Lesson Plan: Equilibrium in a Beaker

FOR THE TEACHER

Summary
In this lesson, students will model equilibrium reactions using plastic chips to represent atoms. The goal of the lesson is to connect the symbolic model of an equilibrium reaction to its particle model.

Grade Level
AP Chemistry

NGSS Standards
HS-PS1-6: Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

Objectives
By the end of this lesson, students should be able to
- Explain the molecular changes that occur when an equilibrium system is disturbed
- Relate the symbolic representation to the particle representation for changes in an equilibrium system

Chemistry Topics
This lesson supports students’ understanding of
- Equilibrium constants
- LeChatelier’s Principle

Time
Teacher Preparation: 5 minutes to copy or construct beaker diagrams; If you want to sort the plastic chips into sets, this will take about 20 minutes.
Lesson: 45 minutes

Materials
- Large image of a beaker that can lay flat on the table (1 per group)
  - You may need to adjust the size to match whatever modeling pieces you choose. It may be easiest to just draw one on poster board. The pictures in the answer key are with 4 pieces of copy paper taped together. This was a good size. Alternatively, you can use the attached picture and enlarge it on a poster printer.
- Chips of two different colors (per group as written: 18 red chips and 48 yellow chips)
  - Many things can be substituted here, such as candies, small paper shapes, Legos, colored magnets, or parts from model kits. I chose plastic chips because they are inexpensive and because model kits may not contain enough parts of the same color.
  - The chips I’m using are from Amazon. There are many choices, so I am not providing a direct link. They are called “counting chips”. Math teachers use them, particularly in elementary school. Flinn also has them (Product # AP4585). These have wire around them so they can easily be gathered with a magnet (sold separately). Here is the link: https://www.flinnsci.com/wire-rimmed-counting-chips/ap4585/#
- Calculator
- Colored pencils or crayons, red and yellow, one set per person
Safety
No specific safety precautions need to be observed for this activity.

Teacher Notes
This activity is meant to help students understand the processes involved in equilibrium reactions, while specifically pointing out that the language we use when modeling them can lead to incorrect assumptions. It will be useful to reinforce this throughout the lesson with individual groups.

It is assumed that students have had a brief introduction to equilibrium prior to this activity. For simplicity, the equilibrium constant expression does not include “eq” as a subscript. Though the reaction quotient, Q, is not specifically addressed, you could certainly introduce it with the systems in Reaction 1. If you want to do this, you may also consider doing some Q/K calculations and analysis before the activity and then ask them to specifically use this in answering the questions. I included answers to these calculations in the answer key.

For the manipulative part of the model, you can use a variety of objects, as noted in Materials, and should either enlarge the attached beaker picture to an appropriate size for your objects or use poster paper and draw the beaker. You may choose to make up plastic bags with the appropriate number of chips (or other colored object) in them. Alternatively, you could ask students to go to a central location and count out the number of each color that they need. This activity is written with red and yellow, but any color could be used. You could edit the worksheet and leave a blank line for color if you don’t have enough of any two colors. This way, students can write in the colors they receive.

In Reaction 1, students are told to round all equilibrium constants to whole numbers. With a sample size this small, that was the best way to allow two different systems to have matching values. Please reinforce this with students in the beginning or they will likely get confused when the constants don’t match.

Reaction 2 uses smaller equilibrium constants, so students should NOT round to whole numbers.

Equilibrium in a Beaker – Expected Answers

Preliminary Questions
1. The word equilibrium hints that something is “equal”. What is equal in an equilibrium system?
   
   The rates of the forward and reverse reactions are equal at equilibrium.

2. Explain what an equilibrium value of $3.1 \times 10^{-5}$ indicates about the relative number of reactant molecules and product molecules.

   This value is much less than one. This indicates that there are very few products compared to reactants.
Reaction 1 – System 1

\[ 2 \text{XY}_2 \rightleftharpoons \text{X}_2 + 2 \text{Y}_2 \]

Red chip = X  
Yellow chip = Y

<table>
<thead>
<tr>
<th>Initial</th>
<th>Equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 \text{XY}_2</td>
<td>10 \text{XY}_2</td>
</tr>
<tr>
<td>4 \text{X}_2</td>
<td>8 \text{Y}_2</td>
</tr>
</tbody>
</table>

\[ K = 2.56 \rightarrow 3 \]

**Analysis Questions**

1. When we talk about the “left side” of the equation, what are we talking about?

   **The reactant particles.**

   a. Under initial conditions, is it possible for only what is represented by the “left side” of the equation to be in the beaker? Explain.

   **Yes, if you start the reaction with only reactants.**

2. When we talk about equilibrium conditions, which side of the reaction represents what is in the beaker?

   **Both sides. Equilibrium systems contain both reactants and products.**

   a. Under equilibrium conditions, is it possible for only what is represented by the “left side” of the equation to be in the beaker? Explain.

   **No. Equilibrium systems contain both reactants and products.**

3. When the reaction was at initial conditions, how did we know that the reaction would proceed in the forward, rather than the reverse direction?

   **There were only reactants present, so the reaction could not proceed in the reverse reaction if there were no product molecules to react.**
Reaction 1 – System 2

<table>
<thead>
<tr>
<th>Initial</th>
<th>Equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 XY₂</td>
<td>12 XY₂</td>
</tr>
<tr>
<td>4 X₂</td>
<td>3 X₂</td>
</tr>
<tr>
<td>14 Y₂</td>
<td>12 Y₂</td>
</tr>
<tr>
<td>Q=7.84 → 8</td>
<td>Q=K=3</td>
</tr>
</tbody>
</table>

Analysis Questions

4. Under initial conditions for this system, which side of the reaction was represented in the beaker? Explain.
   
   Both. The initial conditions in this case was a mixture of reactants and products.

5. How did we know that the reaction would shift left in this system?

   Since the previous system was at equilibrium and we added more product molecules, these molecules would have to react to reduce the equilibrium constant back to its original value. OR
   Since the previous system was at equilibrium, both forward and reverse rates were equal. When product molecules were added, the reverse reaction sped up, thus creating more reactants until the rates were again equal.

6. How was the reaction able to reach equilibrium again, after the original addition of molecules?

   Product molecules reacted and rearranged into reactant molecules to change the ratio of products to reactants.

7. When discussing this kind of change, we often say that we “add molecules to the right side of the equation”. As you see in the beaker, there is no “right side” portion of the beaker! Use what you did with your model to find a better way to state the change that was made.

   Additional product molecules are added to an equilibrium system.

8. When discussing this kind of equilibrium shift, we often say that “the reaction shifted to the left to relieve the stress”. Again, from your beaker model, you should realize that there are no “sides” of a real reaction! Use what you did with your model to find a better way to state the change that occurs.
The additional product molecules reacted (in the reverse reaction) to form reactant molecules until the ratio of concentrations again equaled the value of the equilibrium constant. 
OR
The additional product molecules caused the rate of the reverse reaction to increase, so more reactant molecules were generated.

**Reaction 2**

\[ 2A + B_2 \rightleftharpoons 2AB + \text{heat} \]

Red chip = A
Yellow chip = B

<table>
<thead>
<tr>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 A</td>
<td>14 A</td>
</tr>
<tr>
<td>2 B₂</td>
<td>4 B₂</td>
</tr>
<tr>
<td>8 AB</td>
<td>4 AB</td>
</tr>
<tr>
<td>K=1.3</td>
<td>K=0.33</td>
</tr>
</tbody>
</table>

**Analysis Questions**

9. How many total A atoms are present in the initial beaker? How many B atoms?

18 A atoms and 12 B atoms

10. How many total A atoms are present in the equilibrium beaker? How many B atoms?

18 A atoms and 12 B atoms

11. Why is the total number of A and B atoms the same in each beaker?

Law of conservation of mass. All atoms present in the beginning must still be present in the end, but may not be arranged in the same way.

12. How many total particles (molecules or unbonded atoms) are present in the initial beaker? In the equilibrium beaker?

20 particles in initial. 22 particles in equilibrium
a. How is it possible that the number of particles in the equilibrium beaker is not equal to the number of particles in the initial beaker?

Only atoms must be conserved. Atoms can rearrange in different ways so that the total number of particles could change throughout the reaction.

13. Both the initial and the final beakers were at equilibrium.
   a. What condition changed from initial to final?

   Temperature was increased.

   b. Why did the reaction shift to the left when this change occurred?

   This is an exothermic reaction. Heat will increase the rate of the reverse reaction more than the forward reaction, thus creating more reactants.

   c. What is the value of the equilibrium constant in each of the beakers?

   Initial: 1.28    Final: 0.33

   d. What is the effect on the equilibrium constant of adding heat to an exothermic reaction?

   Adding heat decreases the value of the equilibrium constant.

Conclusion
When we use models to explain chemical changes, we often use words that apply to the model, but not to the actual system. Write a one-paragraph summary of how the language used when modeling with chemical equations differs from that used when modeling with physical representations of atoms in a beaker.

When using the chemical equation as a model, it is written in a left to right direction, so we use left and right to talk about reactants and products and to which direction the reaction is proceeding. In physical representations, there are no left and right. The beginning of a reaction may have only reactants or may have a mixture of reactants and products. All of these are present in the same beaker, so there are no sides. When molecules react, their atoms rearrange until the requirements of equilibrium are met. The chemical equation model is a good way to organize information but does not show what the atoms are doing. The physical representation is a better way to show what the atoms are doing in a chemical reaction.
Lesson

Equilibrium in a Beaker

Background
You have previously learned that equilibrium reactions are reversible reactions that result in a mixture of species. The equilibrium constant, K, for a given reaction is a number that allows us to predict relative amounts of reactant and product molecules in a system. The value of the equilibrium constant can be calculated if equilibrium concentrations are known. Following is an example of this calculation for a given reaction:

\[ aA + bB \rightleftharpoons cC + dD \]

\[ K = \frac{[C]^c[D]^d}{[A]^a[B]^b} \]

Preliminary Questions
3. The word equilibrium hints that something is “equal”. What is equal in an equilibrium system?

4. Explain what an equilibrium value of \(3.1 \times 10^{-5}\) indicates about the relative number of reactant molecules and product molecules.

Objective
Upon completion of this activity, you will be able to explain the molecular changes that occur when equilibrium systems are established or disturbed.

Materials
- Large image of a beaker that can lay flat on the table
- Chips of two different colors (as written: 18 red chips and 48 yellow chips)
- Calculator

Procedure
- Lay out the beaker image on the table.
- Gather your chips and be sure you know which color represents each atom.
- Follow the directions in each section to create your models and to answer the questions.
  - For equilibrium calculations, treat each modeled molecule as 1-molar
  - All equilibrium values should be rounded to whole numbers unless specified!
Reaction 1 – System 1

\[ 2 \text{XY}_2 \rightleftharpoons \text{X}_2 + 2 \text{Y}_2 \]

Red chip = X  
Yellow chip = Y

- In the beaker, use the colored chips to represent 18 molecules of reactant. This is your “initial conditions”. Draw a model of this in your “Initial” box below.
- Using the chips, decompose your \(\text{XY}_2\) molecules into the designated products until you have enough products to give you an equilibrium value of 3.
- This is your “equilibrium conditions”. Draw a model of this in your “Equilibrium” box below.

<table>
<thead>
<tr>
<th>Initial</th>
<th>Equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analysis Questions

14. When we talk about the “left side” of the equation, what are we talking about?

a. Under initial conditions, is it possible for only what is represented by the “left side” of the equation to be in the beaker? Explain.

15. When we talk about equilibrium conditions, which side of the reaction represents what is in the beaker?
a. Under equilibrium conditions, is it possible for only what is represented by the “left side” of the equation to be in the beaker? Explain.

16. When the reaction was at initial conditions, how did we know that the reaction would proceed in the forward, rather than the reverse direction?

**Reaction 1 – System 2**

A reaction in equilibrium has a certain number of molecules of each reactant and product. This number can change if conditions are changed.

*Change in concentration*

Question to explore: If additional molecules are added, can the reaction find equilibrium again?

- To your beaker model from Reaction 1 – System 1, use additional chips to add six more molecules of $Y_2$ to the mixture.
- This is your new “initial conditions”. Draw this in the “Initial” box below.
- The reaction will now shift to the left. Simulate this by reacting $X_2$ molecules with $Y_2$ molecules until the equilibrium value again equals 3.
- This is your “equilibrium conditions”. Draw a model of this in your “Equilibrium” box below.

<table>
<thead>
<tr>
<th>Initial</th>
<th>Equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Analysis Questions

17. Under initial conditions for this system, which side of the reaction was represented in the beaker? Explain.

18. How did we know that the reaction would shift left in this system?

19. How was the reaction able to reach equilibrium again, after the original addition of molecules?

20. When discussing this kind of change, we often say that we “add molecules to the right side of the equation”. As you see in the beaker, there is no “right side” portion of the beaker! Use what you did with your model to find a better way to state the change that was made.

21. When discussing this kind of equilibrium shift, we often say that “the reaction shifted to the left to relieve the stress”. Again, from your beaker model, you should realize that there are no “sides” of a real reaction! Use what you did with your model to find a better way to state the change that occurs.
Reaction 2

\[ 2A + B_2 \rightleftharpoons 2AB + \text{heat} \]

Red chip = A  Yellow chip = B

- Clear your beaker of the chips used in reaction 1 and start with an empty beaker.
- An equilibrium system at room temperature has been shown to contain the following mixture:

  10 A; 2 B; 8 AB

  o Use the chips to model this equilibrium on your beaker image.
  o This is your “initial conditions”. Draw a model of this in your “Initial” box below.
- When heated to a certain temperature and maintained, this causes 4-molar of the AB to decompose into A and B₂.
  o Use the chips to model this change on your beaker image.
  o This is your “final conditions”. Draw a model of this in your “Final” box below.

### Analysis Questions

Do NOT round equilibrium values to whole numbers for this set.

22. How many total A atoms are present in the initial beaker? How many B atoms?

23. How many total A atoms are present in the equilibrium beaker? How many B atoms?

24. Why is the total number of A and B atoms the same in each beaker?
25. How many total particles (molecules or unbonded atoms) are present in the initial beaker? In the equilibrium beaker?

   a. How is it possible that the number of particles in the equilibrium beaker is not equal to the number of particles in the initial beaker?

26. Both the initial and the final beakers were at equilibrium.
   a. What condition changed from initial to final?

   b. Why did the reaction shift to the left when this change occurred?

   c. What is the value of the equilibrium constant in each of the beakers?

   d. What is the effect on the equilibrium constant of adding heat to an exothermic reaction?

**Conclusion**
When we use models to explain chemical changes, we often use words that apply to the model, but not to the actual system. Write a one-paragraph summary of how the language used when modeling with chemical equations differs from that used when modeling with physical representations of atoms in a beaker.