EXPERIMENT

Le Châtelier's Principle

Goal

The goal of this laboratory is to see the shift in the **equilibrium position** and to connect the observations to **Le Châtelier's Principle**, which states that:

Any change in status quo prompts an opposing reaction in the responding system.

Background

A double arrow in a chemical reaction indicates that the reaction can proceed in both directions. Products can react with each other to generate the original reactant.

$$A + B \rightleftharpoons C + D$$

Since the speed of most reactions depends on the concentration of the combining species, the forward reaction rate will decrease when products are formed, and the reverse reaction rate will increase. The latter will replenish the concentration of reactants which in turn will accelerate the forward reaction. Eventually, forward and backward reaction rates will equal each other and the concentrations of reactants and product will remain constant; at this point, the equilibrium has been reached.

The experiment

The experiment today is divided into the following parts: colored complexed ions ($FeSCN^{2+}$), colored complexed ions ($Ni(NH_3)_6{}^{2+}$), the effect of pH on an indicator, effect of pH on solubility, and heat as a product.

Part A. Colored complexed ions; $FeSCN^{2+}$.

Many metals form colored complex ions with several ligands, such as iron (III) ion Fe^{3+} with thiocyanate SCN:

$$\underset{\text{yellow}}{Fe^{3+}\,(aq)} + SCN^{-}\,(aq) \rightleftharpoons \underset{\text{red}}{FeSCN^{2+}\,(aq)}$$

The Iron (III) solution is yellow, the thiocyanate is transparent and the Iron (III) thiocyanate is red. The final color of the solution will be determined by the concentrations in the final equilibrium position.

Part B. Colored complexed ions; $Ni(NH_3)_6{}^{2+}$

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In the case of Hexaaminenickel (II), you will also study the change in equilibrium position when adding an acid. The ligand will act as a base reacting with the acid and detaching from the metal.

$$\overset{\text{green}}{Ni^{2+}\,(aq)} + 6\,NH_3\,(aq) \rightleftharpoons \overset{\text{blue}}{\mathbf{Ni(NH_3)_6{}^{2+}\,(aq)}}$$

$$\Downarrow$$

$$\underset{\text{blue}}{\mathbf{Ni(NH_3)_6{}^{2+}\,(aq)}} + 6\,HCl\,(aq) \rightleftharpoons \underset{\text{green}}{NiCl_2\,(aq)} + 6\,NH_4Cl\,(aq)$$

Part C. Effect of pH on an indicator.

pH indicators are substances that change color depending on the medium pH. Typically they are weak bases or acids. As such, they dissociate slightly in water forming ions. Those ions might be colored species. The general expression for the dissociation of a divalent weak acid indicator (H2In) is:

$$\underset{\text{yellow}}{H_2In_{(aq)}} \quad + \quad H_2O \rightleftharpoons \quad \underset{\text{red}}{HIn^-_{(aq)}} \quad + \quad H_3O^+$$

In the case of Methyl orange, the protonated form is red, while the conjugated base is yellow. Notice that hydronium is a product in this equilibrium. How will adding an acid affect this equilibrium?

Part D. Effect of pH on solubility.

Hydroxide salts of Group II elements (Ca, Sr, and Ba) are slightly soluble. Adding acid will neutralize the hydroxides in the solution while adding more hydroxide will increase the ion product. In both cases, the amount of precipitate will be affected.

$$Ca(OH)_2\,(s) \rightleftharpoons Ca^{2+}\,(aq) + OH^-\,(aq)$$
$$\Downarrow$$
$$OH^-\,(aq) + H^+\,(aq) \rightleftharpoons H_2O\,(aq)$$

Part E. Heat as a product

Lastly, you will experience Le Châtelier's Principle in an exothermic reaction, where the heat can be viewed as a product of the reaction.

$$\underset{\text{violet}}{CoCl_4{}^{2-}\,(aq)} + 6\,H_2O\,(l) \rightleftharpoons \underset{\text{pink}}{Co(H_2O)_6{}^{2+}\,(aq)} + 4\,Cl^-\,(aq) + \textbf{HEAT}$$

Example

The following endothermic reaction is allowed to reach equilibrium:

$$\underset{blue}{A(aq)} + B(aq) + HEAT \rightleftharpoons C(aq) + D(aq)$$

Where A, the only colored compound, is blue. How will the following changes affect the color/equilibrium: (a) Adding more B reactant, (b) Adding more C product, (c) Heating the mixture.

Answer: (a) less blue/equilibrium shifts to the right. (b) more blue/ equilibrium shifts left. (c) Heat is a reactant; less blue/equilibrium shifts to the right.

Procedure

Part A. Colored complexed ions: $FeSCN^{2+}$

☐ *Step 1:* – Find 3 test tubes and a 100 mL beaker, clean them, and mark the test tubes with letters A, B, and R.

☐ *Step 2:* – Read the Good Lab Practice box

Good Lab Practice

- ✍ Concentrated solutions of ammonia, sodium hydroxide and hydrochloric acid should be handled with care.
- ✍ Do not shake open test tubes. Do not use your fingers as stoppers, even if you wear gloves.

☐ *Step 3:* – Add about 20 mL of distilled water to the beaker, 20 drops of 0.1 M $Fe(NO_3)_3$ and 20 drops of 0.1 M KSCN. Mixed the solution until the color is homogeneous.

☐ *Step 4:* – Use a 10 mL graduated cylinder to add 3 mL of the mixture to each of the test tubes.

☐ *Step 5:* – Add 20 drops of 0.1 M $Fe(NO_3)_3$ to test tube A. Put a stopper and mix the solution.

☐ *Step 6:* – Add 20 drops of 0.1 M KSCN to test tube B. Put a stopper and mix the solution.

☐ *Step 7:* – Add 20 drops of distilled water to test tube R. Put a stopper and mix the solution.

☐ *Step 8:* – Compare the color of the test tubes A and B to R and write down your observations.

Part B. Colored complexed ions: $Ni(NH_3)_6{}^{2+}$.

☐ *Step 1:* – Obtain 1 test tube and clean it.

☐ *Step 2:* – Add 10 drops of 0.1 M $Ni(NO_3)_2$. Indicate the color on the results page.

☐ *Step 3:* – Add drops of 6 M NH_3 until the color changes.

☐ *Step 4:* – Add drops of 6 M HCl until the color changes.

Part C. Effect of pH on an indicator.

☐ *Step 1:* – Obtain two 50 mL beakers, clean them, and mark them with letters A (for Acid) and B (for Base). Find and clean a test tube.

☐ *Step 2:* – Add 10 mL of distilled water to each beaker and 1 mL of distilled water to the test tube.

☐ *Step 3:* – Add 4 drops of 6 M HCl to beaker A and stir it (this is the diluted acid).

☐ *Step 4:* – Add 4 drops of 6 M NH_3 to beaker B and stir it (this is the diluted base).

☐ *Step 5:* – Add 4 drops of the indicator (methyl orange) to the test tube.

☐ *Step 6:* – Add 2 drops from the diluted acid in beaker A to the test tube. Mix gently the solution. Record the color on the results page.

☐ *Step 7:* – Drop by drop, add the diluted ammonia solution from beaker B until the color changes. Homogenize the solution from time to time. Write down the number of drops.

☐ *Step 8:* – Attempt one more time for another color change by adding drop-by-drop diluted acid solution. Write down the number of drops.

Part D. Effect of pH on solubility.

☐ *Step 1:* – Add 5 mL of 6 M NaOH to a 50mL beaker using the graduated cylinder.

☐ *Step 2:* – Rinse a 10mL cylinder with water 3 times. Then, use it to add 5 mL of 1 M $Ca(NO_3)_2$ to the beaker.

☐ *Step 3:* – Stir the mixture.

☐ *Step 4:* – Make a cone with filter paper and place it in afunnel, on top of the Erlenmeyer. Filter the solution with the precipitate. Carry out a couple of washings with distilled water to make sure you collect all solids. Transfer with a spatula the white solid to a small clean beaker.

☐ *Step 5:* – Add 10 mL of distilled water to the beaker with the white solid. Stir the mixture. Do not expect the solid to completely dissolve. The solution is saturated.

☐ *Step 6:* – Add drops of 6 M HCl until a change is observed. Record your results.

☐ *Step 7:* – Add drops of 6 M NaOH until a change is observed. Record your results.

Part E. Heat as a product.

☐ *Step 1:* – Obtain a Bunsen burner, a stand, two iron rings, a wire gauze, two 250 mL beakers, and a test tube.

☐ *Step 2:* – Prepare the setup for the bunsen burner, using the second iron ring to protect the beaker from falling. Put about 100 mL of distilled water in the beaker and bring the water to a boil.

☐ *Step 3:* – Add 5 drops of 0.1 M $Co(NO_3)_2$ to the test tube.

☐ *Step 4:* – Record the color of the liquid solution after each step.

☐ *Step 5:* – Add drops of 12 M HCl until the color of the solution changes. You might need to stir the test tube to help mix the reagents.

☐ *Step 6:* – Add 5 drops of distilled water and mix.

☐ *Step 7:* – Place the test tube in the boiling water and wait for another color change.

☐ *Step 8:* – Attempt to reverse the reaction by placing the test tube in a beaker with ice or cold water.

STUDENT INFO

Name: ______________________ Date: __________

Pre-lab Questions

Le Châtelier's Principle

1. Write the equilibrium constant expressions for all reactions involved in this experiment.

2. How does pH affect the solubility of $Ca(OH)_2$?

3. Is heat being consumed (reactants) or produced (product) in an endothermic reaction?

4. Is heat being consumed (reactants) or produced (product) in an exothermic reaction?

STUDENT INFO

Name: ______________________ Date: ________

Results
EXPERIMENT

Le Châtelier's Principle

Part A. Colored complexed ions: $FeSCN^{2+}$

$$\underset{\text{yellow}}{Fe^{3+}\,(aq)} + SCN^{-}\,(aq) \rightleftharpoons \underset{\text{red}}{FeSCN^{2+}\,(aq)}$$

After step #			Before color	After color
5	Add Fe^{3+}	Solution in test tube A	__________	__________
6	Add SCN^{-}	Solution in test tube B	__________	__________
7	Add H_2O	Solution in test tube R	__________	__________

Part B. Colored complexed ions: $Ni(NH_3)_6{}^{2+}$.

$$\overset{\text{green}}{Ni^{2+}\,(aq)} + 6\,NH_3\,(aq) \rightleftharpoons \overset{\text{blue}}{\mathbf{Ni(NH_3)_6{}^{2+}\,(aq)}}$$

$$\Downarrow$$

$$\underset{\text{blue}}{\mathbf{Ni(NH_3)_6{}^{2+}\,(aq)}} + 6\,HCl\,(aq) \rightleftharpoons \underset{\text{green}}{NiCl_2\,(aq)} + 6\,NH_4Cl\,(aq)$$

After step #	Color		
2	Add Ni^{2+}	__________	
3	Add NH_3	__________	# drops added ______
4	Add HCl	__________	# drops added ______

Part C. Effect of pH on an indicator.

$$\underset{\text{yellow}}{H_2In_{(aq)}} + H_2O \longrightarrow \underset{\text{red}}{HIn^-_{(aq)}} + H_3O^+$$

After step #		Before color	After color	
5	Add indicator	____________	____________	
6	Add diluted acid	____________	____________	
7	Add diluted base	____________	____________	# drops added ___
8	Add diluted acid	____________	____________	# drops added ___

Part D. Effect of pH on solubility.

$$Ca(OH)_2\,(s) \rightleftharpoons Ca^{2+}\,(aq) + OH^-\,(aq)$$
$$\Downarrow$$
$$OH^-\,(aq) + H^+\,(aq) \rightleftharpoons H_2O\,(aq)$$

After step #		Indicate # drops added
7	Add acid	___
8	Add base	___

Part E. Heat as a product.

$$\underset{\text{violet}}{CoCl_4^{2-}\,(aq)} + 6\,H_2O\,(l) \rightleftharpoons \underset{\text{pink}}{Co(H_2O)_6^{2+}\,(aq)} + 4\,Cl^-\,(aq) + \textbf{HEAT}$$

After step #		color	
3	Add Co^{2+}	____________	
5	Add acid	____________	# drops added ___
6	Add H_2O	____________	

STUDENT INFO

Name: ______________ Date: ________

Post-lab Questions

Le Châtelier's Principle

1. In part A. Explain the different colors based on the equilibrium reaction and Le Châtelier's Principle.

2. In part A. Given that water is not involved in the equilibrium, explain the color change you observed after adding water to the mixture.

3. In part B. What did you observe after adding the acid and after adding the base? Explain the different colors based on the equilibrium reaction and Le Châtelier's Principle.

4. In Part C. What did you observe after adding the acid and after adding the base? Explain the changes based on the equilibrium reaction and Le Châtelier's Principle.

5. In Part D. What did you observe after adding the acid and after adding the base? Explain the changes based on the equilibrium reaction and Le Châtelier's Principle?

6. In Part E. What did you observe after heating and after cooling? Explain the changes based on the equilibrium reaction and Le Châtelier's Principle.