Equilibrium Doesn’t Equal Equality

An exploration of Equilibrium and Le Chatelier’s Principle

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EQUILIBRIUM DOESN'T EQUAL EQUALITY

Science Lesson with Demonstrations by Laura Laughlin
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Purpose:

When considering the conceptual ideas in an introductory high school chemistry course, equilibrium and Le Chatelier's Principle are among the most misunderstood. One of the problems is that students tend to begin with the deeply ingrained misconception that equilibrium in a chemical reaction implies equal amounts of reactants and products. This lesson is designed to provide multiple examples that will enable students to reconstruct a more accurate concept of equilibrium and what causes it to shift to the right or to the left.

Equilibrium, in reality, exists in all situations in chemistry and chemical reactions, because all processes are, to some degree, reversible. Whenever the temperature, concentration of reactants or products, or partial pressure of various components of the reaction are changed, Le Chatelier's Principle applies, and equilibrium will shift toward the reactants or products in a way that will resolve the stress on the system. Once a reaction reaches equilibrium, the rates of the forward and backward reactions are equal, but the amounts of reactants and products are generally unequal.

The instructional goals for this lesson are for students to understand that equilibrium is reached at the most stable ratio of reactants and products, and that when stress is placed on a system at equilibrium, the system acts in a way to counteract the stress and restore equilibrium. This will provide students with a fundamental conceptual understanding of equilibrium prior to later lessons that may explore equilibrium from a more mathematical perspective.

Materials and Equipment needed for the lesson:

- Copies of student handouts to distribute
- Two large, clear containers of water
- Two beakers of different sizes (250 ml and 500 ml beakers will work)
- Food coloring, preferably blue and yellow
- Computer with internet access and projector
- White board with dry erase markers

Instructional Objectives

- Students will explain, in a paragraph, what is happening when a reaction is at equilibrium in terms of the amounts of reactants and products and the rates of the forward and backward reactions.
- Students will restate Le Chatelier's Principle in their own words.
- Students will predict shifts in equilibrium when a chemical is added or removed from a reaction at equilibrium and when heat is added or removed, and give a brief explanation of why the equilibrium will shift in each case.

Instructional Procedure (with questions and answers)

1. The teacher will explain the setup for the first demo (with 2 buckets of water). Start with water arranged as follows:

Place larger beaker next to container A and smaller beaker next to container B. Tell students that you will use the large beaker to transfer liquid from container A to container B and the small beaker to transfer water in the opposite direction. Ask students to individually write down a prediction to answer each the following questions (#1 and #2 on student handout):

What will eventually happen to the amounts of water in each container?
(answers will vary)
What will eventually happen to the amounts of water being transferred each direction? *(answers will vary)*

2. The teacher will call on two volunteers to transfer the water from one container to another. Each time they transfer water, the volunteers will announce an approximate reading on the amount of water they transfer. After approximately 5-10 transfers, the color of the mixture in each container should be pretty much the same, and the amounts of water being transferred each direction will be equivalent. To confirm that the reaction has reached equilibrium, the teacher may mark the water level on each container and do one additional transfer, showing that the water levels remain constant. This is when the "reaction" has reached equilibrium. After observing this, students will be given time to discuss and answer questions 3-6 on their handouts, as follows:

What happened to the amounts of water in each container?
(The water amounts in each container stabilized and remained constant after several transfers of water. However, the amounts of water in each container were not equal when the reaction reached equilibrium.)

What happened to the amounts of water being transferred each direction?

(The amounts of water being transferred at equilibrium were equal each direction even though the beakers used to transfer the water had different sizes. This was because the larger beaker did not fill completely in the container that had less water.)

What do each of the following represent in terms of a reversible reaction?

- The amount of water in container A *(Amount of reactant)*
- The amount of water in container B *(Amount of product)*
- The amount of water transferred from A to B *(The rate of the forward reaction)*
- The amount of water transferred from B to A *(The rate of the backward reaction)*

What does this demonstration show about a reaction that is at equilibrium?

(The demonstration shows that although the amounts of reactants and products are generally <u>not</u> equal at equilibrium, the rates of the forward and backward reactions – represented by the amounts of water being transferred each way – are equal. Because the same amount of water is being transferred in both directions, the amounts of the reactant and product stabilize at equilibrium, even though there is an unequal amount of reactant and product)

3. Redo the demonstration starting with a smaller amount of water in container A and a greater amount of water in container B. Ask students to predict what will happen before beginning the experiment, and ask them to answer questions 8-9 on their handout after completing this follow-up demonstration. In this demonstration, if the same beakers are used to transfer water in the same directions, the larger containers should eventually reach the exact same equilibrium point.

What was similar and what was different about the demonstration when we started with a smaller amount in container A? Why did the reaction behave this way?

(The reaction reached the same equilibrium levels in terms of the amount of water in each container and the amount of water being transferred each way. However, instead of transferring a larger amount from A to B initially, a larger amount was transferred from B to A initially, indicating that equilibrium was shifting to the left this time. The reaction reaches the same equilibrium because this is the most stable ratio of A to B, or reactants to products)

Suppose that at equilibrium for the reaction: $2\ NH_{3\ (g)} \Leftrightarrow 3\ H_{2\ (g)} + N_{2\ (g)}$ there is a much greater amount of ammonia than hydrogen gas. Explain what might cause the equilibrium to be more heavily weighted towards the reactants.

(In most cases, the equilibrium is weighted more heavily one direction because of the conditions in the environment – temperature, pressure, etc, and because one side of the chemical reaction generally has greater stability)

4. Set up the computer to be connected to the projector and open the following website: http://phet.colorado.edu/simulations/sims.php?sim=Reversible_Reactions
This website has a link that will enable you to download a computer simulation of reversible reactions. In the simulation, the teacher can manipulate temperature, activation energy between reactants and products, and potential energy of the reactants and products. For the sake of simplicity in this lesson, the activation energy will be left at the zero. Students can easily see the "weighting" of the reaction between reactants and products by looking at the letters A and B at the top of the computer program.

Begin by moving the potential energy of A and B to be at equal levels and ensuring that there is no barrier between them in terms of activation energy, and before adding molecules of A for the first demonstration, ask students to make a prediction regarding the relative amounts of A (reactant) and B (product) that will be present at equilibrium. This is question # 10 on the student handout, and answers will vary.

5. Add approximately 75 atoms of molecule A to the container and ask students to make some observations about what happens. Students will answer questions # 11 - 12 on the handout:

> What happened to the reaction? (Which way did the reaction shift and where was the final equilibrium point?)
>
> > *(The molecules shifted gradually from left to right. When the reaction reached equilibrium, the amounts of A and B stabilized equal to each other. Also at equilibrium, equal numbers of molecules were shifting each direction across the barrier between reactants and products.)*
>
> What do you think would have happened if we had started by adding molecule B instead of molecule A?
>
> > *(The equilibrium would have shifted from right to left, but the equilibrium point would have been at the same amounts of A and B. Note: It is optional that the teacher can then show this demonstration to the students)*

6. Change the energy level of molecule A so that it is higher than that of molecule B. Also adjust the heat control and later add more of molecule B to the reaction vessel so that students can see the effects of this. Repeat the experiment after asking students to answer question # 13 (the prediction question: answers may vary). After students see the demonstration (in which the balance at equilibrium will be heavily weighted towards molecule B – the product) students will answer questions # 14 -16:

> What happened to the reaction? (Which way did the reaction shift and where was the final equilibrium point?)
>
> > *(The reaction still shifted towards the products, but it shifted until there was a larger amount of molecule B than molecule A. This is because molecule B is more stable at equilibrium. However, when the reaction reaches equilibrium, there is still an equal reaction rate moving both directions along the barrier.)*

What happens to the molecules in the container when it is heated? How does this affect the final equilibrium ratio?

(The molecules speed up. Also, the equilibrium shifts slightly back toward molecule A – to the left. This is because the additional heat pushed the molecules toward a higher amount of energy, represented by molecule A. Also, if the reaction were written as follows: A ←→ B + heat, the addition of heat on the right side of the reaction shifts the equilibrium away from the stress toward the reactants)

What happens to the equilibrium when more of compound B is added to the container?

(The equilibrium shifts to the left, away from the additional B)

7. Now that the students have seen several examples of Le Chatelier's Principle in action, the teacher should introduce that vocabulary and the concept. The teacher should write Le Chatelier's Principle on the board as follows (#17 on student handout):

Le Chatelier's Principle
For a reversible process at equilibrium, when conditions of concentration, temperature, or pressure are changed, the reaction shifts in a direction that will counteract the stress and restore equilibrium.

Since the students have now seen the principle in action, they should also be able to restate this idea in their own words and give an example. Use a think-pair-share technique here: First give students time to individually think through what this means and write down a definition in their own words. Then ask students to share this definition with a partner and modify their definition to refine their thoughts based on what they hear. Then the teacher may call on individual students to share their definitions with the class.

8. The teacher will guide the students through the practice on the handout, question #18. This has examples of applying Le Chatelier's Principle to the real process associated with water's vapor pressure: $H_2O_{(l)}$ + heat ←→ $H_2O_{(g)}$

Change/Stress on system	**Direction of shift**	**Reason for shift**
Adding heat	*Right*	*Decrease excess heat*
Adding water vapor	*Left*	*Decrease excess water vapor*
Removing water vapor	*Right*	*Replace lost water vapor*
Decreasing temperature	*Left*	*Compensate by producing heat*
Increasing the pressure	*Left*	*Decrease the amount of gas to decrease pressure*

After the teacher guides the students through the first two examples, students will be expected to answer the remaining examples independently. The teacher should actively monitor the students in order to check for understanding.

Real-World Applications – additional examples that may be used for classroom discussion in order to differentiate for Gifted and Talented learners

Students may further discuss the real-world applications of the reaction in question # 18 on the handout (regarding the transition between liquid and gas of water with the addition or removal of heat) in order to discuss why water boils as heat is added or condenses as heat is removed.

Another real-world application of this process is the use of chemicals in medications that are designed to inhibit the action of enzymes by competition. In this situation, if the enzyme is considered to be a "reactant" in a reversible process, the inhibitory medication/chemical acts by effectively removing the enzyme from the system by binding to it. This would cause the equilibrium to shift to the left toward the reactants, resulting in a decrease in the rate of that forward reaction inside the body. Some examples of these medications are protease inhibitors used to treat HIV/AIDS, ethanol as an antidote to methanol poisoning, and acid pump inhibitors used to treat acid reflux disease by preventing the stomach from producing acids.

Assessment

At the end of class, the teacher may give the students 5 minutes to answer the following questions in order to assess their learning.

1. Explain in a paragraph what it means for a reaction to be at equilibrium. Include in your answer references to the amounts of reactants and products and the rates of the forward and backward reactions.

2. What is Le Chatelier's Principle and how does it apply to reversible reactions?

3. For the process A + B ←→ C + heat, what would happen to the equilibrium and why if:
    a) Some of compound A were added?
    b) The concentration of C were decreased?
    c) The temperature of the reaction were increased?

Equilibrium and Le Chatelier's Principle – Student Handout

Demo #1: water buckets

1. What will eventually happen to the amounts of water in each container?

2. What will eventually happen to the amounts of water being transferred each direction?

3. What happened to the amounts of water in each container?

4. What happened to the amounts of water being transferred each direction?

5. What do each of the following represent in terms of a reversible reaction?
   - The amount of water in container A
   - The amount of water in container B
   - The amount of water transferred from A to B
   - The amount of water transferred from B to A

6. What does this demonstration show about a reaction that is at equilibrium?

Demo # 2 – water buckets starting with different amounts

7. Make a prediction – what do you think will happen?

8. What was similar and what was different about the demonstration when we started with a smaller amount in container A? Why did the reaction behave this way?

9. Suppose that at equilibrium for the reaction: $2\ NH_{3\ (g)} \Leftrightarrow 3\ H_{2\ (g)} + N_{2\ (g)}$ there is a much greater amount of ammonia than hydrogen gas. Explain what might cause the equilibrium to be more heavily weighted towards the reactants.

Demo #3 – Computer simulation – A and B at equal Energy

10. Make a prediction about what you expect for the relative amounts of A and B at equilibrium.

11. What happened to the reaction? (Which way did the reaction shift and where was the final equilibrium point?)

12. What do you think would have happened if we had started by adding molecule B instead of molecule A?

Demo #4 – Computer simulation – A and B at different energies

13. Make a prediction about what you expect for the relative amounts of A and B at equilibrium.

14. What happened to the reaction? (Which way did the reaction shift and where was the final equilibrium point?)

15. What happens to the molecules in the container when it is heated? How does this affect the final equilibrium ratio?

16. What happens to the equilibrium when more of compound B is added to the container?

Summary Questions

17. Write Le Chatelier's Principle and then restate the concept in your own words.

18. Fill in the chart:

Change/Stress on system	Direction of shift	Reason for shift
Adding heat		
Adding water vapor		
Removing water vapor		
Decreasing temperature		
Increasing the pressure		