Solubility

Chapter 23-1 through Chapter 23-4

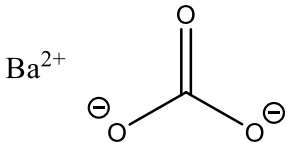
The solubility of salts can be described with the solubility product, K_{sp}. Like any other "BIG K", the K_{sp} is an **equilibrium constant** that is used to describe the dissolution of *any* sparingly soluble salt. These dissolution reactions typically take the form of:

Sparingly Soluble Salt (s) ⇌ *Positive Charged Species* (aq) + *Negative Charged Species* (aq)

Thus the K_{sp} is dependent solely on the products as the reactant is solid and has an activity of "1". Due to these being sparingly soluble salts, the solubility products are extremely small. However, what does dissolve completely dissociates (which is why it is classified as a salt).

The solubility product allows us to determine the molar solubility which is the amount of the sparingly soluble salt that dissociated. Remember: **WHEN IN DOUBT, ICE IT OUT!**

1. Barium carbonate is used in the manufacturing of TV screens and fireworks. It's also widely used in rat poison, cement, and ceramic glazes. It is a "sparingly soluble" salt with K_{sp} = 8.1 × 10^{-9}.



a. Write a chemical equation for the dissolution of barium carbonate. (Remember to include the phases of matter [(s), (aq), (g), etc.] because they are incredibly important in solubility!)

b. We all know that it wouldn't be super fun times without another equilibrium constant! Write the equilibrium constant expression (K_{sp}) for barium carbonate.

c. What is the MOLAR solubility of barium carbonate in water at 25°C?

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d. What is the SOLUBILITY (in g/L) of barium carbonate in water at 25°C?

e. Suppose the molar concentration of both Ba^{2+} and CO_3^{2-} is 2.55×10^{-9} M. Classify this solution as unsaturated, saturated, or supersaturated. (HINT: compare Q to K_{sp})

f. If HCl (aq) were titrated into a solution of barium carbonate, what reaction would occur?

e. As a result of the above titration, which direction would the dissolution reaction shift according to Le Chatelier's Principle?

2. Strontium fluoride (SrF_2) is a salt that is sparingly soluble in water at 25°C ($K_{sp} = 4.3 \times 10^{-9}$). It is often used as an optical coating on lenses. Consider a saturated solution of SrF_2.

a. Write a chemical equation for the dissolution of strontium fluoride. (Remember to include the phase of matter [(s), (aq), (g), etc.] because they are incredibly important in solubility!)

b. What will happen when NaF(aq) is added to a saturated solution of SrF_2? Will the reaction shift to the left or to the right? Why?

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c. What will happen when a strong acid solution is added to a saturated solution of SrF_2? Will the reaction shift to the left or to the right? Why? Write the balanced chemical reaction for the addition of H^+ (aq) to saturated solution of SrF_2.

d. Calculate the molar solubility of SrF_2 in pure water at 25°C.

e. Calculate the molar solubility of SrF_2 in 0.020 M NaF at 25°C.

3. Does a precipitate of AgCl form when 100 mL of 1.5 M $AgNO_3$ is added to a beaker containing 1 L of water with a Cl^- ion concentration of 1.0×10^{-5} M at 25°C? K_{sp} (AgCl) = 1.6×10^{-10}

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4. Let's consider calcium hydroxide, $Ca(OH)_2(s)$, which has $K_{sp} = 8.0 \times 10^{-6}$.

a. Even though $Ca(OH)_2(s)$ is considered insoluble, is it still a strong base? Why or why not?

b. What is the pH of a saturated solution of $Ca(OH)_2(s)$ in water at 25°C?

c. Is $Ca(OH)_2(s)$ more soluble in acidic solutions or basic solutions? Why?

d. Let's say you have a 0.5 M solution of $CaCl_2$. What concentration of hydroxide ion (OH^-) needs to be added to begin precipitation of $Ca(OH)_2(s)$ at 25°C?

e. If you have an aqueous solution with a pH = 9.2, what concentration of $CaCl_2(aq)$ is needed to begin precipitation of $Ca(OH)_2(s)$ at 25°C?

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5. A solution is 0.1 M in Br^-, CO_3^{2-}, I^-, and SO_4^{2-} Rank the following compounds in order of precipitation as silver nitrate ($AgNO_3$) is added to the solution? (HINT: Write out the dissociations and equilibrium constant formulas!)

AgBr(s), $K_{sp} = 7.7 \times 10^{-13}$

Ag_2CO_3(s), $K_{sp} = 8.1 \times 10^{-12}$

AgI(s), $K_{sp} = 8.3 \times 10^{-17}$

Ag_2SO_4(s), $K_{sp} = 1.5 \times 10^{-5}$

6. Leaching is a method of extracting metals from sparingly soluble salts that can sometimes involve some pretty dangerous chemicals. Take, for instance, cyanide, a ligand that can be used to extract silver. What is the K_{eq} of the following reaction?

$$AgCl(s) + 2\ CN^-(aq) \rightleftharpoons [Ag(CN)_2]^-(aq) + Cl^-(aq)$$

K_{sp} of AgCl = 1.8×10^{-10}
K_f of $[Ag(CN)_2]^-$ = 3.0×10^{20}

7. Given what you know about ways to modulate solubility, which of the following would increase the molar solubility of $CuCO_3$ ($K_{sp} = 2.5 \times 10^{-10}$)?

i. Decrease the pH of the solution
ii. Add $CuCl_2$ to the solution
iii. Add Na_2CO_3 to the solution
iv. Add NH_3 to the solution

(K_f of $[Cu(NH_3)_4]^{2+} = 5.6 \times 10^{11}$)

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8. Equilibrium problems involving the formation of complex ions

a. The addition of 5 x 10^{-3} total moles of Zn^{2+} to a 1.0 L solution of NaCN gives a solution of the complex ion $[Zn(CN)_4]^{2-}$ ($K_f = 4.2 \times 10^{19}$). What is the concentration of uncomplexed Zn^{2+} ions at equilibrium if the concentration of cyanide ions in the final solution is 0.5 M?

b. $ZnCO_3$ is a sparingly soluble salt with a K_{sp} of 1.0×10^{-7}. The addition of CN^- (aq) to $ZnCO_3$(s) yields the complex ion $[Zn(CN)_4]^{2-}$(aq) with $K_f = 4.2 \times 10^{19}$. Write out the overall reaction below.

c. What will be the K_{eq} for this overall reaction?

d. What is the solubility of $ZnCO_3$ (s) in a solution of NaCN(aq) where the equilibrium concentration of cyanide in the solution is 0.2 M? Use the calculated K_{eq} in part c.

e. Why does ethylenediamine (en) have a much larger K_f than ammonia when forming a complex ion with metal cations?

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GROUP ACTIVITY

NAMES: _____

ACCESS IDS: _____

(such as abc12@psu.edu, NOT your 9 digit number)

Instructions:

- In a group of 4 or less, complete all parts of the following activity.
- You may finish outside of class.
- Please write legibly or we can't give you full credit.
- Every member needs to submit **their own copy** to Canvas by **11:59 PM** the day of your assigned Recitation.

Question 1: $HgBr_2$ is slightly soluble in water, with a K_{sp} of 6.20×10^{-20} at 298 K. Please analyze its solubility in a 0.35 M solution of KBr at this temperature.

- **Write the salt dissociation reaction for KBr.** Determine the initial concentration of the common ion.

- **Write the dissolution reaction and determine the molar solubility of $HgBr_2$ in the KBr solution.** (HINT: Use an ICE Table.)

- **Given that K_f of $[HgCl_4]^{2-}$ is 1.70×10^{16}, write the formation reaction.** Will the $HgBr_2$ dissolution reaction above shift left or right upon the addition of Cl^- to the solution? Does the addition of chloride ion increase or decrease the molar solubility of $HgBr_2$?

- **Calculate the K_{eq} for the reaction below. (HINT: Compare the formation reaction to the dissolution reaction.)** $HgBr_2\,(s) + 4Cl^-\,(aq) \rightleftharpoons 2Br^-\,(aq) + [HgCl_4]^{2-}\,(aq)$

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