

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: $\text{H}_2 + \text{Cl}_2 \rightarrow 2\text{HCl}$

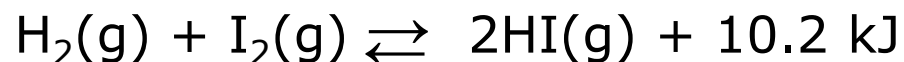
2. If $R_f < R_r$, then reverse spontaneous: $\text{H}_2 + \text{Cl}_2 \leftarrow 2\text{HCl}$

3. If $R_f = R_r$, then equilibrium: $\text{H}_2 + \text{Cl}_2 \rightleftharpoons 2\text{HCl}$

Chemical equilibrium 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



Concentration changes...

inc. $[\text{H}_2]$	shifts right
inc. $[\text{HI}]$	shifts left
dec. $[\text{I}_2]$	shifts left

Temperature changes...

inc. temp	shifts left
dec. temp	shifts right

Volume changes... change pressure (concentration) of gases

dec. volume → inc. pressure... shifts to side with less gas

inc. volume → dec. pressure... shifts to side with more gas



inc. vol. shifts right

dec. vol. shifts left

inc. $[\text{N}_2\text{O}_4]$ shifts right

dec. $[\text{NO}_2]$ shifts right

inc. temp. shifts right

dec. temp. shifts left

Equilibrium Constant

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

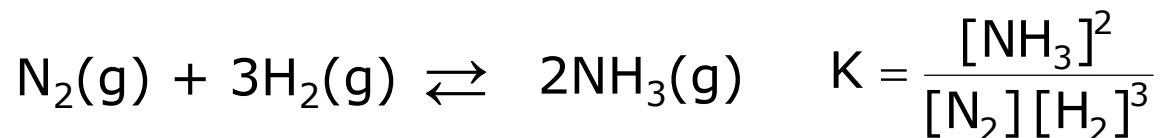
For... $aA + bB \rightleftharpoons cC + dD$

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

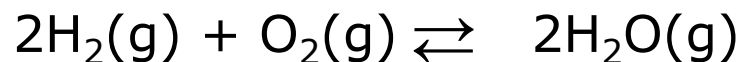


Equilibrium reactions with K values that are...

...large are complete... equilibrium lies to far right

...small are incomplete... equilibrium lies to far left

Find K_{eq} for



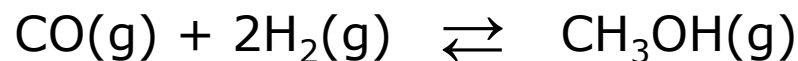
in a flask that is 2.0 M H_2 , 2.0 M O_2 , and 8.0 M H_2O at equilibrium

$$K = \frac{[\text{H}_2\text{O}]^2}{[\text{H}_2]^2 [\text{O}_2]} = \frac{(8.0 \text{ M})^2}{(2.0 \text{ M})^2 (2.0 \text{ M})} = 8.0 \text{ M}^{-1} = \underline{8.0}$$

What's $[\text{O}_2]$ if $[\text{H}_2] = [\text{H}_2\text{O}] = 4.0 \text{ M}$?

$$K = \frac{[\text{H}_2\text{O}]^2}{[\text{H}_2]^2 [\text{O}_2]} \Rightarrow [\text{O}_2] = \frac{[\text{H}_2\text{O}]^2}{[\text{H}_2]^2 K} = \frac{(4.0)^2}{(4.0)^2 (8.0)} = \underline{0.13 \text{ M}}$$

Find K_{eq} for



in a flask that is 0.489 M CO, 0.146 M H₂, and 0.151 M CH₃OH at equilibrium

$$K = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}][\text{H}_2]^2} = \frac{(0.151 \text{ M})}{(0.489 \text{ M})(0.146 \text{ M})^2} = 14.5 \text{ M}^{-2} = \underline{14.5}$$

What's [CH₃OH] if [CO] = [H₂] = 2.0 M?

$$K = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}][\text{H}_2]^2} \Rightarrow [\text{CH}_3\text{OH}] = K[\text{CO}][\text{H}_2]^2 = 14.5(2.0)^3 = \underline{120 \text{ M}}$$

Solubility Product Constant

The dissolution of a salt is an equilibrium process...



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

Molar solubility 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, $K_{sp} = 5.2 \times 10^{-13}$?



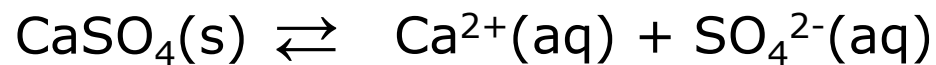
$$K_{sp} = [\text{Ag}^+][\text{Br}^-] = (x)(x) = 5.2 \times 10^{-13}$$

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

How many mg of AgBr dissolve in 1.0 L?

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

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



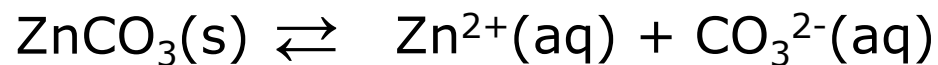
$$K_{\text{sp}} = [\text{Ca}^{2+}][\text{SO}_4^{2-}] = (x)(x) = 6.2 \times 10^{-5}$$

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

How many g of CaSO_4 dissolve in 50.0 mL?

$$0.0500 \text{ L} \times \frac{0.0079 \text{ mol CaSO}_4}{\text{L}} \times \frac{136.15 \text{ g CaSO}_4}{\text{mol}} = \underline{0.054 \text{ g}}$$

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



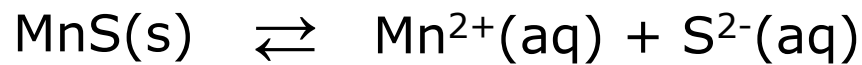
$$K_{sp} = [\text{Zn}^{2+}][\text{CO}_3^{2-}] = (x)(x) = x^2 \quad \Rightarrow \quad x = \text{molar solubility}$$

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

$$\frac{1.8 \times 10^{-3} \text{ g}}{1.0 \text{ L}} \times \frac{1 \text{ mol}}{125.42 \text{ g}} = \frac{1.43 \times 10^{-5} \text{ mol}}{\text{L}} \quad (\text{molar solubility})$$

$$K_{sp} = (1.43 \times 10^{-5})^2 = \underline{2.1 \times 10^{-10}}$$

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



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

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

$$\frac{0.042 \times 10^{-9} \text{ g}}{1.0 \times 10^{-6} \text{ L}} \times \frac{1 \text{ mol}}{87.01 \text{ g}} = \frac{4.82 \times 10^{-7} \text{ mol}}{\text{L}} \quad (\text{molar solubility})$$

$$K_{sp} = (4.82 \times 10^{-7})^2 = \underline{2.3 \times 10^{-13}}$$