Exploring Equilibria Name: _____

Chem 112

This experiment explores a variety of equilibrium systems. A reference Table of Reactions is attached to aid in your explanations. In this qualitative lab, your observations, predictions, and explanations should be recorded in the spaces provided. Using what you know about equilibria and the Table of Reactions included, you should be able to explain all your observations in terms of the relative sizes of equilibrium constants and LeChatelier's principle. Because your investigation is qualitative, the exact amounts of the solutions you work with are not critical. You will be transferring around 1 mL of solution, which is about the same as 20 drops. Don't use much more than that of any solution.

***Notice and make use of the table of some common reaction found on the last page of the handout.***

## Investigation 1: Chromate-Dichromate Solutions

There are two forms of chromium in high oxidation states: chromate ion ($CrO_4^{2-}$) and dichromate ion ($Cr_2O_7^{2-}$). This experiment explores the equilibrium between them.

What to do:

1. Place about 0.5 mL of 1 M potassium chromate solution in a small test tube. Describe the solution. Write a balanced equation for the dissolution of $K_2CrO_4$.

2. Add a few drops of 3 M sulfuric acid ($H_2SO_4$). Write your observations.

3. The chromate anion ($CrO_4^{2-}$) is converted into dichromate ion ($Cr_2O_7^{2-}$) in the presence of acid. Write a net ionic equation for this reaction.

4. Add several drops of 6 M sodium hydroxide (NaOH). Record your observations and write a net ionic equation for what occurs.

5. Comment on the reversibility or lack thereof in the reactions converting chromate and dichromate.

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## Investigation 2: Precipitation of Barium Chromate

Many but not all barium salts are insoluble. This experiment explores the reactions between $Ba^{2+}$ ion and other anions.

What to do:

1. Put 1 mL of 0.1 M barium chloride ($BaCl_2$) solution and one drop of 1 M potassium chromate of ($K_2CrO_4$) into three test tubes. Record your observations and write a net ionic equation for what occurs.

2. Based on your equation, the results of Investigation 1, and the data in the Table of Reactions, predict what will occur if you add some hydrochloric acid (HCl) to this mixture.

3. Go ahead and add a few drops of 6 M HCl to one of these test tubes. Record your observations and write a net ionic equation for what occurs.

4. To a second test tube containing $BaCl_2$ and $K_2CrO_4$, add a few drops of sulfuric acid, $H_2SO_4$. Record your observations and explain how adding sulfuric acid differs from adding hydrochloric acid. Write net ionic equations to explain.

5. To the third test tube containing $BaCl_2$ and $K_2CrO_4$, add a few drops of nitric acid, $HNO_3$. Record your observations. Does nitric acid act more like hydrochloric acid or like sulfuric acid. Explain.

6. As a final test, mix some $BaCl_2$ and $H_2SO_4$. Write your observations and the reaction that occurs. Is K for this process large, medium or small?

## Investigation 3: Weak Acids and Bases

An acid is a compound that ionizes to form H+ ions in water. A base is a compound that ionizes or dissociates to form $OH^-$ ions in water. In an acid-base reaction, the acid donates an $H^+$ ion and the base accepts the $H^+$ ion. Strong bases donate $OH^-$ ions to water, which accept $H^+$ ions from the acid to form water, $H_2O$. Weak bases, however, accept $H^+$ ions from an acid to form their conjugate acid. This investigation explores the chemistry of special conjugate acid-base pairs where one or both species are colored in solution. These are called acid-base indicators, and their acid-base state depends on the solution pH.

The general equilibrium for a weak acid indicator in solution is,

$$HInd(aq) \rightleftarrows H^+(aq) + Ind^-(aq)$$

Two possible reactions are: $HInd(aq) + OH^-(aq) \rightleftarrows H_2O(l) + Ind^-(aq)$

$$Ind^-(aq) + H^+(aq) \rightleftarrows HInd(aq)$$

Indicators can act as the primary acid or base species in solution. But, if another acid or base is present in greater amounts, the indicator will simply lie to either the acid or base side of its equilibrium. That is, its acid-base state will be controlled by the external, more concentrated agent. In acidic solutions, it will exist in the HInd form; in basic solutions it will exist in the $Ind^-$ form.

What to do:

### *Investigating Methyl Orange*

1. Place several drops of methyl orange solution in four small test tubes. What color is it?

2. To one of the test tubes, add about 1 mL of 0.1 M HCl. Record what happens.

3. To the second test tube, add about 1 mL of 0.1 M NaOH. Record what happens.

4. To the third test tube, add about 1 mL of 0.1 M acetic acid ($CH_3CO_2H$). Record what happens. In what state is the indicator in this solution, HInd or $Ind^-$?

## Weak Acids and Bases, Continued:

5. To the fourth test tube, add 1 mL of 0.1 M sodium acetate, $NaCH_3CO_2$. Record what happens. In what state is the indicator in this solution, HInd or $Ind^-$?

6. Perform a series of additions of acids and bases to a single sample of methyl orange to explore the reversibility of the transformation between the two states (HInd and $Ind^-$). Is conversion of the two forms reversible?

7. In yet another test tube, mix 1 mL of methyl orange and 1 mL of 0.1 M ammonia. In what acid-base form is the indicator in this solution?

8. Mix 1 mL of methyl orange with 1 mL acetic acid + 1 mL sodium acetate (this combination forms a buffer of about pH = 4.7). What happens? Explain.

9. Repeat the above using a buffer of 1 mL of ammonia + 1 mL of ammonium chloride. This buffer has a pH of about 9.25.

Explain how addition of acids and bases shift the equilibrium between the acid and base forms of methyl orange.

## Weak Acids and Bases, Continued:

### *Investigating Thymolphthalein*

Repeat the experiments you performed with methyl orange, instead using the indicator thymolphthalein. Answer the following questions:

1. What color is thymolphthalein in the acid (HInd) state?

2. What color is thymolphthalein in the base ($Ind^-$) state?

3. Mix a few drops of thymolphthalein with 1 mL of 0.1 M solutions of the following and determine in which acid-base state it exists in each case:

a. acetic acid

b. sodium acetate

c. ammonia (after adding 1 mL of this, try adding 2 more mL and see what happens)

d. sodium hydroxide

e. acetic acid/acetate buffer

Explain how additions of acids and bases shift the equilibrium between the acid and base forms of thymolphthalein.

4. Is the conversion of the acidic and basic forms of thymolphthalein reversible?

## Investigation 4: Complex Ion Equilibria

Some metal ions react in solution as Lewis acids to form complex ions. For example, $Cu^{2+}$ ion reacts with four ammonia molecules (which are acting as Lewis bases) to form the $Cu(NH_3)_4^{2+}$ complex ion. In this experiment you will explore the complexation between $Fe^{3+}$ ion and thiocyanate ion ($SCN^-$).

What to do:

1. Add 2 mL of 0.1 M potassium thiocyanate (KSCN) to a clean 50 mL beaker and add about 40 mL of deionized water. Add about 0.5 mL of 0.2 M iron (III) nitrate, $Fe(NO_3)_3$ solution to a separate 100 mL beaker and add about 40 mL deionized water. What colors are the solutions?

2. Combine the solutions in the 100 mL beaker. Record your observations and write a net ionic equation for what occurs. What is the color of the product?

3. The solution should be lightly red in color and not so dark that you cannot see writing on a piece of paper viewed through the beaker. If it is too dark, dilute it with water.

4. Pour about 1 mL of this solution into four test tubes. One of these will serve as a color standard.

5. To the second test tube, add another 1 mL of KSN solution. What happens? Was the reaction “complete” after the first mixing? Explain what occurs using LeChatelier’s principle.

6. Cool the third test tube in an ice bath for 5 minutes. Record your observations.

7. Warm the fourth test tube to nearly boiling. Use the wire test tube holder and aim the tube away from you and anyone else in case it spatters. Watch what happens as the solution cools. Record your observations. Are the changes reversible?

8. Is the formation of the product in this reaction an endothermic process or an exothermic process? Explain using LeChatelier's principle.

| **Reaction** | **K** | **Classified as:** | **Compound** |
|---|---|---|---|
| $HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$ | Huge | strong acid | |
| $H_2SO_4(aq) \rightarrow H^+(aq) + HSO_4^-(aq)$ | Huge | strong acid | |
| $HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$ | Huge | strong acid | |
| $CH_3CO_2H(aq) \rightleftarrows H^+(aq) + CH_3CO_2^-(aq)$ | Medium | weak acid | acetic acid |
| $NH_4^+(aq) \rightleftarrows H^+(aq) + NH_3(aq)$ | Medium | weak acid | ammonium ion |
| $HInd(aq) \rightleftarrows H^+(aq) + Ind^-(aq)$ | Medium | | |
| $H_2O(l) \rightleftarrows H^+(aq) + OH^-(aq)$ | Tiny | autoionization | |
| $H_2O(l) + NH_3(aq) \rightleftarrows NH_4^+(aq) + OH^-(aq)$ | Small | weak base | |
| $NaSCN \rightarrow Na^+(aq) + SCN^-(aq)$ | Huge | | sodium thiocyanate |
| $NaHSO_4 \rightarrow Na^+(aq) + HSO_4^-(aq)$ | Huge | | |
| $NaOH \rightarrow Na^+(aq) + OH^-(aq)$ | Huge | Strong base | |
| $KCl \rightarrow K^+(aq) + Cl^-(aq)$ | | Very soluble salt | |
| $KOH \rightarrow K^+(aq) + OH^-(aq)$ | | Strong base | |
| $K_2CrO_4 \rightarrow 2\ K^+(aq) + CrO_4^{2-}(aq)$ | | Very soluble salt | potassium chromate |
| $KHSO_4 \rightarrow K^+(aq) + HSO_4^-(aq)$ | Huge | | |
| $KSCN \rightarrow K^+(aq) + SCN^-(aq)$ | Huge | | |
| $BaCr_2O_7 \rightleftarrows Ba^{2+}(aq) + Cr_2O_7^{2-}(aq)$ | medium | Moderately soluble salt | barium dichromate |
| $BaCrO_4 \rightleftarrows Ba^{2+}(aq) + CrO_4^{2-}(aq)$ | Tiny | Insoluble salt | |
| $BaCl_2 \rightarrow Ba^{2+}(aq) + 2\ Cl^-(aq)$ | Huge | | |
| $BaSO_4 \rightleftarrows Ba^{2+}(aq) + SO_4^{2-}(aq)$ | Tiny | Insoluble salt | |
| $2\ H^+ + 2\ CrO_4^{2-} \rightleftarrows Cr_2O_7^{2-}(aq) + H_2O(l)$ | Medium | | chromate/dichromate |
| $Fe^{3+} + SCN^- \rightarrow FeSCN^{2+}(aq)$ | Medium | | iron thiocyanate complex |
| $AgSCN \rightleftarrows Ag^+(aq) + SCN^-(aq)$ | | Insoluble salt | |
| $AgNO_3 \rightarrow Ag^+(aq) + NO_3^-(aq)$ | Huge | | |
| $Fe(OH)_3 \rightleftarrows Fe^{3+}(aq) + 3\ OH^-(aq)$ | Small | | |