Equilibrium/Le Chatelier's Principle

Modified from an activity originally created by participating teachers. 2008 Summer Green Chemistry Workshop.

Teacher Background Information:

Traditionally, equilibrium experiments and Le Chatelier's Principle are illustrated using the following experiments. In this experiment, everyday, non-toxic materials replace these materials.

(A) $CoCl_4^{2-} + 6H_2O \underset{\text{endo}}{\overset{\text{exo}}{\leftrightarrows}} Co(H_2O)_6^{2+} + 4Cl^-$

blue → red

This experiment is used to demonstrate the effects of both temperature changes and concentration changes on an equilibrium mixture.

(B) $Cr_2O_7^{2-} + H_2O \leftrightarrows 2CrO_4^{2-} + 2H^+$

orange → yellow

This experiment is used to demonstrate the effects of concentration changes on an equilibrium mixture.

(C) $Fe^{3+} + CNS^- \leftrightarrows Fe(CNS)^{2+}$

yellow → red

This experiment is also used to demonstrate the effects of concentration changes on an equilibrium mixture.

Safety Information:

Safety glasses should be used whenever working in the lab. Iodine is a minor eye irritant **and** vinegar and ammonia can cause skin irritation.

Educational Goals:

- Provide students with an understanding of the concept of chemical equilibrium and to demonstrate Le Chatelier's Principle, i.e. if a stress is applied to a system at equilibrium, the system readjusts to relieve the stress applied.

Student Objectives: Students will…

- Explain the concept of chemical equilibrium
- Distinguish between static and dynamic equilibrium
- State Le Chatelier's Principle
- Describe how to set up an experiment that is at chemical equilibrium
- Predict the effect of adding a stress to the system at equilibrium

Time: 45 minutes

Materials (per group of 2-4 students):

- Bottle of soda water
- Balloon
- Matches
- Candle
- Universal indicator
- 5 Erlenmeyer flasks
- Black tea
- Vinegar
- Ammonia – cleaning solution
- Tincture of iodine
- Starch spray
- Drinking straw
- Hot plate
- Ice bath
- Glass stirring rods
- Test tube

Teacher Prep:

- Starch solution: Spray starch into a 400 mL beaker (cover the bottom of the beaker with spray or use 5-10 drops of liquid starch). Fill the remainder of the beaker with water and stir.
- Black tea: Prepare a 1000 mL beaker of black tea the darker the better. Prepare with electric kettle and allow it to cool to room temperature.

Teacher Demonstration Activator (Optional):

Materials:

- Bottle of soda water
- 1 balloon
- Candle
- Matches
- Universal indicator

Procedure:

Carry out the Teacher Demonstration and discuss in class as an introduction to Le Chatelier's Principle and the concept of equilibrium.

- Introduce to class the idea of a bottle of soda water. Does equilibrium exist inside the bottle?
- What gas is present in the bottle (dissolved and above the solution)?
- Remove gas from bottle by shaking and then trapping the gas in the balloon.
- Test for gas by pouring some of gas over a lighted candle. What can we deduce?
- Bubble gas into litmus indicator or cabbage juice (or better, limewater). The gas is acidic (or turns limewater milky)– what is the name of the acid in the soda water?
- Discuss the equilibrium inside the bottle:

$$CO_2 + H_2O \leftrightarrows H_2CO_3$$

Activity 1 – Iodine and Starch

- Assign pre-lab for homework and review equilibrium
- Introduce the concept of the starch-iodine complex. Is this an example of an equilibrium reaction?
- Add a one drop of tincture of iodine to 30 ml of starch solution. Note the formation of a blue-black color.
- Heat the solution to about 80 °C. Note that the blue-black color disappears. What can we deduce from this?

- Cool the container by placing it in ice. What do we observe?
- Discuss equilibrium with the class:

Iodine + Starch ⇆ Starch-Iodine Complex
colorless blue-black

The soluble starch acts as an "indicator" of molecular iodine. The shifts in equilibrium position produced by temperature changes are in accordance with Le Chatelier's principle. ΔH is +ve (endothermic) in the *forward direction as written above*. Warming the solution causes a 'shift' to the right and the solution becomes blue (and vice versa because ΔH for the reaction is –ve, exothermic, in the reverse direction).

When its chilled more starch iodine complex is formed which creates the darker color. When heat is added as a stressor the starch iodine complex is colorless.

Which direction is exothermic and which is endothermic? How do we explain our results?

exo
Iodine + Starch ⇆ Starch-Iodine complex
colorless endo blue-black

Activity 2 – Tea

- Each student group will prepare 60 ml black tea solution from a stock solution prepared by the teacher.
- Students will then separate 20 ml into three test tubes or small Erlenmeyer flasks. One of these will be used as a control.
- To one of the samples, add a 15 drops of vinegar. Note the change in color to a lighter color compared to the control. This indicates the increase in the number of H^+ ions. The number of drops of vinegar can be manipulated. What happens when you add less or more?
- To another flask, add 5 drops of ammonia cleaning solution. Note the change to a darker color compared to the control. The basic solution of ammonia removes the H^+ ions. Again the number or drops can be changed-ask students to try 3 trials and record the variables.
- Students can then use the flashlight feature on their cell phones to see the changes.
- Discuss shifting of the equilibrium:

Tea + H^+ ⇆ $TeaH^+$
dark light color

Keys for Success:

- Introduce the lesson covering the following points:
- You may have come across the word "equilibrium" in your study of physics
- If you look up the meaning of "equilibrium" in a dictionary you will find it explained using words like "state of balance". A meter stick which is suspended at its center of gravity is said to be balanced or in equilibrium. A meter stick suspended at its center of gravity remains stationary or static. Thus, this type of equilibrium is often referred to as **static equilibrium**. In other words, the entire system is not moving.
- Consider now the case of a man running on a treadmill. Overall, there is no change in the position of the man. He is running forward at the same speed as the belt is moving in the opposite direction. The two opposing motions balance each other. This is an example of a type of equilibrium called **dynamic equilibrium**, the word dynamic means "moving".
- Another example of a dynamic equilibrium is if you walk down an escalator at the same speed as it is

moving up. There is no overall change in your position because the two opposing motions are balanced.

- Chemical equilibrium is a state of dynamic balance where the rate of the forward reaction is the same as the rate of the backward reaction.
- Examples of reactions at equilibrium

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

$$2NO_{2(g)} \rightleftharpoons N_2O_{4(g)}$$

Disposal Information:

- All waste safe for disposal down the drain

Le Chatelier's Principle

Pre Lab Exercise

Background Information:

Chemical equilibrium is a state of dynamic balance where the rate of the forward reaction is the same as the rate of the backward reaction. Examples of reactions at equilibrium are:

$$N_2 + 3H_2 \leftrightarrows 2NH_3$$

$$2NO_2(g) \leftrightarrows N_2O_4(g)$$

You may have come across the word "equilibrium" in your study of physics. If you look up "equilibrium," you will find it explained using words like "state of balance." A meter stick which is suspended at its center of gravity is said to be balanced or in equilibrium. A meter stick suspended at its center of gravity remains stationary or static. Thus, this type of equilibrium is often referred to as **static equilibrium**. In other words, the entire system is not moving. Consider now the case of a man running on a treadmill. Overall, there is no change in the position of the man. He is running forward at the same speed that the belt is moving in the opposite direction. The two opposing motions balance each other. This is an example of a type of equilibrium called **dynamic equilibrium**, the word dynamic means "moving." Another example of a dynamic equilibrium is if you walk down an escalator at the same speed as it is moving up. There is no overall change in your position because the two opposing motions are balanced.

Problem:

How can Le Chatelier's Principle be used to predict the direction in which a system at equilibrium will shift when conditions are altered? The equilibrium system that we will study in the Pre-Lab is:

$$\underset{\text{green}}{CuCl_2(aq)} \leftrightarrows \underset{\text{blue}}{Cu^{+2}(aq)} + \underset{\text{colorless}}{2Cl^{-1}(aq)} + \text{heat}$$

1. Write out the balanced reaction between $AgNO_3$ (aq) and $CuCl_2$ (aq) and identify the precipitate formed.

2. For each change listed, predict the equilibrium shift, using the reaction from question number one and your knowledge of Le Chatelier's Principle:

Stress	**Direction of Shift** (→; ←; or *no change*)
Raise temperature	
Lower temperature	
Add $Ag^+NO_3^-$	
Add Na^+Cl^-	

Le Chatelier's Principle

Student Sheet

Activity 1 – Iodine and Starch

Materials:

- Starch solution
- 100 mL graduated cylinder
- 3 x test tubes (18x150 mm)
- Tincture of iodine
- Plastic pipettes
- Glass stirring rod
- Ice
- 2 x 300 mL beakers
- Thermometer
- Hot plate/electric kettle
- Test tube rack

Procedure:

1. Measure 60 mL of starch solution using a graduated cylinder.
2. Pour 20 mL of the starch solution into three separate test tubes.
3. Add 1 drop of tincture of iodine with the plastic pipette to each test tube and stir with a glass stirring rod.
4. Prepare an ice bath with ice cubes and water in a 300 mL beaker.
5. Prepare a hot water bath by heating a 300 mL beaker filled with water on a hot plate until it reaches 80^0C; measure the temperature with a thermometer. (Alternatively, heat water in an electric kettle and then transfer to a 300 mL beaker (faster method).
6. Place one test tube in the ice bath, one in the hot water bath, and leave one as a control (not stressed).
7. Observe and record the changes that occur.

Activity 2 – Tea

Materials:

- Black tea solution
- 100 mL graduated cylinder
- 3 x (18x150mm) test tubes
- 2 x plastic pipettes
- Vinegar
- Ammonia cleaning solution
- Glass stirring rod

Procedure:

1. Measure 75 mL of black tea solution with graduated cylinder.
2. Pour the tea into three test tubes there should be 25 mL of tea in each.
3. Use a plastic pipette to add 15 drops of vinegar to one of the beakers, stir with a stirring rod, and label.
4. Use a different pipette to add 5 drops of household ammonia to the second beaker, stir with a stirring rod, and label.
5. Leave the third beaker as a control.
6. Observe and record the color changes that occur.

Le Chatelier's Principle

Name: ___________________________________

Activity 1 – Iodine and Starch

Data and Observations:

Iodine + Starch ⇆ Starch-Iodine Complex
colorless blue-black

Stress	Resulting Color
Control	
Raise temperature	
Lower temperature	

Questions:

1. What effect did heating the test tube have on the concentration of starch-iodine complex? Explain how you know this by using Le Chatelier's Principle.

2. What effect did cooling the test tube have on the concentration of starch-iodine complex? Explain how you know this by using Le Chatelier's Principle.

3. Which direction is exothermic? Which direction is endothermic? Explain your results.

Activity 2 – Tea

Data and Observations:

$$\underset{\text{dark}}{\text{Tea}} + H^+ \leftrightarrows \underset{\text{light color}}{\text{TeaH}^+}$$

Stress	Resulting Color
Control	
Vinegar addition	
Ammonia addition	

Questions:

1. In this activity, how could you determine whether or not a change occurred in equilibrium? Explain.

2. For each reaction in Activity 2, demonstrate how each change can be explained by Le Chatelier's Principle. Be specific about where the chemical was added (the stress) and its impact on the other components of the Tea Equilibrium.

Vinegar (Acetic acid, $HC_2H_3O_2$): $\underset{\text{dark}}{\text{Tea}} + H^+ \Leftrightarrow \underset{\text{light color}}{\text{TeaH}^+}$

Ammonia (NH_3): $\underset{\text{dark}}{\text{Tea}} + H^+ \Leftrightarrow \underset{\text{light color}}{\text{TeaH}^+}$

3. Did these activities help you to understand Le Chatelier's Principle? Why or why not?

4. Explain why this is a green chemistry lab.