Name ______________________________

Date ________________ Period _____

Law of Chemical Equilibrium

The law of chemical equilibrium is shown in the box to the right. For the reaction $aA + bB \rightleftharpoons cC + dD$, A and B represent the reactants, C and D represent the products, and *a*, *b*, *c*, and *d* represent the respective coefficients. The equilibrium expression is equal to the multiple of the concentrations of the products raised to the power of their respective coefficients divided by the multiple of the reactants raised to the power of their respective coefficients.

If $aA + bB \rightleftharpoons cC + dD$

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

There are several things that can be done to interpret equilibrium using the law. First, since the numerator of the fraction is based on the concentration of the products, an equilibrium constant greater than one ($k_{eq} > 1$) refers to a reaction that favors the formation of product, while an equilibrium constant less than one ($k_{eq} < 1$) refers to a reaction that favors the formation of the reactants [example (a)]. Second, appropriate equilibrium expressions need to be written based on the balanced equation [example (b)]. And third, mathematical problems can be done substituting values for the concentration into the equilibrium expression, either to determine if equilibrium has been reached, or to determine the equilibrium concentration of one of the reactants or products. [examples (c) and (d)].

Sample Problems

The reaction $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ is at equilibrium at 1 atm and 298 K. The equilibrium constant for the reaction at 1 atm and 298 K is as follows: $K_{eq} = 3.5 \times 10^{-1}$

(a) Which is favored, the forward or the reverse reaction?

Answer: The reverse reaction is favored ($K_{eq} < 1$)

(b) What is the equilibrium expression?

Answer:

$$3.5 \times 10^{-1} = \frac{[HI]^2}{[H_2][I_2]}$$

(c) If the concentration of hydrogen iodide is $2.65 \times 10^{-2} M$, the concentration of hydrogen is $5.0 \times 10^{-3} M$, and the concentration of iodine is $4.0 \times 10^{-1} M$, is the reaction at equilibrium?

Answer:

$$K_{eq} = \frac{\left(2.65 \times 10^{-2}\right)^2}{\left(5.0 \times 10^{-3}\right)\left(4.0 \times 10^{-1}\right)} = 3.5 \times 10^{-1}$$

Yes!

(d) If the reaction is at equilibrium, what is the concentration of hydrogen iodide if the concentration of hydrogen is $3.0 \times 10^{-3} M$, and the concentration of iodine is $2.5 \times 10^{-2} M$?

Answer:

$$3.5 \times 10^{-1} = \frac{[HI]^2}{\left(3.0 \times 10^{-3}\right)\left(2.5 \times 10^{-2}\right)}$$

$$[HI] = \sqrt{\left(3.5 \times 10^{-1}\right)\left(3.0 \times 10^{-3}\right)\left(2.5 \times 10^{-2}\right)}$$

$$[HI] = \sqrt{2.625 \times 10^{-5}} = 5.1 \times 10^{-3}\ M$$

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Refer to the table below to answer the questions that follow(assume all reactions are at 1 atm and 298 K):

CONSTANTS FOR VARIOUS EQUILIBRIA AT 1 atm AND 298 K			
$H_2O(\ell)$	=	$H^+(aq) + OH^-(aq)$	$K_w = 1.0 \times 10^{-14}$
$H_2O(\ell) + H_2O(\ell)$	=	$H_3O^+(aq)$ + OH–(aq)	$K_w = 1.0 \times 10^{-14}$
$CH_3COO^-(aq) + H_2O(\ell)$	=	$CH_3COOH(aq) + OH(aq)$	$K_b = 5.6 \times 10^{-10}$
$NaF(aq) + H_2O(\ell)$	=	$Na^+(aq) + OH^-(aq) + HF(aq)$	$K_b = 1.5 \times 10^{-11}$
$NH_3(aq) + H_2O(\ell)$	=	$NH_4^+(aq) + OH^-(aq)$	$K_b = 1.8 \times 10^{-5}$
$CO_3^{2-}(aq) + H_2O(\ell)$	=	$HCO_3^-(aq) + OH^-(aq)$	$K_b = 1.8 \times 10^{-4}$
$Ag(NH_3)_2^+(aq)$	=	$Ag^+(aq) + 2NH_3(aq)$	$K_{eq} = 8.9 \times 10^{-8}$
$N_2(g) + 3H_2(g)$	=	$2NH_3(g)$	$K_{eq} = 6.7 \times 10^{5}$
$H_2(g) + I_2(g)$	=	$2HI(g)$	$K_{eq} = 3.5 \times 10^{-1}$

Compound	K_{sp}	*Compound*	K_{sp}
AgBr	5.0×10^{-13}	Li_2CO_3	2.5×10^{-2}
AgCl	1.8×10^{-10}	$PbCl_2$	1.6×10^{-5}
Ag_2CrO_4	1.1×10^{-12}	$PbCO_3$	7.4×10^{-4}
AgI	8.3×10^{-17}	$PbCrO_4$	2.8×10^{-13}
$BaSO_4$	1.1×10^{-10}	PbI_2	7.1×10^{-9}
$CaSO_4$	9.1×10^{-6}	$ZnCO_3$	1.4×10^{-11}

1. A solution of ammonia is prepared [$NH_3(aq) + H_2O(\ell) = NH_4^+(aq) + OH^-(aq)$]

   a. Which is favored, the forward or reverse reaction? ____________________

   b. What is the equilibrium expression?

   c. If the reaction is at equilibrium and $[NH_4^+] = [OH^-] = 7.35 \times 10^{-3}$ *M*, what is the concentration of $NH_3(aq)$?

2. Ammonia is prepared from its elements [$N_2(g) + 3H_2(g) = 2NH_3(g)$]

   a. Which is favored, the forward or reverse reaction? ____________________

   b. What is the equilibrium expression?

   c. If the reaction is at equilibrium, $[N_2]$ = 0.500 M, and $[H_2]$ = 0.300 *M*, what is the concentration of $NH_3(g)$?