of equilibrium has shifted to the right.

- 14 State how entropy and Gibbs free energy vary as a system moves towards equilibrium.

Entropy increases – maximum at equilibrium

Gibbs free energy decreases – minimum at equilibrium

- 15 For a system at equilibrium: $A \rightleftharpoons B$

state the relationship between the Gibbs free energy of A and B and hence the value of ΔG .

At equilibrium Gibbs free energy of A and B equal so $\Delta G = 0$

- 16 For each of the following situations state whether the value of the equilibrium constant is less than or greater than 1.

ΔG is negative

$K_c > 1$

ΔG is positive

$K_c < 1$

- 17 Calculate the value of ΔG (with units) from the following data. $R = 8.31 \text{ JK}^{-1}\text{mol}^{-1}$

Value of K	temperature	$\Delta G / \text{kJ mol}^{-1}$
1.5×10^3	$500 \text{ }^\circ\text{C}$	-47.0
2.0×10^{-4}	300 K	21.2
10	400 K	-7.65

- 18 Calculate the value of the equilibrium constant from the following data
 $R = 8.31 \text{ JK}^{-1}\text{mol}^{-1}$

$\Delta G / \text{kJ mol}^{-1}$	temperature	K
-100	$300 \text{ }^\circ\text{C}$	1.32×10^9
40	400 K	5.94×10^{-6}
-500	500 K	1.83×10^{52}

- 19 Explain for each of the system in 17 and 18 whether the position of equilibrium lies more to the left or more to the right.

If ΔG –ve then position of equilibrium more to right. If $K > 1$ then position of equilibrium to right.