



Connected Chemistry

Equilibrium Unit

Lesson 1: Introduction to Dynamic Equilibrium



Student's Lesson at a Glance

Lesson Summary

In this lesson, students compare the properties of both reversible and irreversible reactions. Some of these reactions are in a state of dynamic equilibrium. Through this lesson students discover the meaning of dynamic equilibrium through observing submicroscopic interactions as well as dynamic plots of concentration versus time.

SWBAT (Student will be able to)

- Use submicroscopic chemical representations and chemical symbols to represent chemical reactions observed macroscopically in the laboratory.
- Determine whether a system is at equilibrium using macroscopic and submicroscopic observations.
- Use models to reason about the submicroscopic world and know that models can only approximate that world.
- Define reversible reactions as the interconversions of reactants to products and products to reactants.
- Define equilibrium as a system in which the rate of the conversion of reactants to products is equal to the rate of conversion of products to reactants.
- Define irreversible reactions as the conversion of reactants to products only.

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in bold. Additional words that will expand your scientific vocabulary are in italics.



CCC Reminder

Students and teachers from many different schools helped design CCC so that the lessons are more helpful and meaningful for all classroom participants.

- Many questions ask you “what you think” or “to make predictions.” The only answer that is wrong is the answer that is left blank.
- Prefixes and suffixes on words can help you discover the meaning of a word.
- Use the vocabulary section and note section to take good notes so that studying for tests and quizzes is easier.
- When sketching concentration plots, draw the lines quickly and focus on getting the slope as accurate as you can.
- Draw a key when you are sketching. Keys can help you and others decode your sketches later.
- In the Student Appendix ([page 53](#)), there is a supplement to help you learn how to calculate K_{eq} and show how the calculation was derived.

Notes

Homework

Upcoming Quizzes/ Tests



*This page has been left blank.
Please turn to the next page.*



Activity 1: Connecting

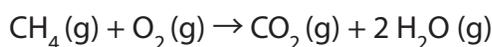
1. Based on what you know about physical and chemical changes, what is the difference between a chemical change and a physical change at the submicroscopic level?

In a chemical change, the atoms of the reactants are rearranged into new products. These new products may or may not be in the same state.

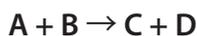
Many of the *chemical* and *physical changes* that we investigate in chemistry involve either the transformation of one substance into another substance or one physical state into another state. Some transformations are irreversible. For example, once an orange is squeezed, you cannot put the juice back into the orange; such a physical change is irreversible. Similarly, some chemical reactions are also irreversible. Consider a piece of toast that is burnt in a toaster. It is impossible to undo the combustion reaction that produced the black and inedible bread.

In addition to being irreversible, many chemical reactions involve the complete conversion of reactants to products. In these reactions, all of the reactants are converted into products leaving behind no reactants. For example, when a hydrocarbon fuel like methane gas combusts in the presence of oxygen gas, gaseous water and carbon dioxide gas are produced as shown by the following equation:

Forward Reaction →

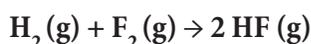


This reaction is **irreversible**. These types of reactions progress in the **forward** direction only. In an irreversible reaction, reactants are converted into products and once the products form, they cannot be converted back into the reactants. As shown in the symbolic example below, an irreversible reaction is represented with a single arrow that points in the direction from the reactants (A and B to the products (C and D).

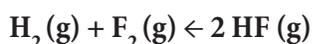


Other transformations can be **reversible**. This means that both a forward and reverse process can occur. For example, some physical changes, such as liquid water becoming steam upon boiling, are reversible. Some chemical changes are also reversible, meaning that a forward reaction and a reverse reaction can both occur. At the submicroscopic level, reversible reactions involve two reactions that occur simultaneously. For example, the forward reaction and the reverse reaction involving hydrogen, fluorine, and hydrogen fluoride are shown in the following equations:

Forward Reaction →



Reverse Reaction ←

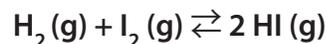
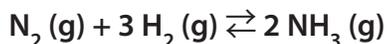




Instead of writing out two separate equations, chemists denote these reversible reactions with a set of two arrows as shown in the sample equation below:



The set of two arrows used in chemistry may look similar to a two-way road sign, which indicates that cars can drive in either direction on a road. Examine the two reversible reactions below:

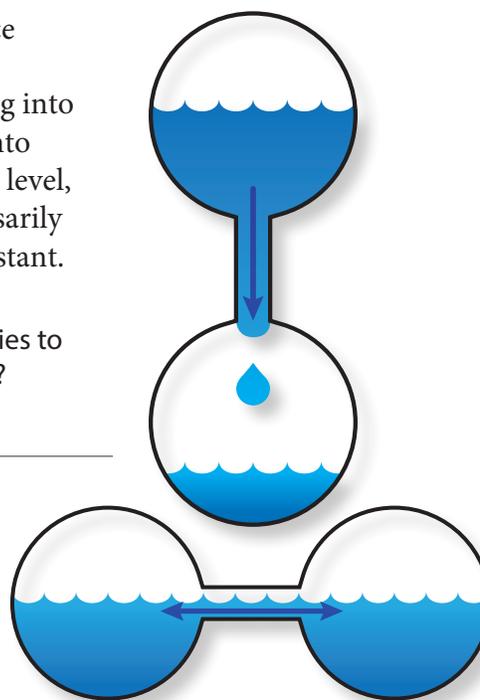


2. Do you think that the double arrows mean that the amount of products and reactants are equal to each other? *Support your claim with evidence.*

Some reversible reactions can reach a state of **dynamic equilibrium**; that is, the rate at which the reactants produce products is equal to the rate at which products produce reactants. In reversible reactions, reactants are transforming into products at the same rate that products are transforming into reactants on the submicroscopic level. On the macroscopic level, the concentrations of reactants and products are not necessarily equal at equilibrium, but the *concentrations* do remain constant.

3. What does the word dynamic mean? How do you think it applies to what is happening when a reaction is in a state of equilibrium?

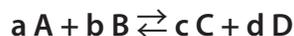
4. How are the pictures on the right similar to what happens in an irreversible reaction and a reaction that reaches a state of dynamic equilibrium?





Activity 2: Exploring the Equilibrium Constant

Consider the general equation for an equilibrium reaction in which a, b, c, and d are the coefficients for substances A, B, C, and D:



For this reaction to proceed, the right conditions are necessary. A and B must collide in a precise manner and with enough energy to convert to C and D. Similarly, C and D must collide in a precise manner and with enough energy to convert to A and B. The concentration of each substance is important because concentration will determine how many collisions take place at any given moment. The reaction progresses in the forward direction when A and B collide and progresses in the reverse direction when C and D collide.

The two sides of the equation are dependent on the other. As the reaction progresses forward, the concentrations of the products C and D increase and the reactants A and B decrease. As the reaction progresses in reverse, the concentration of the reactants A and B increase, but the products C and D decrease.

In the activity below, consider the reaction between two gases, A and B, to form gas AB. Just as in the general equation above, certain conditions must be met for the reaction to occur and the two sides of the equation are dependent on one another. Unlike the general equation above, only one product is formed.

Part 1

Complete each set of sketches below according to the table headers.

Draw a submicroscopic sketch of the gaseous reactants illustrating a system in which $[A] > [B]$. Draw 10 total atoms.	Draw a submicroscopic sketch of the reaction in which $A(g) + B(g) \rightleftharpoons AB(g)$.
Key	



Draw a submicroscopic sketch of the gaseous reactants illustrating a system in which $[A] < [B]$. Draw 10 total atoms.	Draw a submicroscopic sketch after the reaction of the products in which $A(g) + B(g) \rightleftharpoons AB(g)$.
Key	

1. How can this reaction be identified as a reversible reaction?

2. What must happen for a reaction to occur?

3. Write out the forward and reverse reactions separately, including states.

4. How can you change the molar concentration of any reactant in a reaction? *Be sure to include a discussion at the macroscopic level.*



5. What would have to happen in the reaction above for it to reach a state of dynamic equilibrium?
Be as specific as possible.
-
-
6. If the molar concentration of A increases, how will the molar concentration of B change during the reaction?
-
7. When the molar concentration of either A or B increases, the number of collisions between A and B increases. What effect does this have on the rate of the forward reaction? *Support your claim with evidence.*
-
-
8. If the molar concentration of A is decreased, what effect would this have on the concentration of the product AB? *Support your claim with evidence.*
-
-
9. Is this a reversible or irreversible reaction? *Support your claim with evidence.*
-
-
10. If the molar concentration of AB is increased, what effect would this have on the rate of the forward reaction? *Support your claim with evidence.*
-
-

Part 2

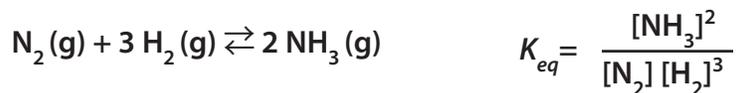
Symbolically, the relative concentration of reactants and products at equilibrium is represented using K_{eq} . The equilibrium constant is specific to each reaction and represents the molar concentration of products versus the reactants.

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



For more information on how to derive the formula to calculate the equilibrium constant, see the Student Appendix (page 53).

The equilibrium constant for the reaction between nitrogen gas and hydrogen gas below would be represented as follows:



To calculate the value of the equilibrium constant, the concentration of each reactant and product at equilibrium must be measured in the laboratory. For the example above, the following concentrations are observed:

$$\begin{aligned} [\text{N}_2] &= 2.16 \text{ mol/L or } 2.16 \text{ M} \\ [\text{H}_2] &= 0.30 \text{ mol/L or } 0.30 \text{ M} \\ [\text{NH}_3] &= 0.50 \text{ mol/L or } 0.50 \text{ M} \end{aligned}$$

Given these values, K_{eq} for this reaction is calculated as follows:

$$K_{eq} = \frac{[0.50]^2}{[2.16][0.30]^3} = \frac{0.25}{0.19}$$
$$K_{eq} = 1.32$$

Not all equilibrium reactions are alike. The equilibrium constant for a reaction provides sufficient information to distinguish between different types of reactions. Some equilibrium reactions contain higher concentrations of products than reactants at equilibrium, while others contain higher concentrations of reactants than products. If the K_{eq} is greater than one ($K_{eq} > 1$), then the products have a higher concentration than the reactants at equilibrium. If the K_{eq} is less than one ($K_{eq} < 1$), then the reactants have a higher concentration than the products at equilibrium. By knowing the K_{eq} constant, a chemist is able to determine if the equilibrium reaction favors the product or the reactant.

Considering the calculation above, the equilibrium reaction favors the product, indicating that there are more products present than reactants because $K_{eq} = 1.32$, which is greater than 1. If the K_{eq} is equal to 1 ($K_{eq} = 1$), then the concentration of products is equal to the concentration of reactants.

K_{eq} can also equal infinity ($K_{eq} = \infty$). Irreversible reactions can be thought to have an infinite equilibrium constant if there are no reactants left.

11. Scientists frequently say that one side of a chemical reaction is favored over the other. What does it mean if someone says "You are my favorite person"? How does this relate to chemical equilibrium?



12. In sports, what does it mean if Team X is favored to win against 10 other teams? How does this relate to chemical equilibrium?

13. Draw a picture using generic $A+B \rightleftharpoons AB$ equation to represent the reaction using three different K_{eq} values: 1, 0.5, and 3.

Draw a submicroscopic picture of the reaction at $K_{eq} = 1$	Draw a submicroscopic picture of the reaction at $K_{eq} = 0.5$	Draw a submicroscopic picture of the reaction at $K_{eq} = 3$
Description of your drawing:	Description of your drawing:	Description of your drawing:



Activity 3: Simulation of Dynamic Equilibrium

Part 1

Use Simulation 1, Sets 1-4

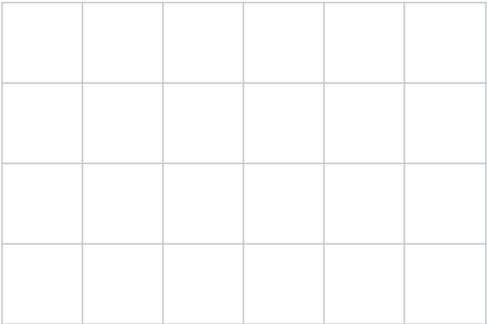
Throughout this four-part activity, the relationships between reaction rate, concentration and dynamic equilibrium will be emphasized.

- *You will make qualitative and quantitative observations about four different reactions in the simulation and complete the table on the following pages.*
- *Follow your teacher's example and directions for completing the observation table on the next two pages.*
- *When creating sketches of the concentration plot, be sure to label axes and to include a key.*
- *Create a balanced equation in the spaces provided on the next pages, including phases of matter and the correct arrows to indicate whether the reaction is reversible or irreversible.*

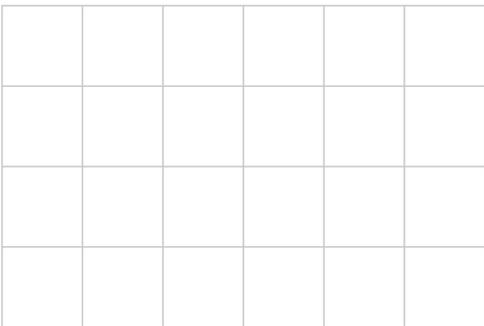


	Simulation 1, Set 1: Teacher Example (0 seconds)	Simulation 1 Set 1: Teacher Example (30 seconds)																								
Submicroscopic Sketch																										
Observations																										
Chemical Formula																										
K_{eq}																										
	Key	Graph																								
		<table border="1" style="width: 100%; height: 100%;"> <tr><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td></tr> </table>																								

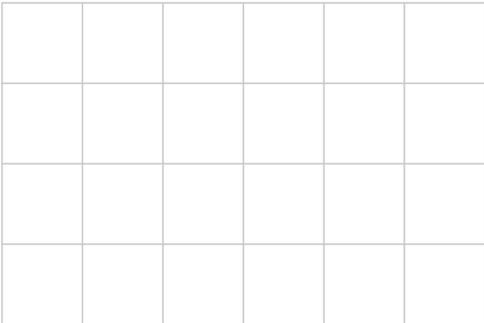


	Simulation 1, Set 2 (0 seconds)	Simulation 1, Set 2 (30 seconds)
Submicroscopic Sketch		
Observations		
Chemical Formula		
K_{eq}		
	Key	Graph 



	Simulation 1, Set 3 (0 seconds)	Simulation 1, Set 3 (30 seconds)
Submicroscopic Sketch		
Observations		
Chemical Formula		
K_{eq}		
	Key	Graph 



	Simulation 1, Set 4 (0 seconds)	Simulation 1, Set 4 (30 seconds)
Submicroscopic Sketch		
Observations		
Chemical Formula		
K_{eq}		
	Key	Graph 



Part 2: Determining Reversible/Irreversible Reactions

- Using your observations from the table, determine which two reactions are reversible and which two reactions are irreversible.
- For each reaction, provide two pieces of evidence from the graph and graphics window that you used to make your conclusion.

1. I have used the following two pieces of evidence to conclude that reaction #1 is **reversible / irreversible**. (*Circle one*)

2. I have used the following two pieces of evidence to conclude that reaction #2 is **reversible / irreversible**. (*Circle one*)

3. I have used the following two pieces of evidence to conclude that reaction #3 is **reversible / irreversible**. (*Circle one*)

4. I have used the following two pieces of evidence to conclude that reaction #4 is **reversible / irreversible**. (*Circle one*)

**Part 3: Determining Chemical Equilibrium**

- Using your observations from the table, complete the following sentences about chemical equilibrium.
- For each reaction, provide two pieces of evidence from the graph and window that you used to make your conclusion. Only two of the four reactions are at equilibrium.

5. Reaction _____ reaches chemical equilibrium at _____ seconds. *Support your conclusion with two pieces of evidence.*

6. Reaction _____ reaches chemical equilibrium at _____ seconds. *Support your conclusion with two pieces of evidence.*

7. What is K_{eq} ? What does it mean?

8. When $K_{eq} > 1$ at equilibrium, there will be more **products / reactants** (*Circle one*). *Support your conclusion with evidence from one of the simulations.*

9. When $K_{eq} < 1$ at equilibrium, there will be more **products / reactants** (*Circle one*). *Support your conclusion with evidence from one of the simulations.*

10. Reactions with K_{eq} values of infinity are **reversible / irreversible** (*Circle one*). *Support your conclusion with evidence.*



11. Back in Activity 2 (starting on page 6), you were asked to complete sketches and answer questions about a generic equilibrium reaction before seeing the simulations. How would your sketches and answers change based on what you have learned?

12. Within any of the sets, did K_{eq} change from the initial start to time 30 seconds? Why do you think this is what happened?



Activity 4: Physical Modeling of Equilibrium Lab

To better understand what happens during a reaction that reaches a state of dynamic equilibrium, you will work in small groups to simulate the shift between products and reactants. Specifically, you will explore the relationship between product and reactant concentration, the rate of the reaction, and the ratio of products and reactants as you did in the simulation activity earlier in this lesson.

Materials

- 40 pennies for each group
- 1 large blank sheet of paper
- Butcher block paper or half sheet of poster board

Introduction

For this lab, students use pennies to represent substances undergoing a chemical reaction. In groups of two, draw a line down the middle of a sheet of paper. Label the left side of the paper “R” for reactants and the right side “P” for products.

Perform all of your “reactions” on this paper according to the following equation:



To represent molecules that are reactants, put pennies on the reactant side of the paper (left); products are pennies on the product side of the paper (right). Reactions are represented by moving pennies from one side of the paper to the other.

Part 1

1. One person should move pennies from the reactant side and the other should move pennies from the product side of the paper. Start with pennies on the reactant side of the paper.
2. Each round, you exchange pennies between R and P.
3. For each round, R should move half of his or her pennies to the P side. P should move one fourth of his or her pennies to the R side. (If you end up with a decimal for the number to exchange, you should round up.)
4. At the end of each round, count the pennies on each side of the paper and keep track of the numbers in a table.
5. Repeat the procedure above for a total of 10 rounds.
6. After 10 rounds, calculate the ratio of products to reactants (ratio = P/R).



Round	Reactant	Product	P/R Ratio
0	40	0	
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Part 2

- Part 2 is the same as Part 1, except for the starting amounts of reactants and products. Select any number of pennies to put in the reactant side and put the rest on the product side.
- For each round, R should move half of his or her pennies to the P side. P should move one fourth of his or hers to the R side. (If you end up with a decimal for the number to exchange, you should round up.)
- Keep track of the number of pennies on each side after each transaction in the table below.
- Repeat the procedure above for a total of 10 rounds.
- At the end of the last round, calculate the ratio of products to reactants (ratio = P/R).

Round	Reactant	Product	P/R Ratio
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			



Round	Reactant	Product	P/R Ratio
10			

Part 3

- Part 3 follows the same rules as Parts 1 and 2, except you need to join up with another group for this part because it requires more total pennies. Start again with 40 reactants and no products.
- One of the two groups exchange for five rounds and calculate the ratio of products to reactants.
- After the fifth round, add another group's pennies to the reactant side of the equation and continue to exchange for another 10 rounds.
- At the end of the last round, calculate the ratio of products to reactants.

Round	Reactant	Product	P/R Ratio
0	40	0	
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

**Part 4**

Using the information gathered from this activity, complete the following statements:

13. Describe how the rate of the forward reaction relates to the rate of the reverse reaction at equilibrium.

14. Describe how the concentration of the reactants and products are related at equilibrium.

15. Describe what happens to the ratio between products and reactants when equilibrium is reached from different starting points.

16. What happened after several rounds of reaction in each of the three parts?

17. Why do you think this phenomenon is often described as “dynamic” equilibrium?

18. Do you think that temperature would affect these systems in any way? If yes, how? If no, why not?

19. What are the limitations of using this penny model to represent dynamic equilibrium in a chemical system?



Lesson Reflection Questions

Using the information gathered from this activity, complete the following statements:

1. Given what you have learned in this lesson, what do you think it means for a reaction to “shift to the right” or “shift to the left”? Be sure to include **why** a reaction might shift in either direction.

2. To a beaker you add 5g Ba and 2g F_2 ; after 3 hours you find that the beaker contains 2g Ba, 1g F_2 , as well as 4 g BAF_2 . After 24 hours, the beaker still contains 2g Ba, 1g F_2 , and 4 g BAF_2 . Is this reaction reversible or irreversible? Explain, in words, your answer.

3. To a beaker you add 10g H_2 and 5g O_2 ; after 3 hours you find that the beaker contains 0g H_2 , 0.5g O_2 , as well as 14.5 g H_2O . After 24 hours, the beaker still contains 0g H_2 , 0.5g O_2 , and 14.5 g H_2O . Is this reaction reversible or irreversible? Explain, in words, your answer.



Activity 5: Putting It All Together

Dynamic equilibrium is a phenomenon that can be found in many everyday situations, such as in our bodies and our homes. In your small group, select one of the topics below that are connected with the concept of equilibrium. You may also find an original topic if it is approved by your teacher. Research your chosen topic and create a three- to five-minute presentation that explains why the system is important, how the system works, how equilibrium is maintained, what variables influence the system, and what happens if the system is not in a state of equilibrium.

1. Rechargeable Batteries

2. Cellular Diffusion

3. Role of Potassium Ions in the Body

4. pH Buffers in the Blood
