Experiment 8
The Solubility Products of Slightly Soluble Metal Hydroxides

Goals

To measure pH as a way to determine the solubility product constant, K_{sp}, for each of four metal hydroxides in water. To measure pH as a way to find the molar solubility of three metal hydroxide compounds in the presence of a common ion.

Introduction

Solubility products are the equilibrium constants for the aqueous dissolution of slightly soluble ionic solids into their component ions. Metal hydroxides dissociate into metal ions and hydroxide ions, For example, magnesium hydroxide:

$Mg(OH)_2(s)$	$\leftrightharpoons$	$Mg^{2+}(aq)$ +	$2OH^-$ (aq)	$K_{sp} = [M^{n+}][OH^-]^2$
magnesium hydroxide		magnesium ion	hydroxide ion	

Generally, solubility products are reported for room temperature (298 K).

The fact that hydroxide ions are produced when the compound dissolves means that the pH will change (increase). As more of the compound dissolves, the hydroxide concentration will rise, raising the pH of the solution.

Metal hydroxides, with a few exceptions, are only slightly soluble in water. This means that we can measure K_{sp} values for many of them and compare them to literature values. In this experiment, we will study the solubility of $Cu(OH)_2$, $Ca(OH)_2$, $Mg(OH)_2$, and $Ba(OH)_2$.

In the first part of the experiment, you will be provided with a saturated solution of each compound. Using a pH probe, you will measure the pH of the saturated solutions and use the information to calculate the hydroxide ion concentration. You will then use the hydroxide ion concentration of each solution to determine the solubility product of the metal hydroxide.

In Part 2 of the experiment, you will measure the pH of saturated solutions of $Ca(OH)_2$, $Mg(OH)_2$, and $Ba(OH)_2$ in the presence of a common ion. By adding metal chloride solutions we can increase the metal ion concentration. For example, if we add the very soluble $MgCl_2$ salt to a saturated solution of slightly soluble $Mg(OH)_2$, we can test to see if the $MgCl_2$ affects the solubility of $Mg(OH)_2$. Magnesium ion is called a common ion because it is present in both $Mg(OH)_2$ and $MgCl_2$

Chemicals and Equipment Chemicals Equipment

Saturated $Cu(OH)_2$	0.01M $MgCl_2$	Vernier LabPro
Saturated $Ca(OH)_2$	0.5 M $CaCl_2$	pH probe
Saturated $Ba(OH)_2$	1.5M $BaCl_2$	4- 50 mL beakers
Saturated $Mg(OH)_2$	pH 7 and pH 10 buffers	Funnel with paper
		100 mL graduated cylinder

Safety: Work with metal hydroxide solutions requires use of safety goggles, laboratory coats, and gloves. Waste materials should be disposed of in the appropriate waste container.

Experimental Procedure

Part I: Determination of the K_{sp} for $Cu(OH)_2$,$Ca(OH)_2$, $Mg(OH)_2$, and $Ba(OH)_2$

1. Pour 20 mL of filtered saturated $Cu(OH)_2$ solution into a 50 mL beaker using a 100-mL graduated cylinder. The filtering can be done using a filter paper placed in a funnel assembled on a ring stand.

2. You will use a Vernier LabPro unit with a pH probe. You can use the live readout for pH measurements.

3. Calibrate the pH probe using the pH 7 buffer and a pH 10 buffer as your two calibration points. You should have performed a calibration in a previous experiment.

4. Measure and record the pH of the saturated copper (II) hydroxide solution.

5. Rinse the pH probe with distilled water, use a Kimwipe to gently wipe off the drop of distilled water that remains on the tip of the probe, and repeat the pH measurement a second time.

6. Rinse the pH probe with distilled water, use a Kimwipe to gently wipe off the drop of distilled water that remains on the tip of the probe, and repeat the pH measurement a third time. You won't use this solution in Part 2 so you can dispose of it in the proper waste container.

Your final pH will be recorded as the *average* of your three pH measurements.

7. Repeat step 6 using saturated $Ca(OH)_2$, $Mg(OH)_2$, $Ba(OH)_2$ solutions. Do not throw out these three solutions because you will be using them in Part 2.

Part II: Determination of the effect of common ions on the solubility of hydroxide solutions
Experimental Procedure
1. Add 20 mL of 0.5 M calcium chloride to the 20 mL of saturated calcium hydroxide
2. Add 20 mL of 1.5 M barium chloride to the 20 mL of saturated barium hydroxide
3. Add 20 mL of 0.01 M magnesium chloride to the 20 mL of saturated magnesium hydroxide
4. As you did in step 6 of Part 1, measure the pH of each of the three solutions.

Data

Your name___________________________________

Your partner's name___________________________

Part 1: Saturated metal hydroxide solutions

	pH	***pH***	***pH***	***Average pH***
$Mg(OH)_2$				
$Ca(OH)_2$				
$Ba(OH)_2$				
$Cu(OH)_2$				

Part 2: Saturated metal hydroxide solutions with common ion

Concentrations of solutions in bottles in moles/liter

[$MgCl_2$]___________________

[$CaCl_2$] ___________________

[$BaCl_2$] __________________

	pH	***pH***	***pH***	***Average pH***
$MgCl_2$(aq) and $Mg(OH)_2$				
$CaCl_2$(aq) and $Ca(OH)_2$				
$BaCl_2$(aq) and $Ba(OH)_2$				

Calculations

Part 1: Saturated metal hydroxide solutions

Step 1. First we will determine the concentration of hydroxide ion in the solution. You measured the pH of each solution. You can calculate the pOH from the average pH for each solution. *Show you work for each step below* and fill in the table:

pH + pOH = 14.00

Table 1	*pOH*
$Mg(OH)_2$	
$Ca(OH)_2$	
$Ba(OH)_2$	
$Cu(OH)_2$	

Step 2: Next we find the concentration of hydroxide ion from the pOH. Show you work for each step below and fill in the table:

$[OH^-] = 10^{-pOH}$

Table 2	*$[OH^-]$*
$Mg(OH)_2$	
$Ca(OH)_2$	
$Ba(OH)_2$	
$Cu(OH)_2$	

Would this procedure work for finding the solubility product of other compounds like $CaCO_3$? Explain in 2-4 sentences.

Step 3: Now we determine the molar solubility of each compound. We will use $Mg(OH)_2$ as an example. Show all calculations below (including all reaction tables) and fill out the table. Remember that solids do not appear in the reaction table:

	$Mg(OH)_2$ (s) →	Mg^{2+} (aq) +	$2OH^-$ (aq)	
Initial		0	0	
Change		+x	+2x	*because $Q < K_{sp}$*
Equilibrium		x	2x	

The equilibrium concentrations are: $[OH^-] = 2x$ and $[Mg^{2+}] = x$ so $Mg^{2+} = ½[OH^-]$

We know $[OH^-]$ so we can find x and 2x

Table 3	*$[OH^-] = 2x$*	*$[Mg^{2+}] = x$*
$Mg(OH)_2$		
$Ca(OH)_2$		
$Ba(OH)_2$		
$Cu(OH)_2$		

Step 4: Now we can calculate K_{sp} for each compound. Use x and 2x to calculate K_{sp}. Again, we will use $Mg(OH)_2$ as an example. Show all work below and fill out the table.

$$Mg(OH)_2\ (s) \rightarrow Mg^{2+}\ (aq) + 2OH^-\ (aq) \qquad K_{sp} = [Mg^{2+}][OH^-]^2 = x(2x)^2$$

Table 4	*$[OH^-] = 2x$ (copy from Table 3)*	*$[Mg^{2+}] = x$ (copy from Table 3)*	*K_{sp}*
$Mg(OH)_2$			
$Ca(OH)_2$			
$Ba(OH)_2$			
$Cu(OH)_2$			

Part 1: Percent errors

Step 5: Below are literature values of K_{sp} for our compounds at 298 K. Fill in the experimental K_{sp} values you calculated in Step 4. Then do percent error calculations for each compound. Show all work below and fill out the table.

Table 5	***Literature value***	***Experimental value (from step 4)***	***% error***
Magnesium hydroxide	*5.5×10^{-6}*		
Calcium hydroxide	*1.2×10^{-11}*		
Barium hydroxide	*2.6×10^{-4}*		
Copper (II) hydroxide	*1.6×10^{-19}*		

Part 2: Common ion effect (calculations)

Step 1: Now we will determine the effect of adding a common ion to each of the metal hydroxide solutions. Just like in part 1 we begin with pH. Convert to pOH. Use average pH values. Show all work below and fill out the table.

pH + pOH = 14.00

Table 1	*pOH*
$MgCl_2$ and $Mg(OH)_2$	
$CaCl_2$ and $Ca(OH)_2$	
$BaCl_2$ and $Ba(OH)_2$	

Part 2: Common ion effect (calculations)

Step 2: Next we find the concentration of hydroxide ion from the pOH. Show you work for each step below and fill in the table:

$[OH^-] = 10^{-pOH}$

Table 2	*$[OH^-]$*
$MgCl_2$ and $Mg(OH)_2$	
$CaCl_2$ and $Ca(OH)_2$	
$BaCl_2$ and $Ba(OH)_2$	

Part 2: Common ion effect (calculations)

Step 3: Now we determine the molar solubility of each compound. We can use $Mg(OH)_2$ as an example. Remember that solids do not appear in the reaction table. The initial concentration of $MgCl_2$ is half of the stock solution because you add 20 mL of the magnesium chloride solution to 20 mL of the saturated $Mg(OH)_2$ solution, effectively halving its concentration. Show all calculations below (all reaction tables) and fill out the table. Remember to halve the concentration of each metal hydroxide solution:

	$Mg(OH)_2\,(s) \rightleftharpoons$	$Mg^{2+}\,(aq)$ +	$2OH^-\,(aq)$	$K_{sp} = [Mg^{2+}][OH^-]^2$
Initial:		*0.005M*	*0*	
Change:		*x*	*+2x*	*because $Q < K_{sp}$*
Equilibrium:		*0.005M+x*	*2x*	

$[OH^-] = 2x$ so $Mg^{2+} = 0.005 + \frac{1}{2}[OH^-]$

We know $[OH^-]$ so we can find x and 2x

Table 3	*$[OH^-] = 2x$*	*$[Mg^{2+}] = 0.005 + x$*
$MgCl_2$ and $Mg(OH)_2$		
$CaCl_2$ and $Ca(OH)_2$		
$BaCl_2$ and $Ba(OH)_2$		

Part 2: Common ion effect (calculations)

Step 4: Now we can calculate K_{sp} for each compound. Use 0.005+x and 2x to calculate K_{sp}. Again, we will use $Mg(OH)_2$ as an example. Show all work below and fill out the table.

$Mg(OH)_2\ (s) \leftrightharpoons Mg^{2+}\ (aq) + 2OH^-\ (aq)$ $\qquad$ $K_{sp} = [Mg^{2+}][OH^-]^2 = (0.005 + x)(2x)^2$

Table 4	*$[OH^-] = 2x$ (copy from previous table)*	*$[Mg^{2+}] = 0.005 + x$ (copy from previous table)*	K_{sp}
$Mg(OH)_2$			
$Ca(OH)_2$			
$Ba(OH)_2$			

Part 2: Common ion effect (calculations)

Step 5: Here are literature values of K_{sp} for our compounds at 298 K. Fill out the experimental K_{sp} values you calculated (from Table 4). Then do percent error calculations for each compound. Show all work below and fill out the table.

Table 5	***Literature value***	***Experimental value***	***% error***
Magnesium hydroxide	*5.5×10^{-6}*		
Calcium hydroxide	*1.2×10^{-11}*		
Barium hydroxide	*3.0×10^{-4}*		
Copper (II) hydroxide	*1.6×10^{-19}*		

Consider the following statement. "*A higher pH implies that the metal hydroxide is more soluble than a metal hydroxide that gives a lower pH.*" Do your data and results agree with this statement? Explain in 2-4 sentences. Consider Tables 1 and 5 when answering this question.

Part 2: Common ion effect   (calculations)

Step 6: Here we can compare the results of Part 1 and Part 2 for three of the metal hydroxides. Enter the experimental K_{sp} values for each part you performed in the table below.

Table 6	***K_{sp}* (Part 1)**	***K_{sp}* (Part 2)**
Magnesium hydroxide		
Calcium hydroxide		
Barium hydroxide		

Step 7: Now let's look at molar solubility. For each trial the *molar solubility is x*. Enter the value of x for each metal hydroxide in Part 1 and Part 2. Remember that x was something you calculated in each part earlier. We will ignore copper (II) hydroxide for this step.

Table 7	***Molar solubility (Part 1)***	***Molar solubility (Part 2)***
Magnesium hydroxide		
Calcium hydroxide		
Barium hydroxide		

Answer the question below. Was the molar solubility x higher or lower in Part 2 compared to Part 1? Explain why in 2-5 sentences.

Step 8: pK_{sp} is a measure of the K_{sp} and sometimes better for making comparisons

pK_{sp} is calculated just like pH, pOH, or pK_a:

$pK_{sp} = -\log(K_{sp})$

Make a new table with the pK_{sp} values for the literature values (from Part 1 only) and the values for your data. The literature values are done for you, but it's a good idea to check for yourself that the pK_{sp} values are correct. Fill in the table and show all calculations below.

Table 8	***K_{sp} (literature value)***	***pK_{sp} (literature value)***	***Experimental K_{sp} (Part 1)***	***pK_{sp} (Part 1)***
Magnesium hydroxide	*5.5×10^{-6}*	*5.26*		
Calcium hydroxide	*1.2×10^{-11}*	*10.92*		
Barium hydroxide	*3.0×10^{-4}*	*3.52*		

Is a higher pK_{sp} imply a more soluble or less soluble compound than a lower pK_{sp}? Explain in 2-4 sentences.

Step 9: Perform % error calculations using the literature pK_{sp} values and the experimental pK_{sp} values. Fill out the table and show the calculations below.

Table 9	***pK_{sp}* (literature value)**	***pK_{sp}* (Part 1)**	***% error***
Magnesium hydroxide	*5.26*		
Calcium hydroxide	*10.92*		
Barium hydroxide	*3.52*		

Answer the question: *Was the % error using pK_{sp} values higher or lower than for K_{sp} values? Explain in 2-4 sentences why you think that may be the case.*