Equilibrium Exercises

This experiment was written by Joe March and revised by Gordon Bain.
It was then adapted to be used for visually impaired and blind students by Lisa Goetter.

Introduction

This experiment has been adapted to enhance the lab experience of visually impaired and blind students. It uses 2 special tools: the SALS Device and a light box. If you are unfamiliar with using the SALS Device you may want to try one of our more basic laboratory experiments to practice with it before performing this experiment (see *Concentration and Color*).

SALS Device Tips:

- Be sure that the SALS probe is at the same depth when taking readings of the solutions
- The solutions used throughout the experiment should be close to the same volume
- There are two memory spaces on the device: Memory 1 and Memory 2. Each Memory holds one tone, therefore whenever you save a tone in one of the memories any other tone previously saved to that same memory will be erased.
- Always save the beakers of solution in case you forget to save the tone or need to refer back to that solution at a later point in the experiment

Purpose of the Experiment

To build on your understanding of the applications of the common ion effect.
To build on your skills of recording observations.
To investigate the relative solubility of salts of a single metal ion.
To acquire a greater understanding of relative solubility.
To learn about the distinction between K_{sp} and molar solubility.
To introduce the use of indicators to study acid/base equilibria.

Materials

Solutions:

1 M Na_2SO_4
0.5 M $CaCl_2$
0.5 M $BaCl_2$
0.2 M K_3PO_4
0.2 M $AgNO_3$

0.2 M NaCl
0.2 M Na_2S
6 M NH_3
Saturated $Ca(OH)_2$ solution
Methyl orange indicator solution
Phenolphthalein indicator solution
Bromocresol green indicator solution
6 M HCl
6 M NaOH
0.1 M $NaC_2H_3O_2$
1 M $HC_2H_3O_2$ (acetic acid)

Materials:

Deionized/distilled water
Large beaker
3 Large test tubes
Graduated cylinder
Stirring hot plate
Ring stand with 3 prong clamp
Light box
SALS Device
Pen
7 10mL beaker
2 30mL beaker
Glass stir rod
Plastic pipette
White piece of paper
1 150mL beaker
Dry ice (CO_2 (s))

For Your Safety

Do not allow any of the solutions to come into contact with your skin. Silver solutions may discolor your skin.

Disposal

All aqueous chemicals used in this experiment may be disposed of in the sink.

Preparing Yourself for this Experiment

In your notebook, prepare a short summary of the experiment, listing the reactions to be studied. Look up and tabulate the K_{sp} values of all the chemicals you will use *or might precipitate* in Parts 1 and 2 of the experiment. You may need to go to the CRC Handbook of Chemistry and Physics (Reference section, Chemistry Library) for some values which are not contained in the appendix of your textbook.

Note: As experimental methods improve, the accepted values for some sparingly soluble salts are changing, even with respect to the values of just a few years ago. In the event of a conflict between the data in your textbook and those found in the most recent edition of the CRC Handbook (currently the 84th editions), rely on the CRC Handbook.

Pre-Lab Assignment

a) List the three silver compounds you will precipitate in this experiment and rank them in order of K_{sp} (from most soluble to least soluble).
b) Calculate the molar solubilities of the three silver compounds and rank them in order of molar solubility (from most soluble to least soluble).

Experimental

Part 1 – Equilibrium between a solid precipitate and its ions, 1.

1. Set up a hot water bath.

2. Place 4mL of 1 M Na_2SO_4 (aq) in a large test tube. Using a similar test tube, place 4mL of 1 M Na_2SO_4 (aq) in it to be used later (Step 5) as a control to compare final solution. Set this test tube aside.

3. Rapidly add 8mL of 0.5 M $CaCl_2$ (aq). Slowly, add 4mL more of the $CaCl_2$ (aq) solution.

4. Place the test tube in the hot water bath and heat the mixture for about 30 minutes. (Complete the other exercises while you wait.)

5. Tap the test-tube with a pen for 10 seconds to dislodge any gas bubbles attached to the tube walls. Take this test tube and the control test tube (from step 2) to the light box and listen to the tones of both (you may want to set the test tubes in a large, clear, colorless beaker when using the light box). Save the control test tube in Memory 1 and the reacted solution in Memory 2. Allow the mixture to cool, then add 10 more drops of $CaCl_2$ (aq) and allow the mixture to stand (approx. 5 minutes). This is to ensure all solid is precipitated out of solution. Take the test tube to the light box and listen to the tone emitted from the SALS Device. Be sure to save this tone in Memory 2. Compare to the original solution saved in Memory 1.

6. Decant the clear solution into a new test tube. Moving to the light box, use the SALS Device to listen to the tone in this new test tube of solution. Save this solution in Memory 1.

7. Add 4mL of 0.5 M $BaCl_2$ (aq) to the clear solution. Then, using the SALS, listen to the tone this solution emits and compare it to Memory 1 and Memory 2.

Question 1

Solubility of sulfate salts. Use your knowledge of solubility equilibria to *explain* your observations in Part 1. Include the equilibrium equations and equilibrium constants (solubility constants) for all the precipitation reactions you observed to support your explanation.

Part 2 – Equilibrium between a solid precipitate and its ions, 2.

1. Place 3mL of 0.2 M K_3PO_4 (aq) in a small (10mL) beaker. Play the tone using the SALS Device and light box. Save in Memory 1.

2. Add 3mL of 0.2 M $AgNO_3$ (aq) to the beaker. With the beaker on the light box, use the SALS Device to play this tone and compare it to the solution from Part 2, Step 1 which is saved in Memory 1. SAVE THIS BEAKER OF SOLUTION!!

3. Repeat steps one and two replacing K_3PO_4 with 0.2 M NaCl (aq), and then repeat again using Na_2S (aq) instead of NaCl. Using your three saved beakers of solution, compare each one with each other (using the SALS Device and light box) to hear the difference between the precipitates formed by adding $AgNO_3$ (aq) to the different starting materials.

4. Write the formula of the precipitate formed in each of the three 10mL beakers and write the net ionic equation for each reaction.

5. To a new 30mL beaker, add 3mL of 0.2 M K_3PO_4 (aq) and 4.5mL of water. Move to the light box and using the SALS Device listen to the tone and save it in Memory 1. Add 9mL of $AgNO_3$ (aq), mix thoroughly. Use the SALS Device and light box to listen to the tone emitted by this solution. Save this tone in Memory 2. Then, allow the precipitate to settle to the bottom of the beaker (let stand approx. 5 minutes). Decant the supernatant (the liquid above the solid) and save the solid. (If a centrifuge is available, you may separate the solid from the solution by centrifuging).

6. Add 9mL of 0.2 M NaCl(aq) to the solid from the last step. Re-suspend the solid by stirring the beaker for 30 seconds. Move the beaker to the light box and using the SALS Device listen to the tone this makes. Compare this solution to the original solution saved in Memory 1 and the reacted solution (from step 5) saved in Memory 2. Record your observations. Then save this solution in Memory 2.

7. After the suspension has been allowed to stand for 4 minutes, very gradually add 15mL of 6 M NH_3 (aq) while stirring. Continue stirring for 3 more minutes after adding the 15mL of NH_3. Use the SALS Device and light box to listen to the tone this solution makes and compare to the solutions saved in Memory 1 and Memory 2. Record your observations.
   ***Keep the solution on the light box and the SALS probe inserted into the solution for Step 8.

8. Using a plastic pipette, add 0.2 M Na_2S (aq) dropwise to the solution while holding down the play button until a change is heard with the SALS Device. This will happen rapidly so be sure to only add one drop at a time. Compare this solution to the others saved in Memory 1 and Memory 2. Record your observations.

Question 2
Solubility of Silver Compounds.

i) Rank the three silver compounds in order of solubility (from most soluble to least soluble) according to your observations.

ii) Is either ranking order from the pre-lab assignment supported by your experimental results? Explain why the ranking order in (i) agrees or disagrees with (a) or (b) in the pre-lab.

Part 3 – Using indicators to observe equilibria

a) Observing indicators – This part of the experiment will NOT be performed on a light box! Set all solutions on a plain, white piece of paper when testing them with the SALS Device.

   1. Place two drops of methyl orange indicator solution into two 10mL beakers.

   2. Add 5mL of 6 M HCl (aq) to one of the beakers with the indicator solution.

   3. Add 5mL of 6 M NaOH (aq) to the other beaker. Move both beakers to the sheet of white paper - be careful not to confuse the two beakers, and play the tones using the SALS Device. Compare both solutions to each other. Record your observations. ***SAVE THESE SOLUTIONS FOR COMPARISON IN PART 3b!

   4. In two new 10mL beakers, place 6 drops of phenolphthalein.
   5. In one of the 10mL beakers, add 5mL of 6 M HCl, stir.

6. In the other 10mL beaker, add 5mL of 0.12 M NaOH (make this solution using 5mL of 6 M NaOH in 250mL of water). Move both beakers to the white paper - be careful not to confuse the two beakers, and play the tones using the SALS Device. Compare both solutions to each other. Record your observations.
   ***SAVE THESE SOLUTIONS FOR COMPARISON IN PART 3b!

7. Repeat steps 4-6 using ***10 drops*** of *bromocresol green indicator* instead of phenolphthalein.
   ***SAVE THESE SOLUTIONS FOR COMPARISON IN PART 3c!

b) <u>Equilibrium between a solid precipitate and its ions, 1.</u> - This part of the experiment will NOT be performed on a light box! Set all solutions on a plain, white piece of paper when testing them with the SALS Device.

1. Place 50mL of water in a 150mL beaker and add 2 drops of methyl orange indicator. Then pour approx. 5mL of the solution into a 10mL beaker. Use the SALS Device on the white sheet of paper to play the tone of the solution in the 10mL beaker and save it in Memory 1. Compare this to the methyl orange indicator solutions from Part 3a to determine whether the solution is acidic or basic.

2. Add two small pieces of dry ice (CO_2 (s)). After the dry ice has disappeared – wait approx. 10 minutes for this to occur, pour approx. 5mL of the solution into a 10mL beaker. Use the SALS Device and white sheet of paper to play the tone of the solution in the 10mL beaker and compare to the solution saved in Memory 1. Save this solution in Memory 2. In addition, compare to the methyl orange indicator solutions from Part 3a to determine which direction (more acidic or more basic) the solution shifted.
   **Save this beaker of solution to compare to the solution of $Ca(OH)_2$

3. Repeat this experiment (steps 1 and 2 of part b), but place a solution of $Ca(OH)_2$ in the beaker instead of the water. Compare the solutions of water and $Ca(OH)_2$ to one another using the SALS Device *before and after* the dry ice has reacted in them (you can compare the *before* by using the tone saved in Memory 1 from the initial water solution).

4. Repeat the two experiments above using 10 drops phenolphthalein as the indicator instead of the 2 drops of methyl orange. Be sure to compare the solutions to the phenolphthalein indicator solutions from Part 3a instead of the methyl orange solutions.

Question 3

LeChatelier's Principle. The addition of CO_2 (s) to the calcium hydroxide solution involves several equilibria. Use your observations regarding the dry ice exercises to describe, in terms of LeChatelier's Principle, how pH and the rate of gas

evolution are affected by the presence of $Ca(OH)_2$. (Hint: Consider the equilibrium when CO_2 dissolves in water, and the equilibria for reactions between each species in that reaction and Ca^{2+} or OH^-.)

c) Acid-base equilibria – This part of the experiment will NOT be performed on a light box! Set all solutions on a plain, white piece of paper when testing them with the SALS Device.

Use your observations from the indicator exercise to approximate the pH of each solution before and after each addition.

1. Place 3mL of 0.1 M $NaC_2H_3O_2$ (aq) in two different 10mL beakers. To each beaker add ten drops bromocresol green. Place one of the beakers on top of the white piece of paper. Using the SALS Device, play the tone of this solution and save it in Memory 1. Compare this to the bromocresol green solutions from Part 3a. Determine where the pH falls.
   ***Save this solution to compare all three solutions created in part 3c.

2. To one of the 10mL beakers, add 1 M acetic acid (aq) dropwise (max. 12 drops). Mix the solution after adding each drop. Place the beaker on the white sheet of paper and, using the SALS Device, play the tone of this solution and save it in Memory 2. Compare this tone to the bromocresol green solutions from Part 3a. Approximate where the pH falls from this comparison.
   ***Save this solution to compare all three solutions created in part 3c.

3. To the other 10mL beaker, add 6 M HCl (aq) dropwise (max. 12 drops). Mix the solution after adding each drop. Place the beaker on the white sheet of paper and, using the SALS Device, play the tone of this solution and save it in Memory 1. Compare this tone to the bromocresol solutions from Part 3a and the other two solutions from Part 3c (one is saved in Memory 2 and the other will need to be replayed with the SALS). Approximate where the pH falls from this comparison.

Question 4

Sodium Acetate in Water

(i) Write the equilibrium equation for the reaction of $NaC_2H_3O_2$(aq) with water to form $HC_2H_3O_2$ and OH^-. Use your observations to describe how the addition of HCl (aq) affects this equilibrium.

(ii) When you have added slightly more than an *equimolar* amount of HCl to the sodium acetate solution, have you formed a buffer solution? Explain.

(iii) When you have added slightly more than an *equimolar* amount of acetic acid to the sodium acetate solution, have you formed a buffer solution? Explain.