

## Calculations Involving Equilibrium Constant Equation

Basically, there are three types of calculations involved in equilibrium constant equation:

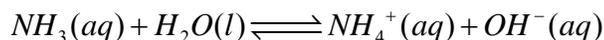
- Calculation of equilibrium constant  $K_c$  or  $K_p$
- Calculation of  $K_c$  or  $K_p$  given  $K_p$  or  $K_c$
- Calculation of equilibrium concentrations (molar concentrations or partial pressures)

Let us illustrate these three types of calculations with examples.

### Calculation of Equilibrium Constant

#### Example

Consider the following equilibrium reaction



If  $[NH_3] = 0.02M$ ,  $[NH_4^+] = 0.05 M$ , and  $[OH^-] = 0.6 M$ , what is the equilibrium constant  $K_c$  for this reaction?

#### Answer

The equilibrium constant equation excluding the water (remember pure liquids do not appear in equilibrium constant expression) for the above reaction is

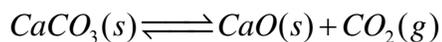
$$K_c = \frac{[NH_4^+][OH^-]}{[NH_3]}$$

Substitute the given concentrations to evaluate  $K_c$ . Hence

$$K_c = \frac{[NH_4^+][OH^-]}{[NH_3]} = \frac{(0.05)(0.6)}{0.02} = 1.5$$

#### Example

Consider the following heterogeneous equilibrium reaction:



At  $800^\circ C$ , the pressure of  $CO_2$  gas is  $0.236 \text{ atm}$ . Calculate (a)  $K_p$  and (b)  $K_c$  for the reaction at this temperature.

### Answer

Since  $\text{CaCO}_3$  and  $\text{CaO}$  are solids, their concentrations do not enter into the equilibrium constant expression. Also, the pressure of  $\text{CO}_2$  is given, and therefore, first we solve for  $K_p$  and then solve for  $K_c$ .

(a)  $K_p = P_{\text{CO}_2} = 0.236$

(b) The relation between  $K_p$  and  $K_c$  is

$$K_p = K_c (0.0821 \times T)^{\Delta n}$$

Here  $T = 273 + 800 = 1073 \text{ K}$ , and  $\Delta n = 1$ . So, we substitute these values into the above equation to yield,

$$0.236 = K_c (0.0821 \times 1073)$$

$$K_c = 2.68 \times 10^{-3}$$

### Calculation of $K_c$ or $K_p$ given $K_p$ or $K_c$

#### Example

The equilibrium constant ( $K_c$ ) for the reaction



is  $4.63 \times 10^{-3}$  at  $25^\circ\text{C}$ . What is the value of  $K_p$  for this reaction at this temperature?

### Answer

Relationship between  $K_p$  and  $K_c$  is

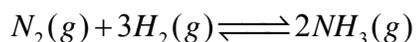
$$K_p = K_c (0.0821 \times T)^{\Delta n}$$

Here  $T = 25 + 273 = 298 \text{ K}$ , and  $\Delta n = 2 - 1 = 1$ . Thus

$$K_p = 4.63 \times 10^{-3} (0.0821 \times 298) = 0.113$$

#### Example

For the reaction



$K_p$  is  $4.3 \times 10^{-4}$  at  $375^\circ\text{C}$ . Calculate  $K_c$  for this reaction.

**Answer**

Here  $T = 273 + 375 = 648 \text{ K}$ , and  $\Delta n = 2 - (1+3) = -2$

Substituting these values and the value of  $K_p$  into the equation  $K_p = K_c (0.0821 \times T)^{\Delta n}$ , we have

$$4.3 \times 10^{-4} = K_c (0.0821 \times 648)^{-2} = K_c \times (53.2)^{-2}$$

or  $K_c = 4.3 \times 10^{-4} / (53.2)^{-2} = 4.3 \times 10^{-4} \times (53.2)^2 = 1.22$

**Calculation of equilibrium concentrations (molar concentrations or partial pressures)**

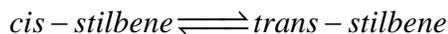
The procedure for calculating the equilibrium concentrations depends on the way the equilibrium is established. Generally, there are three ways of establishing the equilibrium:

- a. starting with certain amount of reactant(s)
- b. starting with certain amount of product(s)
- c. starting with certain amount of reactant(s) and certain amount of product(s)

In addition, the complexity of solving the problem increases as the complexity of the equilibrium increases. For simplicity, let us consider only the first kind where the equilibrium is attained starting with certain amount of reactant only.

**Example**

Let us consider the simple example of equilibrium between two geometric isomers of stilbene in organic solvent



which has an equilibrium constant  $K_c$  of 24.0 at  $200^\circ\text{C}$ . Suppose that we start the reaction using only 0.850 M of cis-stilbene, what will be the equilibrium concentrations of cis-stilbene and trans-stilbene?

**Answer**

From the above stoichiometry of the reaction, it is clear that one mole of cis-stilbene converts to one mole of trans-stilbene. Let  $x$  be the equilibrium concentration of trans-stilbene, then  $(0.850 - x)$  be the equilibrium concentration of cis-stilbene. [Remember

that equilibrium concentration is the difference between initial concentration and the amount (concentration) disappeared at equilibrium]. It is very useful to set up the problem in the following manner:

	$cis - stilbene \rightleftharpoons trans - stilbene$	
Initial concentration (M):	0.850	0
Change in concentration (M)	-x	+x
Equilibrium concentration (M)	0.850 - x	x

A negative (-) change indicates a decrease in concentration and a positive (+) change indicates an increase in concentration at equilibrium. Next, we set up an equilibrium constant expression and substitute these values and solve for x:

$$K_c = \frac{[trans - stilbene]}{[cis - stilbene]}$$

$$24.0 = \frac{x}{0.850 - x}$$

$$x = 0.816 \text{ M}$$

The equilibrium concentrations of cis- and trans-stilbene are

$$[trans-stilben] = x = 0.816 \text{ M}$$

$$[cis-stilbene] = (0.850 - x) = 0.850 - 0.816 = 0.034 \text{ M}$$