

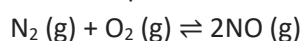
## Lesson 2 Working with equilibrium expressions and constants of homogeneous systems.

Significance of high equilibrium constant – high equilibrium constants indicate that the reaction will use up a high percentage of the reactants to produce a high amount of product. However it does not indicate the rate at which the reaction takes place..

Units of the equilibrium constant-the units of the equilibrium constant depends on the chemical equation and hence the equilibrium expression.

When the total number of moles of products, in a balanced chemical equation, is equal to the total number of moles of reactants, then K has no units.

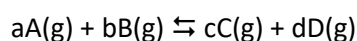
For example:



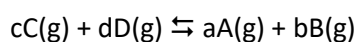
Units of concentration will cancel out in the expression shown.

$$K = \frac{[\text{NO}]^2}{[\text{N}_2][\text{O}_2]}$$

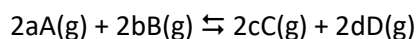
Expression dependent on equation- before an equilibrium expression can be written the balanced chemical equation has to be known. Reactants appear in the denominator and products in the numerator. Below are a few examples.



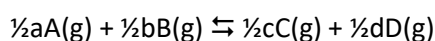
$$\frac{[\text{C}]^c [\text{D}]^d}{[\text{A}]^a [\text{B}]^b} = K_c$$



$$\frac{[\text{A}]^a [\text{B}]^b}{[\text{C}]^c [\text{D}]^d} = \frac{1}{K_c}$$

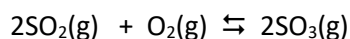


$$\frac{[\text{C}]^{2c} [\text{D}]^{2d}}{[\text{A}]^{2a} [\text{B}]^{2b}} = K_c^2$$



$$\frac{[\text{C}]^{\frac{1}{2}c} [\text{D}]^{\frac{1}{2}d}}{[\text{A}]^{\frac{1}{2}a} [\text{B}]^{\frac{1}{2}b}} = K_c^{\frac{1}{2}} = \sqrt{K_c}$$

eg1 Consider the following reaction at equilibrium.



The equilibrium constant at 1000 °K is  $2.71 \times 10^2 \text{ M}^{-1}$ .

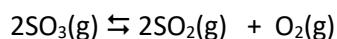
a) Write the equilibrium expression for the reaction  $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$

$$\frac{[\text{SO}_3]^2}{[\text{SO}_2]^2 [\text{O}_2]} = K$$

b) Write the equilibrium expression for the reaction  $\text{SO}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightleftharpoons \text{SO}_3(\text{g})$

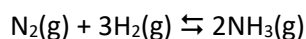
$$\frac{[\text{SO}_3]}{[\text{SO}_2] [\text{O}_2]^{1/2}} = K^{1/2}$$

c) Calculate the equilibrium constant for the reaction below at 1000°K



$$\frac{[\text{SO}_2]^2 [\text{O}_2]}{[\text{SO}_3]^2} = \frac{1}{K} = \frac{1}{271} = 3.69 \times 10^{-3} \text{ M}$$

1) A mixture of nitrogen and hydrogen gases was placed in a sealed vessel and allowed to reach equilibrium according to the equation below at a constant temperature.



When no further change to the mixture was observed the concentration of each gas present was analysed and recorded. The results are given below.

$$[\text{NH}_3] = 0.142 \text{ M}$$

$$[\text{H}_2] = 0.121 \text{ M}$$

$$[\text{N}_2] = 0.101 \text{ M}$$

a) Write the equilibrium expression for the above reaction.

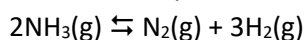
$$\frac{[\text{NH}_3]^2}{[\text{H}_2]^3 [\text{N}_2]} = K_c$$

b) Calculate the value of the equilibrium expression

$$\frac{(0.142 \text{ M})^2}{(0.121 \text{ M})^3 (0.101 \text{ M})} = K_c = 1.13 \times 10^2 \text{ M}^{-2}$$

- c) The temperature in the reaction vessel above was altered and the mixture was again allowed to reach equilibrium. The equilibrium constant at this new temperature is  $1.27 \times 10^4 \text{ M}^{-2}$ .

i. Write the equilibrium expression for the equation below.



$$\frac{[\text{H}_2]^3 [\text{N}_2]}{[\text{NH}_3]^2} = K_c$$

ii. Calculate the equilibrium constant at this temperature for the reaction in i. above.

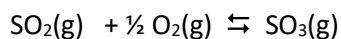
$$7.87 \times 10^{-5} \text{ M}^2$$

$$\frac{[\text{H}_2]^3 [\text{N}_2]}{[\text{NH}_3]^2} = K_c = \frac{1}{1.27 \times 10^4} \text{ M}^2$$

iii. What can you say about the yield of nitrogen and hydrogen gases at this temperature?

*$K_c$  is very low and hence low yields will be achieved at this temperature.*

- 2) A mixture containing 2.00 mol of  $\text{SO}_2$  gas and 2.00 mol of  $\text{O}_2$  gas was placed in a 2.00 litre, sealed, vessel and allowed to react according to the equation below.



The mixture was allowed to reach equilibrium at constant temperature. At equilibrium 0.500 mol of  $\text{SO}_3$  gas was present.

a) Write the equilibrium expression for the reaction.

$$\frac{[\text{SO}_3]}{[\text{SO}_2] [\text{O}_2]^{1/2}} = K_c$$

b) Calculate the equilibrium constant for the system at the given temperature.

*At equilibrium mol of  $\text{SO}_2$  present = 1.50, mol of  $\text{O}_2$  present = 1.75*

$$[\text{SO}_2] = 1.50/2.00 = 0.750 \text{ M}$$

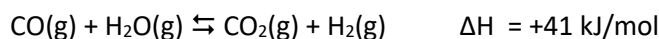
$$[\text{O}_2] = 1.75 / 2.00 = 0.875 \text{ M}$$

$$[\text{SO}_3] = 0.500 / 2.00 = 0.250 \text{ M}$$

$$K_c = 0.356 \text{ M}^{-1/2}$$

$$\frac{[0.250 \text{ M}]}{[0.750 \text{ M}] [0.875 \text{ M}]^{1/2}} = K_c$$

3) Consider the production of hydrogen gas according to the equation below.



A mixture of CO and H<sub>2</sub>O gases was placed in a 2.00 litre vessel at 225°C, a few minutes later the mixture was analysed and found to contain 2.00 mol of CO, 1.00 mol of H<sub>2</sub>O and 2.00 mol of H<sub>2</sub> gas. At 225°C the equilibrium constant for this reaction is 23.6

a) How many mol of CO<sub>2</sub> was present in the mixture at equilibrium?

*The stoichiometry tells us that for every mol of CO<sub>2</sub> formed one mol of H<sub>2</sub> is also formed. The stoichiometric ratio for CO<sub>2</sub> formed to H<sub>2</sub> formed is 1:1. Hence 2.00 mol of CO<sub>2</sub> gas is formed.*

b) Write the equilibrium expression for this reaction.

$$\frac{[\text{H}_2][\text{CO}_2]}{[\text{CO}][\text{H}_2\text{O}]} = K_c$$

c) Calculate the value of the equilibrium expression.

$$[\text{H}_2] = 2.00 / 2.00 = 1.00\text{M}$$

$$[\text{CO}_2] = 2.00 / 2.00 = 1.00\text{M}$$

$$[\text{CO}] = 2.00 / 2.00 = 1.00\text{M}$$

$$[\text{H}_2\text{O}] = 1.00 / 2.00 = 0.500\text{M}$$

$$K_c = 2.00$$

d) Had the reaction reached equilibrium? Explain.

*No. The equilibrium constant for this reaction at 225°C is 23.6. Since there is no temperature change the equilibrium constant is not change, hence, the reaction is still moving in the forward direction when the sampling was done.*

e) What can you say about the forward rate of reaction when compared to the backward rate of reaction? Explain

*The forward rate is greater than the backward rate since the reaction is still moving forward to achieve equilibrium once more.*

f) In another vessel, of unknown volume, a mixture of CO and H<sub>2</sub>O gases was allowed to react and reach equilibrium at 225°C. After reaching equilibrium the mixture was sampled and revealed the following concentrations, [CO] = 3.00M and [H<sub>2</sub>O] = 2.24 M. Calculate the concentration of H<sub>2</sub> gas.

*Since the number of mol of H<sub>2</sub> and CO<sub>2</sub> formed are the same so will their concentrations also be the same. So we can write the following expression.*

$$\frac{[\text{H}_2]^2}{[\text{CO}][\text{H}_2\text{O}]} = K_c$$

Now we solve for [H<sub>2</sub>]

$$[\text{H}_2] = 12.6 \text{ M}$$

$$\frac{[\text{H}_2]^2}{[3.00][2.24]} = 23.6$$