**Counting Equilibrium and Le Chatelier’s Principle**

**Introduction:** Equilibrium is a key principle in chemistry, biology, physics and a host of other disciplines. When a system is at equilibrium, no change in the state of the system occurs unless an external force is applied. Two types of equilibrium exist in nature, static and dynamic. In a static equilibrium, no change occurs to a system over time because all forces acting on the system cancel. In a dynamic equilibrium, the system is continually changing, but each of these changes cancel, leaving the system in the same state. Almost all equilibria in chemistry and biology are dynamic. In today’s first activity, you will model dynamic chemical equilibria using candies or coins. In today’s second activity, you will predict and model what happens to dynamic equilibria when they are perturbed by an external factor. We will then discuss the theory used to predict changes in equilibria when they are perturbed. In the third activity, you will model a three-component system, and observe how adding a third component affects the nature of an equilibrium. In today’s final activity, you will model equilibrium in a more complex system, a simplified food chain, and predict how different external influences will affect the balance of this system.

**Learning Goals:**

* You will be able to define the scientific terms **system**, **surroundings**, and **equilibrium**.
* You will be able to describe the difference between a static and dynamic equilibrium and identify examples of each of these types of equilibria.
* You will be able to predict how external forces will affect systems at equilibrium.

**Schedule:**

* *11:00-11:20 Cultural connection*
* *11:20-11:45 Introduction to Equilibrium*
* *11:45-12:10 Activity I – Modeling a Dynamic Equilibrium*
* *12:10 - 12:35 Activity II – Perturbing a Dynamic Equilibrium*
* *12:35-1:10 Lunch*
* *1:10-1:30 Le Chatelier’s Principle – Predicting Changes in Equilibrium*
* *1:30-2:00 Activity III – Modeling a Three Component Equilibrium*
* *2:00-2:20 Equilibria and Ecosystems*
* *2:20-2:45 Activity IV – Modeling a Simple Food Chain*
* *2:45-3:00 Wrap up*

**Activity 1 – Modeling a Dynamic Equilibrium**

**Materials:**

* 2-3 Sheets of Graphing Paper
* 1 Marker
* 2 Cups
* 40-50 Coins or Candies
* 1 Pencil

**Instructions:**

1. Label one of your cups “liquid” and the other cup “gas” using your marker.
2. Place 24 coin or candy “water molecules” in the “liquid” cup.
3. Make three columns on one sheet of graphing paper.
4. Label the columns “Time Step”, “Liquid”, and “Gas”.
5. Following example 1 below, move your “water molecules” between the “Liquid” and “Gas” cups, recording the number of “molecules” in each cup at each time step.
6. Continue moving “molecules” until the system reaches equilibrium.
7. Make a line graph of your equilibrium data using the step # as the x-axis and the number of “molecules” in each cup as the y-axis.
8. Leave all “molecules” in their respective cups for the next activity.

**Example 1:**

If we have the reaction:



For the first time point, 24/3 = 8 “Liquid” molecules will move to the “Gas” cup, 0/4 = 0 “Gas” molecules will move to the “Liquid” cup. At time point one you will thus have 16 “Liquid” molecules and 8 “Gas” Molecules. At time point two 16/3 = 5 (always round down) “Liquid” molecules will to the “Gas” cup, and 8/4 = 2 “Gas” molecules will move to the “Liquid” cup. At time point two you will have (16 - 5 + 2) = 13 “Liquid” molecules and (8 + 5 - 2) = 11 “Gas” molecules. The data in your chart should look like this:

|  |  |  |
| --- | --- | --- |
| Step | Liquid | Gas |
| 0 | 24 | 0 |
| 1 | 16 | 8 |
| 2 | 13 | 11 |
| 3 |  |  |
| 4 |  |  |

**Questions:**

How many steps did it take for your system to reach equilibrium? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

If you started with twice as many “water molecules”, how many steps would it take to reach equilibrium? Why? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

What does your graph look like when equilibrium is reached?

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What is the relationship between the number of “molecules” in each cup at equilibrium and the number that move during each time point? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Activity 2 – Perturbing a Dynamic Equilibrium**

**Materials:**

* All materials from activity 1.

**Instructions:**

1. Add an additional 20 “molecules” to the cup labeled “Gas”.
2. Record the number of “molecules” in each cup in your chart as before, and put an asterisk next to that time point.
3. Following the example above, move your “water molecules” between the “Liquid” and “Gas” cups, recording the number of “molecules” in each cup at each time point.
4. Continue moving “molecules” until the system reaches equilibrium.
5. Extend the line graph of your equilibrium data using your new data, marking on the graph the time point when the additional molecules were added.

**Questions:**

What happened to the number of “Liquid” molecules at equilibrium when you added more “Gas” molecules?: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

What is the relationship between the equilibrium values before you added extra “Gas” molecules and the equilibrium values after you added the “Gas” molecules? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Activity 3 – Modeling a Three Component Equilibrium**

**Materials:**

* 2-3 Sheets of Graphing Paper
* 1 Marker
* 3 Cups
* 40-50 Coins or Candies
* 1 Pencil or 3 Colored Pencils

**Instructions:**

1. Label one of your cups “Solid”, one cup “Liquid”, and the final cup “Gas”.
2. Place 40 coin or candy “molecules” into the “Solid” cup.
3. Make four columns on one sheet of graphing paper.
4. Label the columns “Time point”, “Solid”, “Liquid”, and “Gas”.
5. Following example 2 below, move your “molecules” between each cup, and record the number of molecules in each cup at each time point.
6. Continue moving “molecules” until the system reaches equilibrium.
7. Make a line graph of your equilibrium data using the time point as the x-axis and the number of “molecules” in each cup as the y-axis.
8. Once you have reached equilibrium, continue to example 3 below, which contains an irreversible reaction.

**Example 2:**

If we have the reaction:



For the first time point, 40/4 = 10 “Solid” molecules will move to the “Liquid” cup, 0/2 = 0 “Liquid” molecules will move to the “Solid” cup, 0/2 = 0 “Liquid” molecules will move to the “Gas” cup and 0/4 = 0 “Gas” molecules will move to the “Liquid” cup. At time point one you will thus have 30 “Solid” molecules, 10 “Liquid” molecules and 0 “Gas” molecules. At time point two 30/4 = 7 (always round down) “Solid” molecules will to the “Liquid” cup, 10/2 = 5 “Liquid” molecules will move to the “Solid” cup, 10/2 = 5 “Liquid” molecules will move to the “Gas” cup and 0/4 = 0 “Gas” molecules will move to the “Liquid” cup. At time point two you will have 28 “Solid” molecules, 7 “Liquid” molecules, and 5 “Gas” molecules. The data in your chart should look like this:

|  |  |  |  |
| --- | --- | --- | --- |
| Time point | A | B | C |
| 0 | 40 | 0 | 0 |
| 1 | 30 | 10 | 0 |
| 2 | 28 | 7 | 5 |
| 3 | 24 | 9 | 7 |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
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**Example 3:**

In an irreversible reaction, molecules that reach a certain state cannot re-enter the equilibrium. You can model this by removing the molecules that would be going into cup “C” from the system. **If these are candy, you may now eat them when they are placed in cup “C”.**



For the first time point, 40/4 = 10 “A” molecules will move to cup “B”, 0/2 = 0 “B” molecules will move to cup “A”, and 0/2 = 0 “B” molecules will move to cup “C”. At time point one you will thus have 30 “A” molecules, 10 “B” molecules and 0 “C” molecules. At time point two 30/4 = 7 (always round down) “A” molecules will to cup “B”, 10/2 = 5 “B” molecules will move to cup “A”, and 10/2 = 5 “B” molecules will move to cup “C”. At time point two you will have 28 “A” molecules, 7 “B” molecules, and 5 “C” molecules. The data in your chart should look like this:

|  |  |  |  |
| --- | --- | --- | --- |
| Time point | A | B | C |
| 0 | 40 | 0 | 0 |
| 1 | 30 | 10 | 0 |
| 2 | 28 | 7 | 5 |
| 3 |  |  |  |
| 4 |  |  |  |

**Questions:**

Did this system reach equilibrium? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

How does the number of molecules in each cup vary from example 2 above?

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**Activity 4 – Modeling a Simple Food Chain**

**Materials:**

* A computer with internet access

**Instructions:**

1. Navigate to <http://www.shodor.org/interactivate/activities/RabbitsAndWolves/>
2. Observe the simulation screen, zoom in if it is too small to see well
3. Identify what icons indicate wolves, rabbits, and grass
4. Click the button labeled “View Population Graph” to bring up a graph of the number of wolves and rabbits at each time point, as well as the percentage of grass at each time point.
5. Click the button labeled “Start Simulation” to begin the simulation of this food chain.
6. After the simulation reaches an equilibrium, or after 500 iterations, click the “Pause Simulation” button.
7. Record the results of your simulation in the questions below.
8. Click the button labeled “View/Modify Parameters”, then click the button labeled “View/Modify Start-Up Parameters” in the box that appears.
9. Modify the amount of starting grass, rabbits or wolves.
10. Predict what effect this will have on the simulated ecosystem.
11. Click the “Return to Simulator” button.
12. Click the “Reset Simulation” button.
13. Click the “Start Simulation” button.
14. Observe the population graph for your modified starting numbers and answer the questions below.
15. Try to find starting parameters that lead to a stable equilibrium population of rabbits and wolves.
16. If you find starting parameters that lead to a stable equilibrium, try running the simulation again with those parameters.

**Questions:**

* Did the simulated ecosystem reach equilibrium using the initial settings?:  
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* What happened to the number of rabbits as the simulation progressed?: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* What starting parameter did you change? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* How do you think this change will affect the simulation? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* How did the simulation results change between the initial parameters and your changed parameters? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  
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* Did this match your prediction? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* Were you able to find a set of starting parameters that led to stable equilibrium populations of wolves and rabbits? If so, what were those starting parameters? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_  
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* Was this equilibrium robust? I.e. if you run the simulation again with the same starting parameters do you reach the same equilibrium? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Scientific Standards Addressed in this Activity:

MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

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.

HS-ESS3-3. Create a computational simulation to illustrate the relationships among the management of natural resources, the sustainability of human populations, and biodiversity.