WKS
Solubility Product Equilibrium-- K_{sp}

Name Answer Key
Period ________ Date__________

Writing out K_{sp} expressions: A K_{sp} expression is just a specific type of equilibrium expression. K_{sp} expressions are only used for relatively insoluble solids in water. Every saturated solution must satisfy its K_{sp} expression because every saturated solution is at equilibrium. *(Ion concentrations are constant because rate of dissolving = rate of crystallization.)*

1) Write the balanced chemical equations for the following solids dissolving in water. Then, write the K_{sp} expression for each. *Remember: Pure solids are never written in equilibrium expressions. Don't forget exponents.*

a) $Sb_2S_3\ (s) \rightleftharpoons 2\ Sb^{3+}\ (aq) + 3\ S^{2-}\ (aq)$

$K_{sp} = [Sb^{3+}]^2[S^{2-}]^3$

b) $MnCO_3\ (s) \rightleftharpoons Mn^{2+}\ (aq) + CO_3^{2-}\ (aq)$

$K_{sp} = [Mn^{2+}][CO_3^{2-}]$

First Type of K_{sp} Calculation: Determining a K_{sp} value from concentrations.

2) A sample of $Ba(OH)_2(s)$ is added to pure water and allowed to come to equilibrium. A saturated solution forms. The concentration of Ba^{+2} (aq) in this saturated solution is 0.108 M. What is K_{sp} of $Ba(OH)_2$?

a) Write the balanced equation for the $Ba(OH)_2$ solid in water : $Ba(OH)_2\ (s) \rightleftharpoons Ba^{2+}\ (aq) + 2\ OH^-\ (aq)$

b) Since $[Ba^{2+}]$ = 0.108 M. What must be the concentration of the OH^- ions? *(Use balanced eq.)* 0.216 M

c) Write the K_{sp} expression (no numbers.) Then, plug in $[Ba^{2+}]$ and $[OH^-]$ values and solve for the K_{sp}.

$$K_{sp} = [Ba^{2+}][OH^-]^2 = (0.108)(0.216)^2 = \boxed{0.00504 = 5.04\times10^{-3}}$$

3) A sample of $AgIO_3$ (s) is dissolved in water and a saturated solution is formed. The $[IO_3^-] = 1.7 \times 10^{-4}$ M. Answer these questions to find the K_{sp} of $AgIO_3$.

a) Write the balanced equation for the dissolving process: $AgIO_3\ (s) \rightleftharpoons Ag^+\ (aq) + IO_3^-\ (aq)$

b) What is $[Ag^+]$? 1.7×10^{-4} M

c) Write the K_{sp} expression (no numbers.) Then, plug in $[Ag^+]$ and $[IO_3^-]$ values and solve for the K_{sp}.

$$K_{sp} = [Ag^+][IO_3^-] = (1.7\times10^{-4})(1.7\times10^{-4}) = \boxed{2.9\times10^{-8}}$$

Second type of K_{sp} calculations: Solving for an unknown ion concentration in a saturated solution.

4) Determine the equilibrium concentrations of Pb^{2+} and SO_4^{2-} in a saturated solution of $PbSO_4$.
Given: K_{sp} of $PbSO_4 = 1.3 \times 10^{-8}$ To do so, follow these steps:

a) Write balanced equation for $PbSO_4$ (s) in water: $PbSO_4\ (s) \rightleftharpoons Pb^{2+}\ (aq) + SO_4^{2-}\ (aq)$

b) Suppose $[Pb^{2+}]$ = x. Then, $[SO_4^{2-}]$ = x

c) Write K_{sp} expression and then plug in K_{sp} value and concentration values in terms of "x's". Solve for x.

$$K_{sp} = [Pb^{2+}][SO_4^{2-}] = x \cdot x = x^2 = 1.3\times10^{-8};\ x = \sqrt{1.3\times10^{-8}} = \boxed{1.1\times10^{-4}\ \text{M}}$$

d) Thus, $[Pb^{2+}]$ = 1.1×10^{-4} M and $[SO_4^{2-}]$ = 1.1×10^{-4} M

5) Follow these steps to find the equilibrium concentrations of Ni^{2+} and OH^- in a saturated solution of $Ni(OH)_2$?

Given: K_{sp} of $Ni(OH)_2 = 1.6 \times 10^{-16}$

a) Write balanced equation for $Ni(OH)_2$ solid in water : $Ni(OH)_2$ (s) $\rightleftharpoons$ Ni^{2+} (aq) + 2 OH^- (aq)

b) Suppose $[Ni^{2+}]$ = x. Then, $[OH^-]$ = 2x

c) Write K_{sp} expression and then plug in K_{sp} value and concentration values in terms of "x's". Solve for x.

$$K_{sp} = [Ni^{2+}][OH^-]^2 = (x)(2x)^2 = 4x^3 = 1.6\times10^{-16}$$

$$x = \sqrt[3]{\frac{1.6\times10^{-16}}{4}} = \boxed{3.4\times10^{-6}\text{ M}}$$

d) Thus, $[Ni^{2+}]$ = 3.4×10^{-6} M and $[OH^-]$ = 6.8×10^{-6} M

Third type of K_{sp} calculation: Determining if precipitate will form. Solve for Q. (You're not at equil.)

6) A solution is prepared by dissolving 9.2×10^{-4} moles of $PbCl_2$ (s) into 100. mL of hot water. Should a precipitate form if the solution is cooled to 25°C? *(Assume it is cooled too quickly for a supersaturated solution to form).* Given: *K_{sp} of $PbCl_2$ at 25°C = 1.6×10^{-5}* To answer this question, follow these steps:

a) Write the balanced equation for $PbCl_2$ (s) in water: $PbCl_2$ (s) $\rightleftharpoons$ Pb^{2+} (aq) + 2 Cl^- (aq)

b) Write the Q expression-- no numbers. *(same as K_{sp} expression -- you are just not at equilibrium)*

$$Q = [Pb^{2+}][Cl^-]^2$$

c) Determine the concentrations of the ions in the hot solution.

$[Pb^{2+}] = 9.2 \times 10^{-4}$ mol/0.100 L = 9.2×10^{-3} M; $[Cl^-] = 2\,[Pb^{2+}] = 1.8 \times 10^{-2}$ M

d) Plug in concentrations and solve for Q.

$$Q = (9.2\times10^{-3})(1.8\times10^{-2})^2 = \boxed{3.0\times10^{-6}}$$

e) Q is **(greater than, less than)** the K_{sp}.

f) Thus, there are **(more, fewer)** ions dissolved in the hot solution than at the saturation point at 25°C.

g) Thus, if the solution is cooled to 25°C would solid precipitate? No *(Assume one would disturb the solution if it were supersaturated.)* Thus, the resulting solution at 25°C is **(unsaturated, saturated)**.

7) Suppose 7.5×10^{-13} moles of $Bi(NO_3)_3$ solid and 1.3×10^{-13} moles of Na_2S solid are added to 500 mL of water at 25°C. Does Bi_2S_3 solid precipitate? (K_{sp} of $Bi_2S_3 = 1.1 \times 10^{-73}$) To answer, follow these steps:

a) What is the initial concentration of Bi^{3+} ions in the 500 mL solution? (assume no reaction yet)

$[Bi^{3+}] = [Bi(NO_3)_3] = 7.5 \times 10^{-13}$ mol/0.500 L = 1.5×10^{-12} M

b) initial $[NO_3^-]$?
= 3 $[Bi(NO_3)_3] = 4.5 \times 10^{-12}$ M

initial $[Na^+]$?
= 2 $[Na_2S]$
= 5.2×10^{-13} M

initial $[S^{2-}]$?
= $[Na_2S] = 1.3 \times 10^{-13}$ mol/0.500 L
= 2.6×10^{-13} M

c) Write the balanced equation for Bi_2S_3 solid in water: Bi_2S_3 (s) $\rightleftharpoons$ 2 Bi^{3+} (aq) + 3 S^{2-} (aq)

d) Write the Q expression-- no numbers. *(same as K_{sp} expression -- you are just not at equilibrium)*

$$Q = [Bi^{3+}]^2[S^{2-}]^3$$

e) Plug in the initial concentrations of the ions involved and solve for Q.

$$Q = (1.5\times10^{-12})^2(2.6\times10^{-13})^3 = \boxed{4.0\times10^{-62}}$$

f) Q is **(greater than, less than)** the K_{sp}. Thus, there are **(more, fewer)** ions than at saturation pt.

g) Would a precipitate form? Yes The resulting solution is **(unsaturated, saturated)**