
equilibrium
reaction
concentration
reactants
products
sketch
variable
submicroscopic
shifts
keq
simulation
evidence
system
increasing
activity
formula
physical
changes
claim
inert
increases
constant
cells
equal
conclusion
plot
explain
trial
chemical
reversible
variables
principle
forward
change
observations
dynamic
molar
dependent
gas
pressure
support
kpa
key
lab
catalyst
state
level
product
position
temperature
reactions
vocabulary
irreversible
table
equation
graph
rate
left
create

The Connected Chemistry Curriculum

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The Connected Chemistry Curriculum
Technology

System Requirements

The Connected Chemistry Curriculum has a software component (a set of *Simulations*) which is available at The Connected Chemistry Curriculum website, connchem.org. This software is necessary to use the curriculum, and is open-source and free of charge.

Besides the CCC software, you will need:

- **A personal computer of recent vintage, with an OpenGL-enabled graphics card.**
- **A 13" screen (or larger), with at least 1280 × 800 (WXGA) pixel resolution**
  For most computer monitors this is not a problem. Projectors, on the other hand, sometimes only manage VGA resolution (640 x 480), which will not allow sufficient room for our Simulations.
- **The latest Java runtime environment (JRE)**
  As of this writing, the latest JRE is Java 6, version 29. Java is free of charge: http://www.java.com/en/download/
- **Macintosh OS X 10.6 (Snow Leopard) or later, or Windows 7 or later**
  Earlier versions of the Macintosh OS or Windows may run, but may suffer performance issues. The software should also run on Linux. None of these options have been tested, however, so make sure you run all simulations before using them live in the classroom.

Troubleshooting

Please consult The Connected Chemistry Curriculum website (connchem.org) for up-to-date troubleshooting information, and to download software

The Connected Chemistry Curriculum

Welcome

Welcome to *The Connected Chemistry Curriculum*! The Connected Chemistry Curriculum, or CCC, is designed to help students learn about chemistry by directly exploring the submicroscopic level of matter and phenomena that form the basis of study in chemistry. Educators designed CCC using direct feedback from teachers, students and researchers. CCC uses computer-based simulations to provide a unique submicroscopic perspective of the chemical world for students.

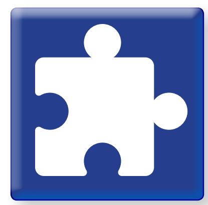
Activity Icons

These icons will be found throughout the teacher and student manuals.
The icons designate the purpose/theme of the activity or section.

Connecting

Hands-On Activity

Student Simulations

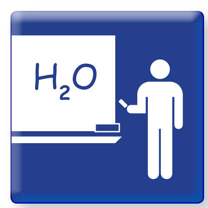


Putting It All Together

Questions

Lab Safety

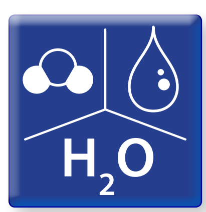
Sketching (without simulations)



Teacher Demonstration

Wet Lab

Teacher Facilitated Discussion



Chemistry Levels

Introductory Reading

Connected Chemistry

Equilibrium Unit

Contents

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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 designed 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

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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 →

$$CH_4\,(g) + O_2\,(g) \rightarrow CO_2\,(g) + 2\,H_2O\,(g)$$

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).

$$A + B \rightarrow C + D$$

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 are shown in the following equations:

Forward Reaction →	**Reverse Reaction←**
$H_2\,(g) + F_2\,(g) \rightarrow 2\,HF\,(g)$	$H_2\,(g) + F_2\,(g) \leftarrow 2\,HF\,(g)$

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:

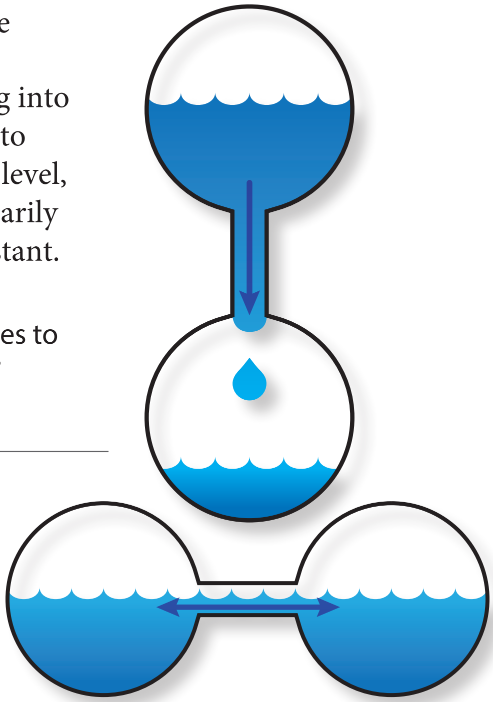
$$H_2\,(g) + F_2\,(g) \rightleftarrows 2\,HF\,(g)$$

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:

$$N_2\,(g) + 3\,H_2\,(g) \rightleftarrows 2\,NH_3\,(g) \qquad H_2\,(g) + I_2\,(g) \rightleftarrows 2\,HI\,(g)$$

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:

$$a\,A + b\,B \rightleftarrows c\,C + d\,D$$

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 after the reaction of the products in which A (g) + B (g) $\rightleftarrows$ 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) $\rightleftarrows$ 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:

$$2\,N_2\,(g) + 3\,H_2\,(g) \rightleftarrows 2\,NH_3\,(g) \qquad K_{eq} = \frac{[NH_3]^2}{[N_2]^2\,[H_2]^3}$$

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:

$[N_2]$ = 2.16 mol/L or 2.16 M

$[H_2]$ = 0.30 mol/L or 0.30 M **$[NH_3]$ = 0.50 mol/L or 0.50 M**

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

$$K_{eq} = \frac{[0.50]^2}{[2.16]^2\,[0.30]^3} = \frac{0.25}{0.13}$$

$$K_{eq} = 1.92$$

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} = 1.92, 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 $A+B \rightleftarrows AB$ 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**

	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:

$$R \rightleftarrows P$$

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

7. 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.
8. 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.)
9. Keep track of the number of pennies on each side after each transaction in the table below.
10. Repeat the procedure above for a total of 10 rounds.
11. 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

12. 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.
13. One of the two groups exchange for five rounds and calculate the ratio of products to reactants.
14. After the fifth round, add another group's pennies to the reactant side of the equation and continue to exchange for another 10 rounds.
15. 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

Connected Chemistry

Equilibrium Unit

Lesson 2: Equilibrium Shifts

Student's Lesson at a Glance

Lesson Summary

In the second lesson, students observe how chemical equilibrium shifts as system variables change. To complete this exploration, students need to make specific observations about how a reaction changes on the submicroscopic level. Students adjust factors, such as temperature and concentrations, in the simulation. Using their observations, students can derive some general rules for shifting equilibrium.

SWBAT (Student will be able to)

- Distinguish between reversible and irreversible reactions based on observations of submicroscopic representations and chemical representations.
- State that increasing concentration of reactants increases the forward rate of reaction.
- State that increasing temperature of an endothermic reaction will increase rate of reaction and decreasing temperature of an exothermic reaction will increase rate of reaction.
- State that catalysts increase rate of reaction, but do not effect the equilibrium position.
- Define equilibrium position of a reaction as the relative concentrations of reactants and products at any given moment.
- State that Le Chatelier's principle indicates that if a system at equilibrium is disturbed (by changes to concentration, pressure, and temperature) the system will shift to partially counter act the change.
- State that inert gases do not effect equilibrium position of a reaction at equilibrium.

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 designed CCC so that the lessons are more helpful and meaningful for all classroom participants.
- Many questions will 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.
- Supporting claims with evidence is not only a skill that scientists use, but a skill that will help you in other classes and everyday life.
- Draw a key when you are sketching. Keys can help you and others decode your sketches at a later time.
- There is a periodic table and list of common elements used in the back of this book. You will need to refer to the periodic table often.

Notes

Homework

Upcoming Quizzes/ Tests

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Please turn to the next page.

Activity 1: Connecting

1. Using your prior knowledge about variables that change within a system, what variables do you think could affect the equilibrium state of a system?

____

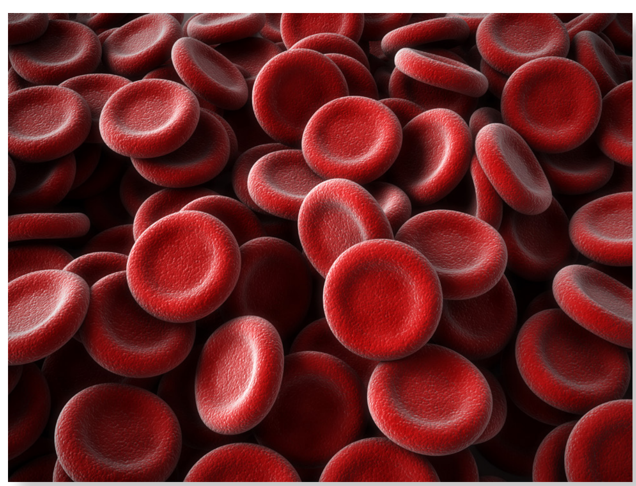
____

____

The rate of a chemical reaction changes as system variables influencing a reaction change. Using the equilibrium constant, K_{eq}, it is possible to determine if the products or reactants are favored at equilibrium. Chemical equilibrium also shifts as system variables change. According to **Le Chatelier's Principle**, if any system at dynamic equilibrium is disturbed by changing its conditions, the position of equilibrium shifts to counteract the change and to restore the system to equilibrium.

Le Chatelier's Principle applies to the *homeostatic* mechanisms in the body much in the same way as it does for reactions that occur in a beaker. Recall from biology that homeostasis is the state of dynamic equilibrium that the body attempts to maintain. The equilibration of oxygen and carbon dioxide in human blood is maintained by a homeostatic mechanism.

One example of Le Chatelier's principle is found in the respiratory system of our bodies. Concentrations of oxygen and carbon dioxide are maintained in the blood by hemoglobin. Each hemoglobin transports four molecules of oxygen from the lungs to the rest of the body. As long as there is a sufficient concentration of oxygen molecules in the air, equilibrium exists between the rate of oxygen absorption and the of rate carbon dioxide release.



When oxygen concentrations in the air fall below "normal" levels, the body responds by shifting equilibrium. Without adequate oxygen provided to the body's cells and tissues, a person can feel light-headed. At high elevations some people can become light-headed. If a climber is not physically prepared for the change in altitude and the low atmospheric concentration of oxygen at high altitudes, he or she may not be able to climb the mountain. For these low oxygen conditions, an oxygen tank and a mask are required to breathe. The tank provides an increased concentration of oxygen to help the body maintain equilibrium.

Using the knowledge of chemical equilibrium in the body, some athletes try to improve their performance. Blood doping is an illegal practice in all sports. Blood doping is when an athlete injects extra red blood cells into his or her body. The increased amount of red blood cells improves performance and delays fatigue. The extra red blood cells allow the athlete to intake much more oxygen from the air than they otherwise would be able to under normal conditions. While athletic performance can improve in the short term, blood doping can lead to infections, blood poisoning, and heart failure.

Alternatively, some athletes undergo hypobaric training. This training achieves similar results to blood doping, but in a legal and safe manner. The athlete trains at high altitudes or in special chambers in which the air pressure and oxygen concentration are lower. Training in these environments allows athletes to condition their bodies to perform well at lower oxygen levels. On the day of competition, these athletes are especially well prepared to compete in environments with ample supplies of oxygen.

2. Explain what the effect of blood doping would be on the concentration of oxygen available to the cells of the body.

3. What other medical conditions may cause the body to shift to maintain equilibrium?

Activity 2: Exploring Shifting Equilibrium

In a reaction where the system variables are altered to favor the products, the **equilibrium position** has been shifted to the right. In a reaction where the system variables are altered to favor the reactants, the equilibrium position has been shifted to the left.

In Activity 2, you will observe how chemical equilibrium shifts as system variables change according to Le Chatelier's Principle. This simulation will model the equilibrium reaction between gaseous NO_2 and N_2O_4.

$$2\ NO_2\ (g) \rightleftarrows N_2O_4\ (g)$$

You will make specific conclusions about equilibrium reactions and Le Chatelier's Principle with qualitative and quantitative observations about each reaction in the simulation.

- *Follow your teacher's instructions for filling out the observation tables on the following pages.*
- *Using your observations, you will learn how changes to concentration, pressure, temperature, volume, the addition of catalysts, and the addition of noble gases affect the equilibrium position of the reaction.*
- *The variables that are manipulated (independent variables) are bolded in the tables.*

Part 1: Effect of Reactant Concentration on Chemical Equilibrium

Use Simulation 2, Set 1

- *For trial 1, use the default settings. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and sketch a graph.*
- *Without resetting the simulation, complete a second trial by altering the reactant concentration by adding more reactant molecules. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and continue your graph from trial 1.*
- *Without resetting the simulation, complete the final trial by altering the reactant concentration by adding more reactant molecules. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and continue your graph from trials 1 & 2.*

After you complete all three trials and all tables, complete the questions below.

	Part 1, **Trial 1**			
Submicroscopic Sketch				
Observations				
Data	Reactants $[NO_2]$		Products $[N_2O_4]$	
	T (K)		P (kPa)	
	K_{eq}		Time	

4. Increasing the reactant concentration shifts the equilibrium towards the **reactants / towards the products / not at all** *(circle one). Support your claim with two pieces of evidence using the graph and window in the simulation.*

5. Decreasing the reactant concentration shifts the equilibrium **towards the reactants / towards the products / not at all** *(circle one). Support your claim with two pieces of evidence using the graph and window in the simulation.*

	Part 1, **Trial 2**				Part 1, **Trial 3**			
Submicroscopic Sketch								
Observations								
Data	Reactants $[NO_2]$		Products $[N_2O_4]$		Reactants $[NO_2]$		Products $[N_2O_4]$	
	T (K)		P (kPa)		T (K)		P (kPa)	
	K_{eq}		Time		K_{eq}		Time	
	Key				**Concentration Graph**			

Part 2: Effect of Product Concentration on Chemical Equilibrium

Continue to use Simulation 2, Set 1

- *For trial 1 use the default settings. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and sketch a graph.*
- *Without resetting the simulation, complete a second trial by altering the product concentration by adding more product molecules. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and continue your graph from trial 1.*
- *Without resetting the simulation, complete the final trial by altering the product concentration by adding more product molecules. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and continue your graph from trials 1 & 2.*

After you complete all three trials and all tables, complete the questions below.

	Part 2, **Trial 1**			
Submicroscopic Sketch				
Observations				
Data	Reactants $[NO_2]$		Products $[N_2O_4]$	
	T (K)		P (kPa)	
	K_{eq}		Time	

6. Increasing the product concentration shifts the equilibrium **towards the reactants / towards the products / not at all** *(circle one). Support your claims with two pieces of evidence using the graph and window in the simulation.*

7. Decreasing the product concentration shifts the equilibrium **towards the reactants / towards the products / not at all** *(circle one). Support your claims with two pieces of evidence using the graph and window in the simulation.*

	Part 2, **Trial 2**				Part 2, **Trial 3**			
Submicroscopic Sketch								
Observations								
Data	Reactants $[NO_2]$		Products $[N_2O_4]$		Reactants $[NO_2]$		Products $[N_2O_4]$	
	T (K)		P (kPa)		T (K)		P (kPa)	
	K_{eq}		Time		K_{eq}		Time	

Key	**Concentration Graph**

Part 3: Effect of Pressure in Chemical Equilibrium

Continue to use Simulation 2, Set 1

- *Boyles' Law applies to this simulation. Pressure cannot be directly adjusted. Pressure can only be adjusted by increasing or decreasing the volume of the container.*
- *For trial 1 use the default settings. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and sketch a graph.*
- *Without resetting the simulation, complete a second trial by altering the pressure by adjusting the volume of the container. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and continue to sketch a graph from where you left off in trial 1.*
- *Without resetting the simulation, complete a final trial by altering the pressure by adjusting the volume of the container. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and continue to sketch a graph from where you left off in trial 2.*

After you complete all three trials and all tables, complete the questions below.

	Part 3, **Trial 1**			
Submicroscopic Sketch				
Observations				
Data	Reactants $[NO_2]$		Products $[N_2O_4]$	
	T (K)		P (kPa)	
	K_{eq}		Time	
			Volume(L)	

8. Increasing the pressure in this reaction shifts the equilibrium **towards the reactants / towards the products / not at all** *(circle one)*.

   Support your claim with two pieces of evidence from the simulation.

9. Describe why the pressure had the effect that you described in question #8. Support your claim with two pieces of evidence from the simulation.

	Part 3, **Trial 2**				Part 3, **Trial 3**			
Submicroscopic Sketch								
Observations								
Data	Reactants $[NO_2]$		Products $[N_2O_4]$		Reactants $[NO_2]$		Products $[N_2O_4]$	
	T (K)		P (kPa)		T (K)		P (kPa)	
	K_{eq}		Time		K_{eq}		Time	
			Volume(L)				Volume(L)	

Key	**Concentration Graph**

Part 4: Effect of Temperature on Equilibrium

Continue to use Simulation 2, **Set 1**

- *Recall that temperature cannot be changed directly. Temperature can be changed by adding or removing energy using the heat slider.*
- *For trial 1 use the default settings. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and sketch a graph.*
- *Without resetting the simulation, complete a second trial by adjusting the heat slider to change the temperature. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and continue to sketch a graph from where you left off in trial 1.*
- *Without resetting the simulation, complete a final trial by adjusting the heat slider to change the temperature. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch. Record the data and continue to sketch a graph from where you left off in trial 2.*
- *Students be sure to increase and decrease the heat added in the simulation for the trials you complete. To increase the temperature you must move the slider up to a positive number. To decrease the temperature you must move the slider to a negative number.*

After you complete all three trials and all tables, complete the questions below.

	Part 4, **Trial 1**			
Submicroscopic Sketch				
Observations				
Data	Reactants [NO_2]		Products [N_2O_4]	
	T (K)		P (kPa)	
	K_{eq}		Time	

10. Increasing the temperature **increases / decreases / does not change** *(circle one)* the K_{eq} of an exothermic reaction. *Support your claim with evidence from the graph and window in the simulation.*

11. Decreasing the temperature **increases / decreases / does not change** *(circle one)* the K_{eq} of the reaction. *Support your claim with evidence from the graph and window in the simulation.*

12. Recall that heat can be considered a reactant or product. Given your observations, rewrite the chemical equation for the reversible reaction of NO_2 and N_2O_4 including heat as either a reactant or product.

	Part 4, **Trial 2**				Part 4, **Trial 3**			
Submicroscopic Sketch								
Observations								
Data	Reactants $[NO_2]$		Products $[N_2O_4]$		Reactants $[NO_2]$		Products $[N_2O_4]$	
	T (K)		P (kPa)		T (K)		P (kPa)	
	K_{eq}		Time		K_{eq}		Time	

Key	**Concentration Graph**

Part 5: Effect of a Catalyst on Equilibrium (Optional)

Continue to use Simulation 2, **Set 1**

- *For trial 1 use the default settings. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch and a graph. Record your data.*
- *Run trial 2 with* **catalyst** *added at time 0s. Run until the reaction reaches equilibrium. Pause the simulation, record your observations, and create a graph.*
- *After you complete both trials, tables and graphs, complete the questions below.*

13. Complete the following sentence: A catalyst causes a reaction to reach equilibrium **faster than / slower than / equal to** *(circle one)* the same reaction without a catalyst. *Support your claim with two pieces of evidence from your observations.*

14. Completed the following sentence: A catalyst shifts an equilibrium reaction **towards the reactants / towards the products / not at all** *(circle one)*. *Support your claim with two pieces of evidence from your observations.*

15. Use what you learned from the Kinetics unit about catalysts to describe why your answers to questions #4 and #5 are true.

	Part 5, **without Catalyst**				Part 5, **with Catalyst**			
Submicroscopic Sketch								
Observations								
Data	Reactants $[NO_2]$		Products $[N_2O_4]$		Reactants $[NO_2]$		Products $[N_2O_4]$	
	T (K)		P (kPa)		T (K)		P (kPa)	
	K_{eq}		Time		K_{eq}		Time	
Graphs								
Key								

Part 6: Effect of an Inert Gas on Equilibrium (Optional)

Continue to use Simulation 2, **Set 1**

- *For trial 1 use the default settings. Once equilibrium is reached, pause the simulation and create a submicroscopic sketch and a graph. Record your data.*
- *Run trial 2 with an* **inert gas** *added at time 0s. Run until the reaction reaches equilibrium. Pause the simulation, record your observations, and create a graph.*
- *After you complete both trials, tables, and graphs, complete the questions below.*

16. In your own words, describe how the addition of an inert gas affects the chemical equilibrium of a gaseous reaction. *Support your claim with two pieces of evidence from your observations.*

	Part 6, **without Inert Gas**				Part 6, **with Inert Gas**			
Submicroscopic Sketch								
Observations								
Data	Reactants $[NO_2]$		Products $[N_2O_4]$		Reactants $[NO_2]$		Products $[N_2O_4]$	
	T (K)		P (kPa)		T (K)		P (kPa)	
	K_{eq}		Time		K_{eq}		Time	
Graphs								
Key								

Activity 3: Teacher Facilitated Discussion

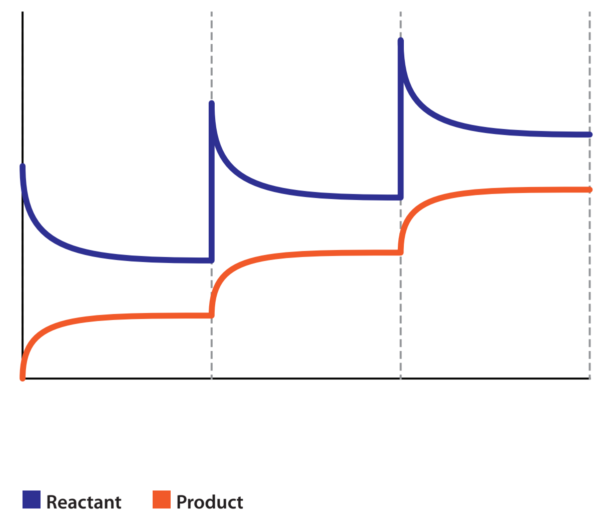
Part 1: Effects of Variables on Concentration

- *In the tables below, identify the dependent variable, independent variable, and constants for each of the parts you completed in Lesson 2, Activity 2 above.*
- *Support your claims with evidence.*
- *Note: there may be more than one answer per variable.*

Part(from Activity2)	Variables			Support your claims with evidence
	Independent	Dependent	Constant	
1: Reactant Concentration				
2: Product Concentration				
3: Pressure				
4: Temperature				
5: Catalyst				
6: Inert Gas				

Part 2

A general equilibrium graph of a reaction has been provided below. Properly label the graph below as instructed by your teacher.



17. Place the concentration label on the appropriate axis.

18. Place the time label on the appropriate axis.

19. Label the points on the graph where stress was applied to system by writing the word "stress applied" on the graph.

20. Circle the areas on the graph where the reaction is in a state of equilibrium.

21. How do you know when a stressor is added in the graph?

22. Explain what is happening at the curved parts of the product and reactant concentration lines and how it relates to Le Chatelier's Principle.

23. How can you identify when equilibrium has been reached in the simulation?

Lesson Reflection Questions

24. Has the ratio between the product and the reactant changed? *Support your claim with evidence.*

25. The picture below represents a reaction at equilibrium (K_{eq} = 0.16). In each box below, draw a submicroscopic picture to show how the reaction looks when the equilibrium shifts to the right or to the left. Below your pictures, explain in words what you drew.

$$2H(g) \rightleftarrows H_2(g)$$

Shifts to LEFT	Shifts to RIGHT

Activity 4: Capstone Activity

As you conclude the lesson, predict the effect of each of the following variables on chemical equilibrium.

Reaction #1 **Heat + $COBr_2(g) \rightleftarrows CO(g) + Br_2(g)$**

26. Describe how increasing the reactant concentration would affect the equilibrium of this reaction.

27. Describe how increasing the pressure would affect the equilibrium of this reaction.

28. Describe how increasing the temperature would affect the equilibrium of this reaction.

29. Describe how adding a catalyst would affect the equilibrium of this reaction.

30. Describe how adding an inert gas would affect the equilibrium of this reaction.

31. Is this reaction endothermic or exothermic? *Support your claim with evidence.*

Reaction #2 **$2HI(g) \rightleftarrows H_2(g) + I_2(s) + Heat$**

32. Describe how increasing the reactant concentration would affect the equilibrium of this reaction.

33. Describe how increasing the pressure would affect the equilibrium of this reaction.

34. Describe how increasing the temperature would affect the equilibrium of this reaction.

35. Is this reaction endothermic or exothermic? *Support your claim with evidence.*

36. Describe the relationship between pressure and equilibrium.

Student's Lesson at a Glance

Lesson Summary

In the final lesson of the unit, students engage in a wet lab. Students observe and explain the effect of changing variables in chemical systems at equilibrium by applying Le Chatelier's Principle. This lab is similar to the simulations that students performed in Lesson 2. Specifically, the lab will explore changing concentration and temperature.

SWBAT (Student will be able to)

- Observe and explain the effect of changing variables in a chemical systems at equilibrium through the application of Le Chatelier's Principle
- Evaluate and clarify common misconceptions about equilibrium using knowledge gained from previous lessons

Essential Vocabulary

Keep a list of all important words from this lesson. This list - in addition to the other 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 designed CCC so that the lessons are more helpful and meaningful for all classroom participants.
- 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.
- Supporting claims with evidence is not only a skill that scientists use, but a skill that will help you in other classes and everyday life.
- There is a periodic table and list of common elements used in the back of this book. You will need to refer to the periodic table often.
- Make sure that you read the labs ahead of time so that on the day you perform the lab, you will be more confident in the procedures and what questions to ask the teacher.
- Take good notes from the observations in the lab; these notes will make answering analysis questions at the end easier.

Notes

Homework

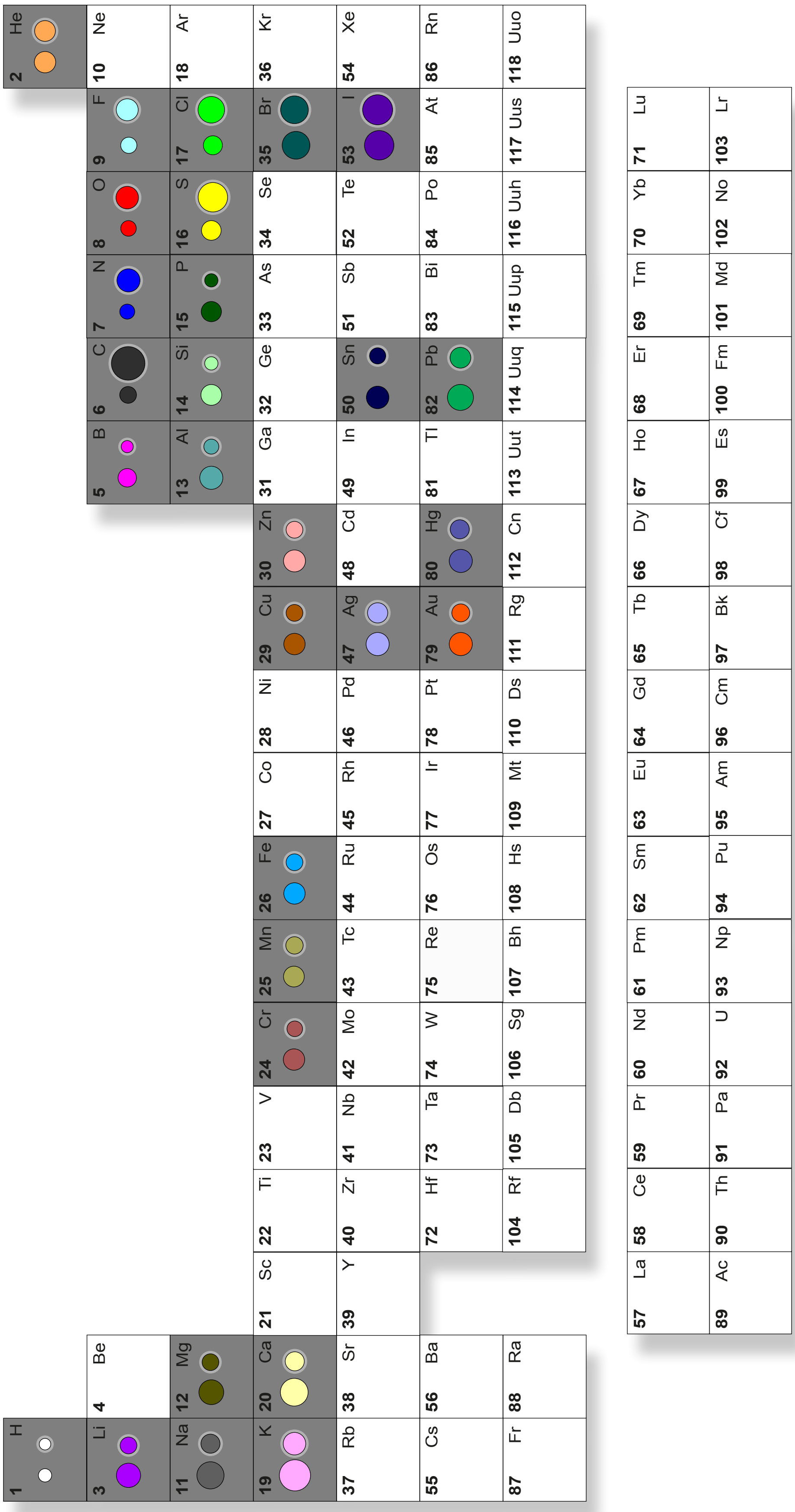
Upcoming Quizzes/ Tests

Activity 1: Chemical Equilibrium Wet Lab

The purpose of this lab is to observe and explain the effect of changing variables in a chemical systems at equilibrium through the application of Le Chatelier's Principle. Specifically, this lab explores changing concentration and temperature.

Student Lab Notes

Elements Used in the Connected Chemistry Curriculum



Name	Symbol	Atomic Number	Atomic Weight
Hydrogen	H	1	1.00794
Helium	He	2	4.00260
Lithium	Li	3	6.941
Boron	B	5	10.811
Carbon	C	6	12.0107
Nitrogen	N	7	14.0067
Oxygen	O	8	15.9994
Fluorine	F	9	18.9984
Sodium	Na	11	22.9898
Magnesium	Mg	12	24.3050
Aluminum	Al	13	26.9815
Silicon	Si	14	28.0855
Phosphorus	P	15	30.9738
Sulfur	S	16	32.065
Chlorine	Cl	17	35.453
Potassium	K	19	39.0983
Calcium	Ca	20	40.078
Chromium	Cr	24	51.9961
Manganese	Mn	25	54.9380
Iron	Fe	26	55.845
Copper	Cu	29	63.54
Zinc	Zn	30	65.38
Bromine	Br	35	79.904
Silver	Ag	47	107.8682
Tin	Sn	50	118.710
Iodine	I	53	126.904
Gold	Au	79	196.967
Mercury	Hg	80	200.59
Lead	Pb	82	207.2

Creating the Equation for the Equilibrium Constant

In the reaction, reactant A and B yields products C and D. The general equation is represented as the following:

$$a\,A + b\,B \rightleftarrows c\,C + d\,D$$

The letters a, b, c, and d represent the molar coefficients of the reaction. Using this equation, the equilibrium constant is determined by:

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

Remember, the brackets indicate molar concentration. Coefficients in the chemical equation become exponents. Any solids or pure liquids that are in the reaction are not included because they have undefined molarities.

When the reaction is at equilibrium in the K_{eq} expression, this means that the rate of the forward and reverse reactions are the same. Recall that the rate of the reaction is the speed at which the reaction occurs.

$$\text{Rate } (aA + bB \rightarrow cC + dD) = \text{Rate } (cC + dD \rightarrow aA + bB)$$

At equilibrium, the concentrations are not necessarily equal. The product or reactant side may be favored. The favored substance has a higher concentration at equilibrium.

The concentration of the substances in the reaction is a measure of how many moles per liter of solution molecules exist. At higher concentrations, there are more molecules, so therefore more chances for collisions to occur to drive a reaction. At lower concentrations there are fewer molecules, so fewer collisions are produced.

The rate of the forward reaction can be described as:

$$\text{Rate} = k_{forward}\,[A]^a\,[B]^b$$

The rate of the reverse reaction can be described as:

$$\text{Rate} = k_{reverse}\,[C]^c\,[D]^d$$

Since the equation is at equilibrium, the forward and reverse rate are equal to each other.

$$k_{forward}\,[A]^a\,[B]^b = k_{reverse}\,[C]^c\,[D]^d$$

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

Effect of Changing Variables on K_{eq}

Changing temperature favors either forward or reverse reactions. Changing the temperature changes the rate constant. This means that temperature directly changes the value of K_{eq}. At constant temperature, changing the equilibrium concentration does not affect K_{eq} because the rate constants are not affected by the concentration changes.

When the concentration of one of the participants is changed, the concentration of the others vary in such a way as to maintain a constant value for the K_{eq}.

Summary Points

- A value of K_{eq} greater than 1 indicates that at equilibrium there is a higher concentration of products relative to the concentration of reactants.
- A value of K_{eq} less than 1 indicates that at equilibrium there is a lower concentration of products relative to the concentration of reactants.
- A large K_{eq} indicates that the forward reaction rate constant is large. A higher reaction rate constant means that the products are more likely to react at a given temperature. The forward reaction increases, so the products are favored in the reaction. When the value of K_{eq} is infinity, this means the reaction fully goes to the products and the reaction is irreversible.
- A small K_{eq} indicates that the reverse reaction rate constant is large. The reactants are favored to form in the reaction.