Outline

- Equilibrium Condition
- Equilibrium Constant
- Solubility Product Constant

Equilibrium Condition

Reactions proceed in both directions... both reactions occurring at their own rate (speed)!

The relative rates of reaction determine net direction of reaction…

1. If $R_f > R_r$, then forward spontaneous: $H_2 + Cl_2 \rightarrow 2HCl$

2. If $R_f < R_r$, then reverse spontaneous: $H_2 + Cl_2 \leftarrow 2HCl$

3. If $R_f = R_r$, then equilibrium: $H_2 + Cl_2 \rightleftarrows 2HCl$

<u>Chemical equilibrium</u> is the condition when the forward and reverse rates of reaction are equal

Le Chatelier's Principle

A system at equilibrium will shift to counteract an applied stress

$$H_2(g) + I_2(g) \rightleftarrows 2HI(g) + 10.2\ kJ$$

Concentration changes…

inc. $[H_2]$	shifts right
inc. $[HI]$	shifts left
dec. $[I_2]$	shifts left

Temperature changes…

inc. temp	shifts left
dec. temp	shifts right

Volume changes… change pressure (concentration) of gases

dec. volume $\rightarrow$ inc. pressure… shifts to side with less gas

inc. volume $\rightarrow$ dec. pressure… shifts to side with more gas

$$N_2O_4(g) + 58.6\ kJ \rightleftarrows 2NO_2(g)$$

inc. vol.	shifts right	dec. vol.	shifts left
inc. $[N_2O_4]$	shifts right	dec. $[NO_2]$	shifts right
inc. temp.	shifts right	dec. temp.	shifts left

Equilibrium Constant

Equilibrium constants (K) give measure of how far a reaction goes…

For… $aA + bB \rightleftharpoons cC + dD$

We write… $K = \frac{[C]^c\,[D]^d}{[A]^a\,[B]^b}$ (equilibrium constant expression)

K expression contains substances whose concentrations can change

gases (g) and dissolved substances (aq) are included

solids (s) and liquids (l) are not included

Write the K expression for

$$N_2(g) + 3H_2(g) \rightleftarrows 2NH_3(g) \qquad K = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

$$C(s) + CO_2(g) \rightleftarrows 2CO(g) \qquad K = \frac{[CO]^2}{[CO_2]}$$

Equilibrium reactions with K values that are…

…large are complete… equilibrium lies to far right

…small are incomplete… equilibrium lies to far left

Find K_{eq} for

$$2H_2(g) + O_2(g) \rightleftarrows 2H_2O(g)$$

in a flask that is 2.0 M H_2, 2.0 M O_2, and 8.0 M H_2O at equilibrium

$$K = \frac{[H_2O]^2}{[H_2]^2\,[O_2]} = \frac{(8.0\,M)^2}{(2.0\,M)^2(2.0\,M)} = 8.0\,M^{-1} = \underline{8.0}$$

What's $[O_2]$ if $[H_2] = [H_2O] = 4.0$ M?

$$K = \frac{[H_2O]^2}{[H_2]^2\,[O_2]} \quad \Rightarrow \quad [O_2] = \frac{[H_2O]^2}{[H_2]^2\,K} = \frac{(4.0)^2}{(4.0)^2(8.0)} = \underline{0.13\,M}$$

Find K_{eq} for

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

in a flask that is 0.489 M CO, 0.146 M H_2, and 0.151 M CH_3OH at equilibrium

$$K = \frac{[CH_3OH]}{[CO][H_2]^2} = \frac{(0.151\,M)}{(0.489\,M)(0.146\,M)^2} = 14.5\,M^{-2} = \underline{14.5}$$

What's $[CH_3OH]$ if $[CO] = [H_2] = 2.0$ M?

$$K = \frac{[CH_3OH]}{[CO][H_2]^2} \quad \Rightarrow \quad [CH_3OH] = K[CO][H_2]^2 = 14.5(2.0)^3 = \underline{120\,M}$$

Solubility Product Constant

The dissolution of a salt is an equilibrium process…

$$AgBr(s) \rightleftarrows Ag^{+}(aq) + Br^{-}(aq)$$

$K_{sp} = [Ag^{+}][Br^{-}]$ (solubility product constant)

<u>Molar solubility</u> is moles of solute dissolved per liter of solution…

…equal to concentration of dissolved ions

…calculated from solubility product constant

What’s molar solubility of AgBr, K_{sp} = 5.2 x 10^{-13}?

$$AgBr(s) \rightleftarrows Ag^{+}(aq) + Br^{-}(aq)$$

$$K_{sp} = [Ag^{+}][Br^{-}] = (x)(x) = 5.2 \times 10^{-13}$$

$$x = \underline{7.2 \times 10^{-7}\ M} \quad (x = \text{molar solubility})$$

How many mg of AgBr dissolve in 1.0 L?

$$1.0\ L \times \frac{7.2 \times 10^{-7}\ \text{mol AgBr}}{L} \times \frac{187.80\ \text{g AgBr}}{\text{mol}} \times \frac{1\ \text{mg}}{1 \times 10^{-3}\ \text{g}} = \underline{0.14\ \text{mg}}$$

What's molar solubility of $CaSO_4$, $K_{sp} = 6.2 \times 10^{-5}$?

$$CaSO_4(s) \rightleftarrows Ca^{2+}(aq) + SO_4^{2-}(aq)$$

$$K_{sp} = [Ca^{2+}][SO_4^{2-}] = (x)(x) = 6.2 \times 10^{-5}$$

$$x = \underline{0.0079\ M} \quad (x = \text{molar solubility})$$

How many g of $CaSO_4$ dissolve in 50.0 mL?

$$0.0500\ L \times \frac{0.0079\ mol\ CaSO_4}{L} \times \frac{136.15\ g\ CaSO_4}{mol} = \underline{0.054\ g}$$

1.8 mg of zinc carbonate dissolve in 1.0 L of water. What's K_{sp}?

$$ZnCO_3(s) \rightleftarrows Zn^{2+}(aq) + CO_3^{2-}(aq)$$

$$K_{sp} = [Zn^{2+}][CO_3^{2-}] = (x)(x) = x^2 \quad \Rightarrow \quad x = \text{molar solubility}$$

$$\frac{1.8\text{ mg}}{1.0\text{ L}} \quad \text{(solubility)}$$

$$\frac{1.8 \times 10^{-3}\text{ g}}{1.0\text{ L}} \times \frac{1\text{ mol}}{125.42\text{ g}} = \frac{1.\underline{4}3 \times 10^{-5}\text{ mol}}{\text{L}} \quad \text{(molar solubility)}$$

$$K_{sp} = (1.\underline{4}3 \times 10^{-5})^2 = \underline{2.1 \times 10^{-10}}$$

0.042 ng of manganese(II) sulfide dissolve in 1.0 mL of water. What's K_{sp}?

$$MnS(s) \rightleftarrows Mn^{2+}(aq) + S^{2-}(aq)$$

$$K_{sp} = [Mn^{2+}][S^{2-}] = (x)(x) = x^2 \quad \Rightarrow \quad x = \text{molar solubility}$$

$$\frac{0.042\ \text{ng}}{1.0\ \mu\text{L}} \quad \text{(solubility)}$$

$$\frac{0.042 \times 10^{-9}\ \text{g}}{1.0 \times 10^{-6}\ \text{L}} \times \frac{1\ \text{mol}}{87.01\ \text{g}} = \frac{4.\underline{8}2 \times 10^{-7}\ \text{mol}}{\text{L}} \quad \text{(molar solubility)}$$

$$K_{sp} = (4.\underline{8}2 \times 10^{-7})^2 = \underline{2.3 \times 10^{-13}}$$