UF UNIVERSITY of FLORIDA

Pre-Health Post-Baccalaureate Program
Study Guide and Practice Problems

Course: CHM2046

Textbook Chapter: 19.3 (Silberberg 6e)

Topics Covered: Equilibria of Slightly Soluble Ionic Compounds

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1. "Setting the Scene"

We have been talking about equilibrium of acid-base reactions for a few weeks now, and in this study guide, we will look at equilibrium and solubility. It's been a little while since we talked about solubility (ch. 13), and when talking about solubility in the context of equilibrium, we think about things slightly differently.

We previously classified some certain ionic compounds as "insoluble," but this isn't really true. Even these so-called "insoluble" compounds are very slightly soluble, and reach an equilibrium position in which the concentration of the solid is much, much greater than the concentration of dissociated ions.

2. Q and K, Back Again

Say that we have the following reaction, which represents a slightly soluble ionic compound, existing in equilibrium between the solid (left) and aqueous ions (right). For this example, M = metal and X = halogen:

$$MX_{2\,(s)} \rightleftharpoons M^{2+}_{(aq)} + 2X^{-}_{(aq)}$$

Like any other reaction at equilibrium, we can come up with an expression for Q:

$$Q_c = \frac{[M^{2+}][X^-]^2}{[MX_2]}$$

If we multiply both sides by the concentration of solid, we get the ion-product expression, Q_{sp}.

$$Q_{sp} = Q_c[MX_2] = [M^{2+}][X^-]^2$$

At equilibrium, as we've seen before, $Q_{sp} = K_{sp}$. This K value gives us an idea of how much a solid ionic compound has dissolved when the reaction has reached equilibrium (saturation).

We can use the same trick we learned in the ch. 17 study guide to determine which way the reaction is shifting given Q and K values.

First, align K before Q ("King before Queen")

Second, put in your greater than, equal to, or less than signs, according to what's given in the problem.

Third, if you have an equal sign, you know you're at equilibrium. If you have a greater than or less than sign, think of the sign as an arrow, where the direction of the arrow is the direction that the reaction is shifting as it approaches equilibrium.

Let's look at the following example. Would we expect to see the formation of calcium carbonate solid in our beaker if $Q_{sp} > K_{sp}$ for the reaction:

$$CaCO_{3(s)} \rightleftharpoons Ca^{2+}_{(aq)} + CO_{3}^{2-}{}_{(aq)}$$

Let's look at the solution:

$Q_{sp} > K_{sp}$, $\therefore$ $K_{sp} < Q_{sp}$

"Arrow" points left, which suggests we will see the formation of solid $CaCO_3$ until the solution is saturated.

3. Le Chat, Revisited

We previously talked about Le Châtelier's principle, so please review the ch. 17 study guide if you do not feel very confident on this topic (it's important this semester and moving forward!).

Le Chat guides a few different processes covered in this chapter, and the first is the common ion effect.

The common ion effect tells us that if we have a saturated solution of a slightly soluble salt, and then add a common ion in the form of another ionic compound to our solution, the reaction will shift back towards the products.

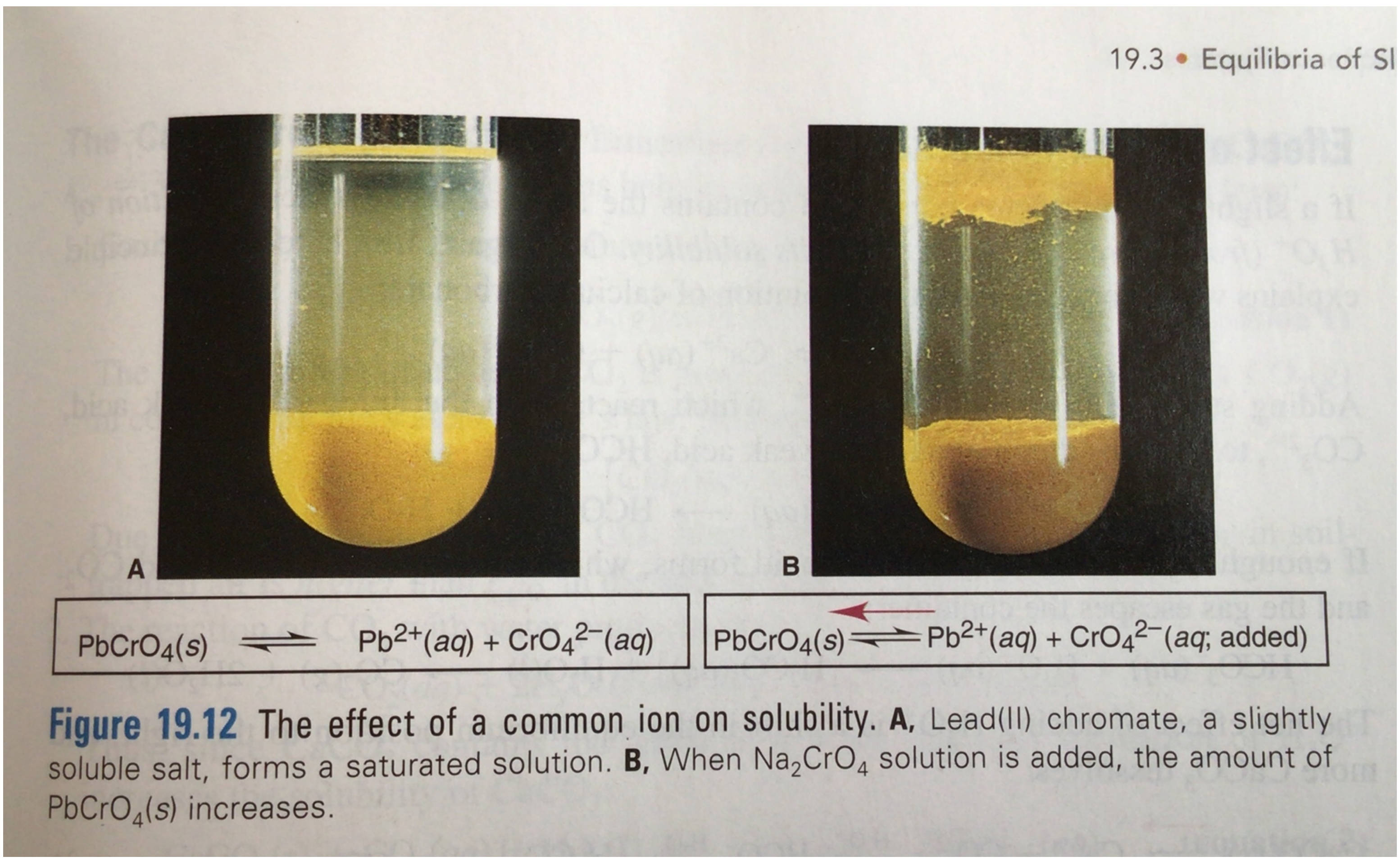

Figure 19.12 The effect of a common ion on solubility. A, Lead(II) chromate, a slightly soluble salt, forms a saturated solution. **B,** When Na_2CrO_4 solution is added, the amount of $PbCrO_4(s)$ increases.

Le Chat also tells us that adding aqueous strong acid (think H_3O^+) to a saturated solution that contains an anion of a weak acid (such as CO_3^{2-}) will shift the reaction towards the right, meaning more solid will dissolve.

Why is this? Because the acid reacts with the anion, decreasing the concentration of the dissolved anions in the solution. The sudden absence of dissolved ions forces the solid to be dissolved into ions (meaning, the reaction shifts right).

4. Selective Precipitation

This can be a confusing topic, and the textbook frankly does not do a good job at explaining it. I found this YouTube video to be incredibly helpful!

https://youtu.be/6kAAXXHc4w8

Problems

① What is the ion-product expression for a saturated solution of calcium phosphate?

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at equilibrium

Ion review:

Calcium phosphate = $Ca_3(PO_4)_2$

Equation:

$$Ca_3(PO_4)_2 \rightleftharpoons 3Ca^{2+} + 2PO_4^{3-}$$

$$Q_{sp_{eq}} = K_{sp} = [Ca^{2+}]^3[PO_4^{3-}]^2$$

(2) Lead (II) sulfate has a solubility in 25°c water of 4.25×10^{-3} g/100mL solution. What is its K_{sp}?

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$$1\,PbSO_{4\,(s)} \rightleftharpoons 1\,Pb^{2+}_{(aq)} + 1\,SO_{4\,(aq)}^{2-}$$

$$\frac{0.00425\,\cancel{g\,PbSO_4}}{} \left| \frac{1\text{ mol } PbSO_4}{303.3\,\cancel{g\,PbSO_4}} \right. = 1.4 \times 10^{-5}\text{ mol}$$

$$\frac{100\,\cancel{mL}}{} \left| \frac{1\text{ L}}{1000\,\cancel{mL}} \right. = 0.1\text{ L}$$

$$\frac{1.4 \times 10^{-5}\text{ mol}}{0.1\text{ L}} = 1.4 \times 10^{-4}\text{ M}$$

Because of 1:1 molar ratio:

$$[Pb^{2+}] = [SO_4^{2-}] = 1.4 \times 10^{-4}\text{ M}$$

$$K_{sp} = [Pb^{2+}][SO_4^{2-}]$$

$$= (1.4 \times 10^{-4})^2 = 1.96 \times 10^{-8}$$

3 Calculate the molar solubility of calcium hydroxide in water.

$K_{sp} = 6.5 \times 10^{-6}$.

③ Calculate the molar solubility of calcium hydroxide in water.

$K_{sp} = 6.5 \times 10^{-6}$.

	$Ca(OH)_{2(s)}$ $\rightleftharpoons$	$Ca^{2+}_{(aq)}$ +	$2HO^-_{(aq)}$
I	We don't care about the left side of this rxn.	0	0
C		$+x$	$+2x$
E		x	$2x$

$$K_{sp} = [Ca^{2+}][HO^-]^2 = 6.5 \times 10^{-6}$$

$$\Rightarrow x(2x)^2 = 6.5 \times 10^{-6}$$

$$\Rightarrow 4x^3 = 6.5 \times 10^{-6}$$

$$\Rightarrow x = \sqrt[3]{\frac{6.5 \times 10^{-6}}{4}}$$

$x = [Ca(OH)_2] = \text{solubility} = 1.2 \times 10^{-2}\ M$

4. How does the addition of H_3O^+ shift the reactions of the following ionic compounds? (multiple choice)

I. Lead (II) Bromide

a) Left

b) No shift

c) Right

II. Copper (II) Hydroxide

a) Left

b) No shift

c) Right

4. How does the addition of H_3O^+ shift the reactions of the following ionic compounds? (multiple choice)

I. Lead (II) Bromide

a) Left
b) No shift
c) Right

Br^- is the anion of a strong acid (HBr), which doesn't affect shift.

II. Copper (II) Hydroxide

a) Left
b) No shift
c) Right

HO^- is the anion of a very weak base (H_2O), which shifts towards increased solubility (right).