Lab #9: Chemical Equilibrium

Objective:
To observe and explain the effect of an applied stress on chemical systems at equilibrium by applying the Le Châtelier's Principle.

Background Information:
In this lab, the effect of applying stresses to a variety of chemical systems at equilibrium will be explored. The equilibrium systems to be studied are given below:

1. **Saturated Sodium Chloride Solution:** $NaCl_{(s)} \rightleftharpoons Na^+_{(aq)} + Cl^-_{(aq)}$
2. **Acidified Chromate Solution:** $2\ CrO_4^{2-}{}_{(aq)} + 2\ H^+_{(aq)} \rightleftharpoons Cr_2O_7^{2-}{}_{(aq)} + H_2O_{(l)}$
   (yellow) (acid) (red)
3. **Ammonia Solution (with phenolphthalein):** $NH_{3\,(aq)} + H_2O_{(l)} \rightleftharpoons NH_4^+ + OH^-_{(aq)} + \text{Heat}$
   (NH_3 clear in phenolphthalein) (OH^- is pink in phenolphthalein)
4. **Cobalt (II) Chloride Solution:** $Co(H_2O)_6^{2+}{}_{(aq)} + 4\ Cl^-_{(aq)} \rightleftharpoons CoCl_4^{2-}{}_{(aq)} + 6\ H_2O_{(l)}$
   (reddish-pink) (blue)
5. **Iron (III) Thiocyanate Solution:** $Fe^{3+}_{(aq)} + SCN^-_{(aq)} \rightleftharpoons Fe(SCN)^{2+}_{(aq)} + \text{Heat}$
   (pale yellow) (colourless) (deep red)

By observing the changes that occur (colour changes, precipitate formation, etc.) the direction of a particular shift may be determined. Such shifts may then be explained by carefully examining the effect of the applied stress as dictated by Le Châtelier's Principle.

Hypotheses:
Predict the *shift in equilibrium* **and** *possible observations* for the following situations.

1. **Saturated Sodium Chloride Solution:** $NaCl_{(s)} \rightleftharpoons Na^+_{(aq)} + Cl^-_{(aq)}$
   a. Adding $HCl_{(aq)}$
2. **Acidified Chromate Solution:** $2\ CrO_4^{2-}{}_{(aq)} + 2\ H^+_{(aq)} \rightleftharpoons Cr_2O_7^{2-}{}_{(aq)} + H_2O_{(l)}$
   (yellow) (acid) (red)
   a. Adding $HNO_{3\,(aq)}$ first b. Adding $NaOH_{(aq)}$ after in the same test tube ($H^+ + OH^-$ forms H_2O)
3. **Ammonia Solution (with phenolphthalein):** $NH_{3\,(aq)} + H_2O_{(l)} \rightleftharpoons NH_4^+ + OH^-_{(aq)} + \text{Heat}$
   (NH_3 clear in phenolphthalein) (OH^- is pink in phenolphthalein)
   a. Adding $NH_4Cl_{(s)}$ b. Decreasing Temperature c. Increasing Temperature
4. **Cobalt (II) Chloride Solution:** $Co(H_2O)_6^{2+}{}_{(aq)} + 4\ Cl^-_{(aq)} \rightleftharpoons CoCl_4^{2-}{}_{(aq)} + 6\ H_2O_{(l)}$
   (reddish-pink) (blue)
   a. Adding $H_2O_{(l)}$ b. Adding $HCl_{(aq)}$ c. Adding $AgNO_{3\,(aq)}$
5. **Iron (III) Thiocyanate Solution:** $Fe^{3+}_{(aq)} + SCN^-_{(aq)} \rightleftharpoons Fe(SCN)^{2+}_{(aq)} + \text{Heat}$
   (pale yellow) (colourless) (deep red)
   a. Adding $Fe(NO_3)_{3\,(aq)}$ b. Adding $KSCN_{(aq)}$
   c. Adding $K_2HPO_{4\,(aq)}$ ($HPO_4^{2-}{}_{(aq)}$ and $Fe^{3+}_{(aq)}$ forms a complex $FeHPO_4^+{}_{(aq)}$)
   d. Decreasing Temperature

Materials:

10 Small Test Tubes	Stirring Rods	6 M $HNO_{3\,(aq)}$	0.1 M $AgNO_{3\,(aq)}$
Test Tube Racks	Medicine Droppers	6 M $NaOH_{(aq)}$	0.1 M $Fe(NO_3)_{3\,(aq)}$ ❖
Hot Plate	Ice and Water	Diluted $NH_{3\,(aq)}$ *	0.1 M $KSCN_{(aq)}$ ❖
3 Beakers (250 mL)	Saturated $NaCl_{(aq)}$	$NH_4Cl_{(s)}$	0.1 M $K_2HPO_{4\,(aq)}$
Test Tube Clamps	Phenolphthalein	0.1 M $K_2CrO_{4\,(aq)}$ ♣	0.1 M $K_2Cr_2O_{7\,(aq)}$ ♣
Scoopula	12 M $HCl_{(aq)}$	0.1 M $CoCl_{2\,(aq)}$ †	0.2 M $KCl_{(aq)}$ †

♣ To make the acidify chromate solutions, combine equal volumes of 0.1 M of $K_2CrO_{4\,(aq)}$ and 0.1 M $K_2Cr_2O_{7\,(aq)}$. Add about one-tenth of the original volume of 6 M $HNO_{3\,(aq)}$. The initial colour of the final solution should be orange.

* Prepare a stock solution by adding 4 drops of concentrated 6 M $NH_{3\,(aq)}$ and 3 drops of phenolphthalein to a medium beaker, then topping it up with 250 mL of water. Mix with a stirring rod. The entire class can share this stock solution.

† $CoCl_{2\,(s)}$ forms complex ions, $Co(H_2O)_6^{2+}{}_{(aq)}$ and $CoCl_4^{2-}{}_{(aq)}$, when dissolves in water. An equilibrium cobalt (II) chloride solution with its complex ions can be prepared by mixing twice equal volume of 0.1 M $CoCl_{2\,(aq)}$ with 0.2 M $KCl_{(aq)}$.

❖ Prepare a stock solution of iron (III) thiocyanate by adding 10 mL of 0.1 M $FeCl_{3\,(aq)}$ and 10 mL of 0.1 M $KSCN_{(aq)}$ to a medium beaker, then topping it up with 100 mL of water. Mix with a stirring rod. The entire class can share this stock solution.

Procedure:

Record all observations on your report form. These should include, but not be limited to, colour changes and precipitates. Note that solution volumes are approximate for all reactions below. Dispose of all chemical waste in the plastic container in the fume hood.

Safety

All of the acids and bases used in this experiment ($HCl_{(aq)}$, $HNO_{3\,(aq)}$ and $NaOH_{(aq)}$) can cause chemical burns. In particular, concentrated 12 M HCl and 6 M HNO_3 are extremely dangerous! If any of these chemicals spill on you, immediately rinse the affected area under running water and notify your instructor. Also note that direct contact with silver nitrate ($AgNO_3$) will cause dark discolourations to appear on your skin. These spots will eventually fade after repeated rinses in water. Finally, in Parts 3, 4 and 5, you will be heating a solution in a test tube directly in a Bunsen Burner flame. If the solution is overheated it will splatter out of the tube, so be careful not to point the tube towards anyone while heating.

Part 1: Saturated Sodium Chloride Solution (**Demo**: 1 test tube)

1. Place 2 mL (about the width of a thumb nail) of saturated $NaCl_{(aq)}$ into a small test tube. Record the initial observation.
2. **(Demo)** Observe as your instructor ***carefully*** add the concentrated 12 M $HCl_{(aq)}$ drop-wise to the test tube containing the saturated $NaCl_{(aq)}$ until a distinct change occurs. Record your observations.

Part 2: Acidified Chromate Solution (**Demo**: 1 test tube)

1. Place about 2 mL (about the width of a thumb nail) of 0.1 M $K_2CrO_{4\,(aq)}$ / $K_2Cr_2O_{7\,(aq)}$ into a small test tube. Record the initial observation.
2. ***Carefully*** add concentrated 6 M $HNO_{3\,(aq)}$ drop-wise to this solution. Record your observations.
3. To the same test tube, ***carefully*** add concentrated 6 M $NaOH_{(aq)}$ drop-wise until a distinct change occurs. Record your observations.

Part 3: Aqueous Ammonia Solution (2 test tubes)

1. To each of the two test tubes, place 2 mL (about the width of a thumb nail) of the previously diluted $NH_{3\,(aq)}$ solution with phenolphthalein. Label these test tubes #1 & #2. Record the initial observation.
2. Add a medium scoop of $NH_4Cl_{\,(s)}$ powder to test tube #1 until it is completely dissolve. Record your observations.
3. Take test tube #2 and add a few drops of phenolphthalein and place it in the beaker full of ice. Wait until a distinct change occurs. Be patient. Record your observations.
4. Prepare hot water bath by placing about 200 mL of water in a 250 mL beaker and heat it up over the hot plate. Turn the heat down once the water boils. Take the previous test tube #2 from the beaker of ice. Firmly hold it with the test tube clamp, and place it in the hot water bath for about 2 minutes, or, until a distinct change occurs. Record your observations. Place the test tube in a beaker of room temperature water when finished. Remove the test tube clamp from the test tube only when it is cooled.

Part 4: Cobalt (II) Chloride Solution (3 test tubes)

1. To each of the three test tubes, place 2 mL (about the width of a thumb nail) of 0.1 M $CoCl_{2\,(aq)}$. Label these test tubes 3 to 5. Record the initial observation.
2. The solution in test tube #3 remains untouched. It is a control for comparison with other tubes.
3. Add about 4 mL of water to one of the test tube #4. Record your observations.
4. **(Demo)** Observe as your instructor ***carefully*** add the concentrated 12 M $HCl_{\,(aq)}$ drop-wise to a test tube containing the 0.1 M $CoCl_{2\,(aq)}$. Record your observations.
5. Add 0.1 M $AgNO_{3\,(aq)}$ drop-wise to the fourth test tube #5 until any distinct changes occur. Record your observations.

Part 5: Iron (III) Thiocyanate Solution (5 test tubes)

1. To each of the five test tubes, place 2 mL (about the width of a thumb nail) of the iron (III) thiocyanate solution into 5 small test tubes. Label these test tubes 6 to 10. Record the initial observation.
2. The solution in test tube #6 remains untouched. It is a control for comparison with other tubes.
3. Add 2 mL of 0.1 M of $Fe(NO_3)_{3\,(aq)}$ to test tube #7. Record your observations.
4. Add 2 mL of 0.1 M of $KSCN_{\,(aq)}$ to one of the test tube #8. Record your observations.
5. Add 2 mL of 0.1 M of $K_2HPO_{4\,(aq)}$ to one of the test tube #9. Record your observations.
6. Take the last test tube, #10 and place it in the beaker full of ice. Wait until a distinct change occurs. Be patient. Record your observations.

Observations:

Part 1: Saturated Sodium Chloride Solution **(Demo)**

Original Saturated Sodium Chloride Solution	
Demo: Addition of Concentrated $HCl_{(aq)}$	

Part 2: Acidified Chromate Solution **(Demo)**

Original Acidified Chromate Solution	
Demo: Addition of Concentrated $HNO_{3\ (aq)}$	
Demo: Further Addition of Concentrated $NaOH_{(aq)}$	

Part 3: Aqueous Ammonia Solution

Original Aqueous Ammonia Solution	
Test Tube #1: Addition of $NH_4Cl_{(s)}$	
Test Tube #2: Placed in Ice	
Test Tube #2: Heating in Hot Water Bath	

Part 4: Cobalt (II) Chloride Solution

Test Tube #3: Original $CoCl_2$ Solution	
Test Tube #4: Addition of $H_2O_{(l)}$	
Demo: Addition of Concentrated $HCl_{(aq)}$	
Test Tube #5: Addition of $AgNO_{3\ (aq)}$	

Part 5: Iron (III) Thiocyanate Solution

Test Tube #6: Original Iron (III) Thiocyanate Solution	
Test Tube #7: Addition of $Fe(NO_3)_{3\ (aq)}$	
Test Tube #8: Addition of $KSCN_{(aq)}$	
Test Tube #9: Addition of $K_2HPO_{4\ (aq)}$	
Test Tube #10: Placed in Ice	

Analysis

In a detailed manner, explain how the stresses affect each of the five equilibrium systems. Be sure to use the Le Châtelier's Principle and any other chemical concepts to account for all your observations.

Evaluation:

How did your hypotheses compare to the observations and the analysis? Account for any discrepancies.

Conclusion:

Summarize what you have learned from this lab.