Equilibrium Demonstrations—The Good, the Bad, and the Ugly

Models and Simulations

Introduction

Set up two water reservoirs containing different amounts of water and start bailing, swapping water from one container to another. Will the water levels in both containers keep changing? Will the water levels eventually be the same in both containers? These demonstrations provide simple ways to introduce key concepts relating to reversible reactions and equilibrium.

Concepts

- Reversible reactions
- Equilibrium
- Equilibrium constant (K_{eq})
- LeChâtelier's Principle

Part A. Transfer via siphon

Materials

Blue food coloring

Yellow food coloring

Water, tap

Beakers, 600-mL, 2

Syringe, 140-mL

Tubing, plastic $^1/_8$-inch, 10 inches

Tubing, plastic, $^1/_4$-inch, 10 inches

Tubing, plastic, $^1/_2$-inch, 10 inches

Wood blocks or other thick plates to raise the beaker's height, 3

Safety Precautions

Although the materials in this lab are considered nonhazardous, follow all standard laboratory safety procedures. Wash hands thoroughly with soap and water before leaving the laboratory.

Preparation

1. Mix several drops of blue food coloring into about 600 mL of water.
2. Place several drops of yellow food coloring into one of the 600-mL beakers.
3. Pour about 400 mL of the blue water into the second 600-mL beaker.
4. Place the two beakers next to each other.
5. Label the edge of each wood block "heat".

Procedure

1. Coil the plastic tubing into the blue water, filling the tubing with blue water.
2. Place a finger over the end of the tubing.
3. Lift the tubing out of the beaker and quickly insert the free end of the tubing into the second beaker.
4. Reinsert the covered end of the tubing into the blue water. The siphon should start the water flowing from the full beaker into the beaker containing the yellow food coloring.
5. Use the larger tubing to explain how different diameter tubing would cause the system to reach equilibrium faster.
6. Once the amount of colored water is equal in the two beakers (equilibrium) use the syringe to remove some of the blue

water shifting equilibrium backward (LeChâtelier's Principle).

7. Insert blocks of wood under the blue water beaker to simulate an endothermic reaction.

Part B. Transfer using tubes

Materials

Blue food coloring
Water, tap
Graduated cylinders, 25-mL, 2
Tubing, glass, 5-mm, 10 inches
Tubing, glass, 7-mm, 10 inches

Safety Precautions

Although the materials in this lab are considered nonhazardous, follow all standard laboratory safety procedures. Wash hands thoroughly with soap and water before leaving the laboratory.

Preparation

1. Mix several drops of blue food coloring into about 100 mL of water.
2. Label one graduated cylinder "reactants" the other "products"
3. Pour about 20 mL of the blue water into the reactants graduated cylinder.
4. Place the two graduated cylinders next to each other.

Procedure

1. Fill one graduated cylinder (*reactants*) with about 20 mL of blue water. Leave the other graduated cylinder (*products*) empty. These will serve as water reservoirs in this activity.
2. Ask for two volunteers from the class, one to measure the amount of water remaining in each graduated cylinder, the other to record the results on the board or overhead projector.
3. Measure and record the initial volume of blue water in the graduated cylinders (*reactants and products*).
4. Insert a glass tube into each of the graduated cylinders.
5. Simultaneously place a finger on the end of each glass tube. Fill the glass tubes as full as possible, without tipping the graduated cylinders (*reactants and products*) in any way.
6. Remove the glass tubes from each graduated cylinder, place the bottom end of the tube into the other graduated cylinder and remove your finger from the end. *Note:* In the first cycle, only the reactant glass tube will contain any blue water as there are no products yet.
7. Place the empty glass tubes back into their original graduated cylinder and record the new volume in the data table.
8. Continue transferring water from one graduated cylinder to another. Measure and record the volume or level of water in graduated cylinder (*reactants and products*) at the end of each transfer cycle.
9. As the demonstration proceeds, ask the class to predict what will happen to the level of water in the two graduated cylinders. Revise the predictions as needed.
10. When no further changes are observed in the level of water in both graduated cylinders (*reactants and products*). Introduce the term *equilibrium* to describe the results.
11. Using the transfer of water from the reactant graduated cylinder to the product graduated cylinder as an analogy, ask students to define the term equilibrium for a *reversible reaction* of the type A—B. The definition should include both the properties of the system at equilibrium and how (or why) it is achieved.

12. (*Optional*) Graph both the amount of reactant per exchange cycle and the amount of product per exchange cycle. Compare these graphs to those in a textbook.

Part C. Transfer using cups

Materials

Blue food coloring
Water, tap
Cup, clear plastic, 10-oz
Cup, polypropylene, 30-mL
Marker
Pan, clear plastic, rectangle
Pan, clear plastic, square

Safety Precautions

Although the materials in this lab are considered nonhazardous, follow all standard laboratory safety procedures. Wash hands thoroughly with soap and water before leaving the laboratory.

Preparation

1. Mix several drops of blue food coloring into about 1-L of water.
2. Label the smaller tub "reactants" and the larger tub "products"
3. Pour about 1-L of the blue water into the reactants tub.
4. Place the two tubs next to each other.

Procedure

1. Two volunteers are needed to transfer blue water from pan *A* to pan *B* and vice versa. Give the first volunteer a 10-oz plastic cup, the second volunteer a 30-mL polypropylene cup.
2. Instruct the two "water" volunteers to use their containers to transfer water from one pan to the other. They should fill their cups as full as possible, without tipping the pans in any way. Each student then pours the water into the other pan. Water cannot be "caught" during the pouring.
3. This is a partnership, not a race, and the students should work cooperatively to ensure that the water is transferred smoothly without spilling. *Note:* In the first cycle, only the student working from pan *A* will be able to transfer any water.
4. Continue transferring water from one pan to another until the amount of blue water transferred is about the same.
5. Determine if equilibrium (the rate of transfer) is equal by marking the amount of blue water in the smaller cup, empty the small cup into the reactants tub then pour the blue water from the large cup into the small cup. If the system is at equilibrium the volume from the larger cup should equal the marked line on the small cup.
6. Place the products tub on top of the reactants tub to explain that the equilibrium constant (K_{eq}) can be calculated by dividing the amount of product by the amount of reactant when the system is at equilibrium.

Part D. Synthesis and decomposition

Materials

Aquarium, 10-gallon
Beakers, Berzelius (tall form), 1000-mL, 2
Film canisters or bottles, plastic, 30-mL, 20
Paper bags, large, 2

Safety Precautions

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Preparation

1. Place the bottoms of the film canisters into one beaker and the caps into the other beaker.
2. Place both beakers into the aquarium.

Procedure

1. One student will synthesize the product—put the cap on the bottom and return the product into the aquarium. A second student will decompose the product into reactants—remove the cap from the bottom and return them to the aquarium.
2. Pour the bottoms and the caps into the aquarium.
3. The two reactions should proceed at the same time. *Note:* The decomposition reaction cannot occur until the first product has been synthesized.
4. Repeat step 3 until both the synthesis and decomposition reactions are occurring at the same rate.
5. Place a paper bag on the head of the synthesizer to simulate a change in the equilibrium point.
6. Place a paper bag on the head of the decomposer to simulate a change in the equilibrium point.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Dispose of the blue water down the drain according to Flinn Suggested Disposal Method #26b.

Tips

- Reinforce the concept that initially no products exist in these demonstrations.
- Extend Part B with the following questions. Why are the water levels different in the two graduated cylinders at equilibrium? Are there any conditions where the water level would be the same in each graduated cylinder at equilibrium? Try the activity with two identical pieces of glass tubing.
- Extend Part B or C with the following questions. Can the equilibrium constant be used to predict what will happen if additional water is added to the first container and the exchange cycle is repeated? Try it!
- Extend any part by introducing *LeChâtelier's Principle* to describe what happens when the initial equilibrium condition is disturbed due to the addition of more reactant. Use LeChâtelier's Principle to predict what would happen if more water were added to the reactant container and the exchange cycle were repeated.
- The following ideas represent typical student misconceptions about the nature of chemical equilibrium. The concentrations of reactants and products must be equal at equilibrium. (*Having equal amounts of water in the two reservoirs at equilibrium is a special-case scenario that will be observed only if the small containers used to transfer the water are exactly identical.*) Reversible reactions occur in one direction only until all the reactants are depleted, and then the reverse reaction begins to take place—think of this as the windshield wiper analogy. (*Both reactions take place simultaneously and reach a state of dynamic equilibrium when the amount of water being removed from each cylinder is the same.*) Use the results of this activity to ask leading questions that will help students build more accurate models of chemical equilibrium.
- The "mechanical" analogy between this demonstration and chemical reactions is not perfect. The most obvious place where the analogy breaks down is in the physical separation of reactants and products in separate containers. In reality, of course, there is no "left side" or "right side" in a reversible chemical reaction.

Discussion

This activity demonstrates by physical analogy many important concepts concerning chemical equilibrium. (1) At equilibrium, the rate of the forward reaction equals the rate of the reverse reaction. In these demonstrations, this is clearly evident because water continues to be exchanged between the two containers, but the amount being removed is the same as the amount being added to each container. (2) The fact that the amounts of reactants and products remain constant once equilibrium is reached is the net result of a dynamic series of events, not a static condition. In the demonstrations, water should continue to be transferred for a few cycles even after the water levels become constant—there is no reason the process cannot continue indefinitely. (3) Equilibrium can be approached from different "directions" (from the reactant or product side). This is easy to demonstrate by starting with different amounts of water in either the reactant or product container.

The application of equilibrium to chemical reactions requires a closed system in which reactants and products can neither be added nor removed from the system. If reactants and products are somehow added or removed from the closed system, then the equilibrium condition is disturbed. LeChâtelier's Principle is then used to predict what will happen when the system is again closed and equilibrium is re-established. In these demonstrations, the amount of water present in the two containers will be different after additional water is added to one of the containers after equilibrium has first been reached, but the ratio of water in the two containers should be the same in both cases.

Graphing the results in Part B—volume of water in each graduated cylinder versus the number of times water has been swapped—is a valuable optional exercise. Students should be able to generate the same types of graphs that their textbooks show for the concentrations of reactants and products as a function of time in the approach to equilibrium.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
- Evidence, models, and explanation
- Evolution and equilibrium

Content Standards: Grades 5–8
- Content Standard B: Physical Science, properties and changes of properties in matter

Content Standards: Grades 9–12
- Content Standard B: Physical Science, chemical reactions

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Equilibrium Demonstrations—The Good, the Bad, and the Ugly* activity, presented by Mike Roadruck, is available in *Models and Simulations*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Equilibrium Demonstrations—The Good, the Bad, and the Ugly* are available from Flinn Scientific, Inc.

Catalog No.	Description
V0003	Food Coloring Dyes, Dye Set of Four Colors
FB0211	Aquarium, 10-gallon
GP1030	Beakers, 600-mL, 2
GP1061	Beakers, Berzelius (Tall Form), 1000-mL, 2
AP8412	Bottles, Plastic, 30-mL, 20
AP6542	Cup, Clear Plastic, 10-oz
AP5442	Cup, Polypropylene, 30-mL
GP2010	Graduated Cylinders, 25-mL, 2
AP5909	Pan, Clear Plastic, Rectangle
AP9171	Pan, Clear Plastic, Square
AP6315	Syringe, 140-mL
GP9005	Tubing, Glass, 5-mm, 24 inches, Pkg./10
GP9015	Tubing, Glass, 7-mm, 24 inches, Pkg./10
AP8373	Tubing, Plastic $^{1}/_{8}$-inch, 10 Feet
AP8375	Tubing, Plastic, $^{1}/_{4}$-inch, 10 Feet
AP8378	Tubing, Plastic, $^{1}/_{2}$-inch, 10 Feet

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.