
reaction
concentration
rate
observations
submicroscopic
simulation
sketch
data
temperature
chemical
slope
time
pressure
evidence
reactants
equation
experiment
energy
initial
order
products
final
claim
hypothesis
catalyst
area
surface
law
lab
collisions
molecules
support
trials
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graphs
determine
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concepts
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gas
kinetic
concentrations
substances
constant
inhibitors
scenarios
system
two
small
review
time
observation
substance
results
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acid
ozone
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computer
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completion
description
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conditions
made
faster
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variables
extent
concerns
changed
completed
day
inhibitor
solid
dissolve
introduce
lessons
intermediate
steps
occur
assign
shows
whole
skin
alka
bubbles
able
manipulate
objectives
used
food
h2o
define
long
equipment
affected
affects
many
soda
oxygen
reading
demonstrate
increases
discretion
recall
right
group
produce
related
computers
form
match
wool
focus
damage
co2
curve
learning
supporting
type
also
graphing
seltzer
pencils

The Connected Chemistry Curriculum

Acknowledgements

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Please direct all questions or concerns regarding The Connected Chemistry Curriculum to Dr. Mike Stieff at mstieff@uic.edu.

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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

Connected Chemistry
Kinetics Unit
Contents

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Please turn to the next page.

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.

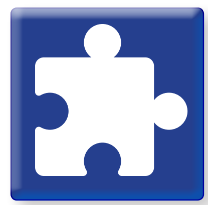
Activity Icons

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

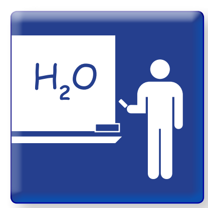


Putting It All Together

Questions

Lab Safety

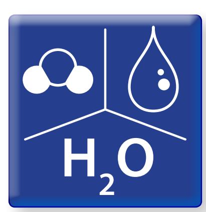
Sketching (without simulations)



Teacher Demonstration

Wet Lab

Teacher Facilitated Discussion



Chemistry Levels

Introductory Reading

Connected Chemistry

Kinetics Unit

Lesson 1: Introduction to Chemical Kinetics

Student's Lesson at a Glance

Lesson Summary

This lesson has two activities. Students will be introduced to chemical kinetics through making connections with chemical reactions from previous lessons. Using a marathon as a metaphor for reaction rate, students will explore the terms "rate" and the "extent of a reaction". In the final activity of the lesson, students will learn that kinetics is a combination of many of the other earlier concepts in chemistry. Students will briefly review these concepts through completion of submicroscopic sketches of the provided scenarios.

SWBAT (Student will be able to)

- Define chemical kinetics
- Define rate of the reaction
- Define extent of the reaction

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

- Use the vocabulary and notes sections to take good notes so studying for tests and quizzes is easier.
- Use vocabulary notes from previous sections to help refresh your understanding of concepts.
- Draw a key when you are sketching. Keys can help you and others decode your sketches at a later time.
- Create clear explanations of the sketches you create so they are usable at a later time to study.
- 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

Activity 1: Connecting

1. What do you think: Why does milk spoil faster when it is at room temperature than when it is placed in a cold refrigerator?

2. What does the word **intermediate** mean to you?

Not all chemical reactions react at the same rate. Some reactions reach completion in less than a second, and other reactions reach completion after many years. The **extent of a reaction** refers to how far a reaction has progressed to completion. The extent of a reaction is comparable to the distance traveled by a runner in a marathon. The **reaction rate** is the change in the concentration of reactants with respect to time, or how quickly the reaction is progressing to completion. Using the same marathon analogy, the reaction rate is comparable to how fast the runner is running.

Chemical kinetics is the study of the reaction rate, the extent of the reaction, the factors affecting reaction rates, the rearrangement of atoms, and the formation of intermediate products. **Kinetics** is derived from the Greek word "kinesis," which means "movement." Chemical kinetics is an important way to study different reactions in nature. For example, all of the following observable phenomena are chemical reactions with important differences in their chemical kinetics:

- Strike a match and it burns quickly
- The Statue of Liberty's copper metal skin turns a shade of light green after years of exposure to weather
- Vinegar and baking soda immediately form bubbles when mixed together
- Real silver jewelry tarnishes over several weeks as it reacts to substances in the environment surrounding it

Chemical kinetics differs from kinetics in that it does not focus solely on movement of molecules. Rather, chemical kinetics is focused on the change of reactant and product concentration over time during a reaction. This is related to kinetics because the motion of the molecules is related to the rate of a reaction.

3. What is the difference in the four examples of chemical reactions above?

Activity 2: Sketching Concept Review Challenge

Chemical kinetics includes concepts from many other areas of chemistry including solutions, reactions, collision theory, and thermodynamics.

As a group, select one of the scenarios below. Fill in the scenario numbers that you select into the tables on the following pages. Create a submicroscopic drawing for each of the scenarios your group selected. Include a key and captions to explain what is happening in the drawing. Use arrows to show both direction and velocity. Make sure to include the arrows in the key.

Scenarios

Select one of the following scenarios

1. A system containing a monatomic and diatomic gas at low temperatures
2. A concentrated solution of sodium chloride (NaCl) and water
3. A monatomic gas under high pressure
4. The products of a combustion reaction between methane gas and oxygen gas
5. Water at 100 °C
6. Table salt (NaCl) added to cold water
7. A mixture with three non-reactive substances representing all three states of matter
8. The final products of a reaction that starts with the reactants: $Pb(NO_3)_2$ (aq) + 2 KI (aq)
9. A mixture of a polar and non-polar substance
10. Helium molecules inside a refrigerated jar that has been set out in a 25°C room

After your group has completed the drawing in your workbooks, be prepared to explain your drawings to the class.

Scenario Number ______	
Sketch	**Description**
Key	

Lesson Reflection Questions

4. Define what *rate* means in your own words.

5. Use your definition of *rate* to define a rate that captures what is happening in the scenario that you chose.

Connected Chemistry

Kinetics Unit

Lesson 2: Exploring the Reaction Pathway

Student's Lesson at a Glance

Lesson Summary

This lesson has three activities. Using the analogy of a board game, students will be introduced to the concept of reaction pathways. The teacher will introduce a CCC simulation to demonstrate how to a create a graph using concentrations taken before, during, and after a reaction. Students will discover how to use the slope of the line to determine the rate of the reaction. Students will then work independently in small groups with a CCC simulation to produce a graph of concentrations and determine slope for a new reaction.

SWBAT (Student will be able to)

- Define what the reaction pathway is
- Identify the stages of the reaction pathway
- Use concentration values to identify the rate of the reaction from calculating the slope
- Indicate what a positive or negative slope indicates about a reaction

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 to design CCC so that the lessons are more helpful and meaningful for all classroom participants.
- Concentration in this unit refers to the molarity (M) of a substance. Brackets (e.g., [NaCl]) around a substance means the lesson requires the concentration of the substance.
- If you have forgotten how to calculate molarity, make sure to look back for your notes in the solutions unit or get help from your teacher.
- 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.

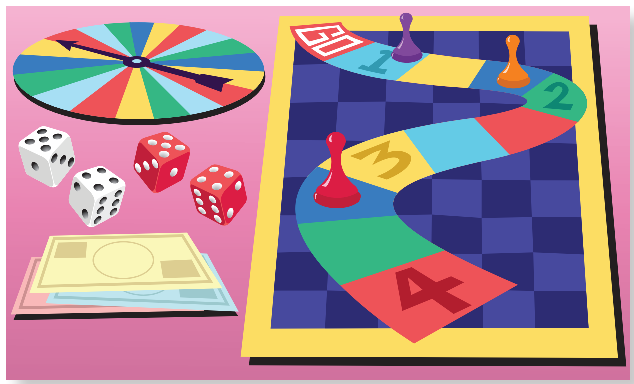
Notes

Homework

Upcoming Quizzes/ Tests

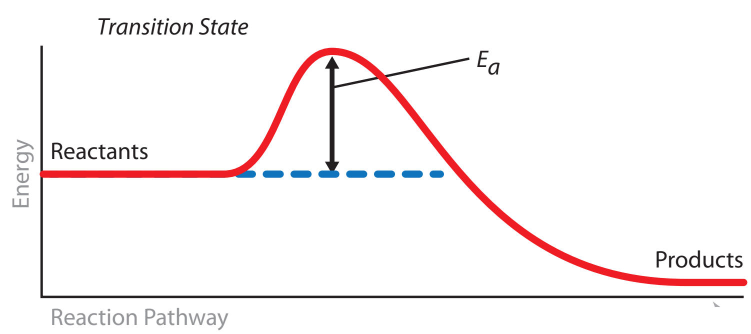
Activity 1: Connecting

While playing a board game, players must engage in a series of steps and meet certain conditions to win. Some actions can slow a player down, while other actions can help the player win faster. In some ways, chemical reactions are similar to a board game. A chemical reaction requires a specific series of steps or conditions for reactants to become products. The time a reaction takes to reach completion varies and depends on the steps involved and the conditions of the system.



A **reaction pathway** is the sequence of steps a reaction undergoes as a reactant transforms into products. The reaction pathway can be shown using a *potential energy diagram* that is shown below. The 'Reaction Pathway' axis refers to the sequence of steps a reaction takes and does not directly represent time. Recall that the time it takes for a reaction to proceed along the chemical pathway from reactions to products is called the **reaction rate** and is measured as the change in reactant concentration over time. Reaction rates vary widely. Some reactions, such as lighting a match, take less than a microsecond to complete. Other reactions, such as the conversion of dead plants and animals into fossil fuels, take thousands of years to complete.

On the macroscopic level, chemical reactions may be seen as observable changes in the reactants. For instance, we might see a fast explosion from a firecracker, a formation of bubbles from an acid and a base mixture, or a few spots of rust developing on a piece of iron. At the macroscopic level, we observe substances as they transform into new substances.



On the submicroscopic level, these transformation result from collisions between the reactant molecules. These collisions may break chemical bonds or form new chemical bonds to generate products. However, not all collisions produce reactions. Sometimes reactants collide and just bounce off each other without reacting because there is not enough kinetic energy to break or form bonds. A minimum amount of kinetic energy is needed for reactants to collide and produce a reaction. This minimum energy is called **activation energy**. With this minimum energy, the reactants enter a temporary **transition state** and continue to reform into new products. When reactants do collide with sufficient energy, **chemical potential energy** in the reactants is converted into usable and unusable kinetic energy. Although sufficient energy may be available to place reactants into the transition state, the reaction will only occur under the correct conditions.

1. If the correct conditions are not met or if no activation energy is available, what do you think happens to a chemical reaction?

2. At the completion of a reaction pathway for a specific reaction, the concentration of reactants **increases** or **decreases** *(circle one)* and the concentration of products **increases** or **decreases** *(circle one)*. *Support your claims with evidence.*

3. While the reaction pathway and rates may vary in a chemical reaction, the total mass of matter before and after the reaction does not change. **True** or **False** *(circle one). Support your claims with evidence.*

Activity 2: Demonstration of Chemical Kinetics

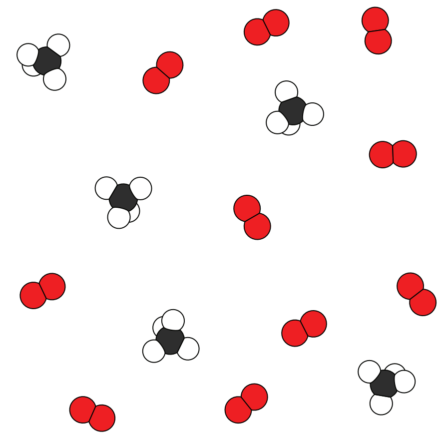
Simulation

Use Simulation 1, ***Set 1***

Using the simulation, your teacher will demonstrate the reaction pathway of a given reaction. Create an initial sketch of the reaction showing the reactants. Record data from the monitors and write down your observations.

- *Your teacher will run the simulation for 15 seconds and then pause. Record data from the monitors and write down your observations.*
- *Your teacher will restart the simulation and run the simulation for another 15 seconds.*
- *Create a final sketch of the products. Record data from the monitors and write down your observations.*

Use the data to create a graph of concentration [M] vs. time (s). Create a key to distinguish between different substances. Include all appropriate labels. Additional graph paper can be found on pages 66-67 if needed.

	Initial State - 0 seconds			
Submicroscopic Picture				
Observations				
Data	[CH_4]		[O_2]	
	[CO_2]		[H_2O]	

<table>
<tr><th></th><th colspan="4">Initial
15 seconds</th><th colspan="4">Final
30 seconds</th></tr>
<tr><td>Submicroscopic Sketch</td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td>Observations</td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><td rowspan="2">Data</td><td>$[CH_4]$</td><td></td><td>$[O_2]$</td><td></td><td>$[CH_4]$</td><td></td><td>$[O_2]$</td><td></td></tr>
<tr><td>$[CO_2]$</td><td></td><td>$[H_2O]$</td><td></td><td>$[CO_2]$</td><td></td><td>$[H_2O]$</td><td></td></tr>
<tr><td></td><td colspan="4">Key</td><td colspan="4">Graph</td></tr>
</table>

The rate of change in the concentrations of the reactants and products can be used to determine the reaction rate. Similar to the graphs you constructed, the reaction rate corresponds to the slope of any function plotted on a concentration versus time graph. For help and examples on calculating slopes see Appendix (page 68).

4. Is the slope the same for each substance that you plotted? *Support your claim with evidence.*

5. What is the sign of the slope for each of the reactants? Why?

6. What is the sign of the slope for the product? Why?

7. Steeper slopes correspond to **slower** or **faster** *(circle one)* reactions. *Support your claim with evidence.*

8. If the slope line of the line representing the change of products over time is not steep, this would indicate that the reaction is **slower** or **faster** *(circle one) Support your claim with evidence.*

9. Based on your sketches, how do you know if the reaction has completely reacted?

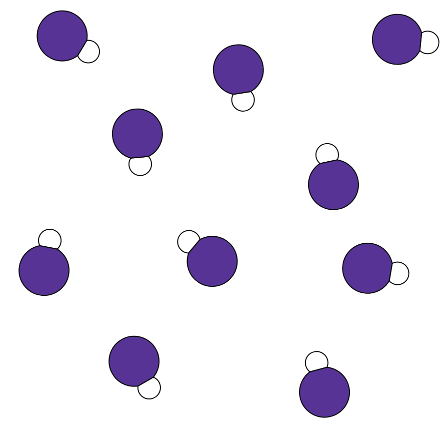
10. Based on sketches, from the simulation which reactant is being used up more quickly? *Support your claim with evidence.*

Activity 3: Simulating the Reaction Pathway

Simulation

Use Simulation 1, ***Set 2***

- *Using the simulation, create an initial sketch of the system showing the reactants, record data from monitors, and write down your observations.*
- *Run the simulation for 15 seconds and then pause.*
- *Record data from the monitors and write down your observations.*
- *Restart the simulation and run it for another 15 seconds and then pause.*
- *Create a final sketch of the products.*
- *Record data from monitors and write down your observations.*
- *Use the data to create a graph of time vs. concentration [M] (Y). Additional graph paper can be found on pages 66-67 if needed.*
- *Create a key for the graph to distinguish between different substances. Include all other appropriate labels.*

<table>
<tr><th></th><th colspan="4">Initial State
0 seconds</th></tr>
<tr><td>Submicroscopic Picture</td><td colspan="4"></td></tr>
<tr><td>Observations</td><td colspan="4"></td></tr>
<tr><td rowspan="2">Data</td><td>$[HI]$</td><td></td><td>$[H_2]$</td><td></td></tr>
<tr><td>$[I_2]$</td><td></td><td colspan="2"></td></tr>
</table>

	15 seconds				**Final** 30 seconds			
Submicroscopic Sketch								
Observations								
Data	[HI]		[H_2]		[HI]		[H_2]	
	[I_2]				[I_2]			

Key	**Graph**

11. Is the slope the same for all of the products and reactants?

12. Describe how the sign of the slop of the line is related to whether the substance is a reactant or product.

13. Is this decomposition reaction faster or slower than the reaction demonstration? *Explain your answer using evidence from the simulation.*How would this be represented graphically?

Lesson Reflection Question

14. Consider the following scenario: During a specific chemical reaction, the concentration of reactant is found to decrease as the concentration of product is found to increase over a 5 minute period. After five minutes the concentration of both the reactant and *remains constant*. Three students discuss what this data means. Student A says that the reaction has stopped and that is why the concentration has not changed. Student B says that the reaction has stopped because of a limiting reactant. Student C says that the reaction did not stop but that the products are turning back into reactants at the same rate as the reactants are turning into products. Explain which student's description you agree with the most and provide evidence for your answer.

Connected Chemistry

Kinetics Unit

Lesson 3: Factors Affecting Reaction Rates

Student's Lesson at a Glance

Lesson Summary

There are nine activities in this lesson. In this lesson, students will explore the factors that affect the rate of chemical reactions. Students will begin the exploration by learning how antioxidants work to inhibit certain reactions in the body. Prior to using the CCC simulations, students will complete a wet lab that allows them to see how different variables affect the rate of certain reactions. The lab is followed up with a series of CCC simulation activities in which students discover how surface area, concentration, temperature, catalysts, inhibitors, and pressure affect the rate of reactions.

SWBAT (Student will be able to)

Identify how concentration, temperature, catalysts, pressure of gases, and surface area can affect the rate of the reaction

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.
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- If you have forgotten how to calculate molarity, make sure to look back for your notes in the solutions unit or get some help from your teacher.
- 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.
- When sketching plots and graphs make sure to include labels.

Notes

Homework

Upcoming Quizzes/ Tests

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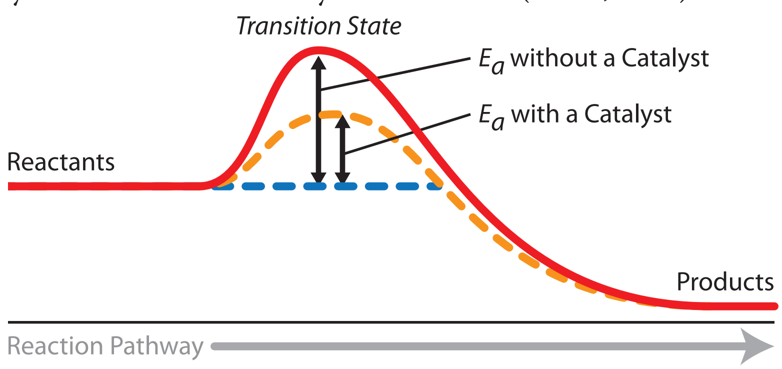
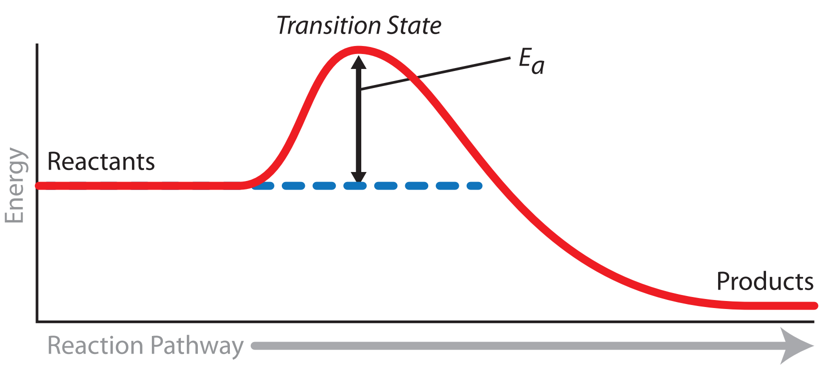
Activity 1: Connecting

Naturally-occurring and man-made chemical reaction rates can be altered by several factors. We can slow down the reaction rate through the use of an **inhibitor** or speed it up through the use of a **catalyst**. A catalyst modifies and increases the rate of a reaction by reducing the amount of activation energy needed. A catalyst can be used in a reaction, but the catalyst is always reformed.

While researching on the web about nutrition and wellness, a student comes across an article about antioxidants in fruits. Below is an excerpt from the article:

"Berries are the crown jewels of summer, the gems that inspire pies, parfaits, cobblers, ice cream treats, and whipped cream wonders. Best of all, berries deliver super-healthy antioxidants that help fight disease. In fact, one landmark study shows that just one cup of berries provides all the disease-fighting antioxidants you need in a single day. Of course, dietitians will tell you, 'Don't stop there.' A healthy diet needs a variety of nutrients from many food sources" (Davis, 2008).



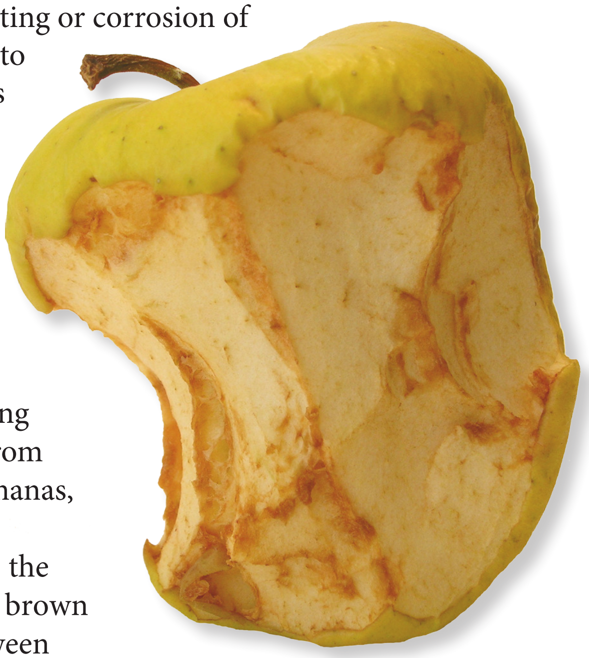


1. On the potential energy diagram, draw a new function that illustrates what you think would happen to the reaction pathway if an inhibitor is added.

2. What does the prefix "anti" mean?

3. What is oxidation?

An **antioxidant** is a substance that inhibits the oxidation of other substances. Recall that an oxidation reaction is when a molecule or atom loses electrons to another molecule or atom in a reaction. Antioxidants may be used to slow down or "inhibit" the reaction rate of oxidation. Oxidation reactions produce effects in biological and non-biological systems. In non-living systems, antioxidants may be used to slow down rusting or corrosion of metals in cars. Some oxidation reactions are critical to normal body function, but other oxidation reactions can cause damage to the cells where the reactions occur. The body makes and ingests substances, including antioxidants, to help slow or inhibit the damage to cells. Vitamin C and E are two common antioxidants involved in protecting cells.



The chemical property of Vitamin C's ability to inhibit oxidation can be observed with enzymes in fruit. Lemon juice, or any other citrus juice containing Vitamin C, will prevent sliced fruit and vegetables from turning brown when they oxidize. Apples, pears, bananas, potatoes, and avocados begin to change to a brown color after they are sliced and the flesh is exposed to the air. Any cut surface of the produce will oxidize. The brown color we see results from an oxidation reaction between atmospheric oxygen and the enzymes in the exposed flesh. Vitamin C inhibits the reaction if the antioxidant is applied immediately to the produce after slicing.

In addition to catalysts and inhibitors speeding up or slowing down reaction rate, surface area, concentration and temperature can also affect the rate of chemical reactions. **Surface area** is the measure of how much exposed area a solid object has. Surface area is expressed in square units (e.g., cm^2, m^2).

Recall that the concentration of a solution in a reaction is defined as the amount of solute per unit of volume. **Concentration** is usually expressed as moles of solute per liter (moles/L) of solution, which is also called **molarity** of the solution. Many scientists also use the letter M as an abbreviation for molarity.

4. In your own words, define how an inhibitor affects the rate of a chemical reaction.

Activity 2: Simulating Catalysts and Inhibitors

Simulation

Use Simulation 3, ***Sets 1–2***

A catalyst can be used in a reaction, but the catalyst is always reformed.

The following simulation demonstrates the reaction between N_2O_4 gas and a catalyst. In the simulation, you can add the catalyst to the reaction to observe how it will impact the reaction. In the simulation, the catalyst is a represented by a single sphere. In reality, some catalysts are very complex arrangements of atoms that are difficult to simulate using the CCC simulations.

- *Before starting the simulation, record the initial data and submicroscopic observations.*
- *Create a sketch of the submicroscopic concentration plot on the axes provided. Make sure to include a key to explain plot.*
- *For* ***Trial 1****, start the simulation. Run the simulation for 30 seconds and then pause. Record your data and submicroscopic observations at 30 seconds. Create a sketch of the submicroscopic concentration plot on the axes provided.*
- *For* ***Trial 2****, add the catalyst to the simulation. Run the simulation for 30 seconds and then pause. Record the initial data and submicroscopic observations. Create a sketch of the submicroscopic concentration plot on the axes provided. Make sure to include a key for your plot. Record your data and submicroscopic observations.*
- *For* ***Trial 3****, add the inhibitor to the simulation. Run the simulation for 30 seconds and then pause. Record the initial data and submicroscopic observations. Create a sketch of the submicroscopic concentration plot on the axes provided. Make sure to include a key for your plot. Record your data and submicroscopic observations.*

	Initial State				**Trial 1 - without Catalysts or Inhibitors** - 15 seconds			
Submicroscopic Sketch								
Observations								
Data	$[N_2O_4]$		$[NO_2]$		$[N_2O_4]$		$[NO_2]$	
	Pressure		Temperature		Pressure		Temperature	
	Volume				Volume			

Key	**Graph**

	Trial 2 - with Catalyst 15 seconds	**Trial 3 - with Inhibitor** 15 seconds
Submicroscopic Sketch		
Observations		

Data								
	$[N_2O_4]$		$[NO_2]$		$[N_2O_4]$		$[NO_2]$	
	Pressure		Temperature		Pressure		Temperature	
	Volume				Volume			

Graph	**Graph**

5. Was there any difference between the reaction rates between Trial 1 and Trial 2? *Support your claim with evidence.*

6. An inhibitor will have an inhibitive or restrictive effect on a reaction, while a catalyst will have a catalytic or promotive effect. In Trial 2, was there inhibitive or catalytic effect on the reaction? *Support your claim with evidence.*

7. Explain how the addition of a catalyst affects the activation energy and the reaction rate.

8. Explain how the addition of an inhibitor affects the activation energy and the reaction rate.

9. How is this reaction different than some of the other reactions in the previous lessons?

10. Hydrogen peroxide is a liquid solution. The variety commonly found in pharmacies is 5% concentration of hydrogen peroxide with water. What do you think would happen to the rate of reaction between a hydrogen peroxide with a 35% concentration and the solid iron?

Lesson Reflection Questions

Enzymes, such as those found in the digestive system, are a type of catalyst. The pancreas produces enzymes that help digest proteins, fats, and carbohydrates. Recall from biology that proteins help build muscle, carbohydrates provide fuel for the body, and fats are essential in providing insulation and some of the energy our bodies need.

Many medications are inhibitors, which can affect hormones and other chemical reactions in the body. Angiotensin is a hormone in the body that causes the muscles in the walls of blood vessels to contract, resulting in narrower vessels. This narrowing increases the pressure inside the vessels, causing high blood pressure.

11. How would the absence of a catalyst affect the chemical reactions that occur in the digestive system? How might the person without enzyme catalysts be affected?

12. How could an inhibitor medication be helpful to a person with high blood pressure?

Activity 3: Kinetics Wet Lab

This lab is designed to help you explore the different factors that affect how fast or slow a chemical reaction progresses. This lab requires multiple smaller experiments to gather the necessary data. Following the lab, you will be able to explore the reactions submicroscopically through the use of the CCC simulations.

Activity 4: Simulation of Surface Area

Simulation

Use Simulation 2, ***Sets 1–2***

This simulation is similar to the reaction that happens when Alka Seltzer® tablets are added to water. This simulation represents the submicroscopic view of a reaction between sodium bicarbonate (baking soda) and concentrated acetic acid.

- *Your teacher will run **Simulation 2, Set 1**, which shows a reaction with baking soda in a solid cube. Create a submicroscopic sketch of the simulation and key at time 0 seconds.*
- *Record the initial concentration of the reactants and other data from monitors.*
- *Your teacher will run the simulation for 10 seconds. After the simulation is paused, create a submicroscopic sketch of the final products.*
- *Record the time it took for the reaction to occur and the concentration of the products.*
- *Write down your observations.*

- *Your teacher will use **Simulation 2, Set 2**, which shows baking soda in fine powder form. Before your teacher starts the simulation, create a submicroscopic sketch of the simulation and key at time 0 seconds.*
- *Record the initial concentration of the reactants.*
- *Your teacher will run the simulation for 10 seconds. After the simulation is paused, create a submicroscopic sketch of the final products.*
- *Write down your observations.*

	Trial 1 - Initial State				**Trial 1 - Final** 10 seconds			
Submicroscopic Sketch								
Observations								
Data	$[NaHCO_3]$		$[HC_2H_3O_2]$		$[NaHCO_3]$		$[HC_2H_3O_2]$	
	$[CO_2]$		$[H_2O]$		$[CO_2]$		$[H_2O]$	
	$[NaCH_3CO_2]$				$[NaCH_3CO_2]$			

Key	**Graph**

	Trial 2 - Initial State				Trial 2 - Final 10 seconds			
Submicroscopic Sketch								
Observations								
Data	[$NaHCO_3$]		[$HC_2H_3O_2$]		[$NaHCO_3$]		[$HC_2H_3O_2$]	
	[CO_2]		[H_2O]		[CO_2]		[H_2O]	
	[$NaCH_3CO_2$]				[$NaCH_3CO_2$]			

Key	**Graph**

13. What is the balanced equation for the reaction?

14. How did the concentration of the reactants and products change over time?

15. In which simulation was the reaction rate quicker? Why?

16. Using the monitors, determine the time that the reactants are no longer reacting to form products. Describe how you determined this time.

17. Compare and contrast the relationship between surface area, physical change (dissolution) and chemical change (chemical reaction).

Activity 5: Simulating Concentration and Reaction Rates

Simulation

Use Simulation 3, ***Set 3***

Recall that concentration of a solution is defined as the amount of solute per unit volume. As you might have learned previously, gases can also form solutions.

In the following simulation activity, you will manipulate the solution by changing the concentration of nitric oxide (NO), one of the reactant gases that is present in the reaction.

- *Follow your teacher's demonstration on how to manipulate the simulation. Create three unique trials by manipulating the concentration of the nitric oxide (NO) used.*
- *Keep all the other variables constant.*
- *For each trial select a unique concentration for the nitric oxide.*
- *Before starting the simulation, record the initial data and your submicroscopic observations.*
- *Create a sketch of the submicroscopic concentration plot on the axes provided.*
- *Start the simulation, run for 10 seconds, and then pause.*
- *Record the data and your submicroscopic observations.*
- *Create a sketch of the concentration plot on the axes provided.*
- *Make sure to include a key to explain plot.*
- *Reset and repeat for two more trials by adjusting NO concentration.*

	Trial 1 - Initial State 0 seconds				Trial 1 - Final 10 seconds			
Submicroscopic Sketch								
Observations								
Data	$[ClNO_2]$		[NO]		$[ClNO_2]$		[NO]	
	[ClNO]		$[NO_2]$		[ClNO]		$[NO_2]$	
	Pressure		Temperature		Pressure		Temperature	
	Volume				Volume			

Key	Graph

	Trial 2 - Initial State 0 seconds	**Trial 2 - Final** 10 seconds
Submicroscopic Sketch		
Observations		

Data								
	[$ClNO_2$]		[NO]		[$ClNO_2$]		[NO]	
	[ClNO]		[NO_2]		[ClNO]		[NO_2]	
	Pressure		Temperature		Pressure		Temperature	
	Volume				Volume			

Key	**Graph**

	Trial 3 - Initial State 0 seconds				**Trial 3 - Final** 10 seconds			
Submicroscopic Sketch								
Observations								
Data	$[ClNO_2]$		[NO]		$[ClNO_2]$		[NO]	
	[ClNO]		$[NO_2]$		[ClNO]		$[NO_2]$	
	Pressure		Temperature		Pressure		Temperature	
	Volume				Volume			

Key

Graph

18. What is the balanced equation for the reaction?

19. Explain how the rate of the reaction changed, if at all, across the three trials. *Support your claims with evidence.*

20. Considering your observations, is there a relationship between concentration of the reactant and rate of the reaction? If so, explain the relationship.

21. What is the relationship between concentration and collisions between molecules?

22. How do collisions between molecules affect the rate of the reaction?

Activity 6: Teacher Facilitated Discussion

In your small group determine whether the following statements are true or false.

Be prepared to share out and defend your answers in a whole class discussion.

23. "A powdered solid will produce a slower reaction than a solid chunk, therefore the powdered solid has less surface area than the single solid chunk." **True** or **False** *(circle one). Support your claim with evidence.*

24. "If there are a greater of number of reactant atoms per area, a reaction would occur quicker. **True** or **False** *(circle one). Support your claim with evidence.*

25. "If there is not enough energy in a system, a reaction may not occur." **True** or **False** *(circle one). Support your claim with evidence.*

26. "Both the mass and concentration of a solid reactant will change over time during a reaction." **True** or **False** *(circle one). Support your claim with evidence.*

Activity 7: Simulating Temperature and Reaction Rates

Simulation

Use Simulation 3, ***Sets 4–6***

- *Follow your teacher's demonstration on how to manipulate the simulation. Keep all other variables constant.*
- *Each set represents a unique temperature.*
- *Using* **Simulation 3, Set 4***, create a sketch of the submicroscopic concentration plot on the axes provided. Start the simulation, run the simulation for 10 seconds, and then pause.*
- *Please record your data and submicroscopic observations. Create a sketch of the concentration plot on the axes provided. Make sure to include a key to explain plot.*
- *Repeat the procedure with* ***Sets 5 & 6.*** *Pictures for initial reactions and their trials have been provided for you.*

	Initial State 0 seconds				**Trial 1 - Final** 10 seconds			
Submicroscopic Sketch								
Observations								
Data	$[ClNO_2]$		$[NO]$		$[ClNO_2]$		$[NO]$	
	$[ClNO]$		$[NO_2]$		$[ClNO]$		$[NO_2]$	
	Pressure		Temperature		Pressure		Temperature	
	Volume				Volume			
	Key				**Graph**			

	Trial 2 - Final 10 seconds				Trial 3 - Final 10 seconds			
Submicroscopic Sketch								
Observations								
Data	$[ClNO_2]$		[NO]		$[ClNO_2]$		[NO]	
	[ClNO]		$[NO_2]$		[ClNO]		$[NO_2]$	
	Pressure		Temperature		Pressure		Temperature	
	Volume				Volume			
	Graph				Graph			

27. Explain how the rate of the reaction changed, if at all, across the three trials. Use evidence from the simulation to support how you know the rate of the reaction changed.

28. Based on your observations, is there a relationship between temperature and the rate of the reaction? If so, explain the relationship.

29. How did increasing the temperature affect the molecules on a submicroscopic level?

30. Explain how extremely cold temperatures affect the kinetic energy of molecules and how extremely cold temperatures would impact the rate of a reaction.

Activity 8: Simulating Pressure and Reaction Rates

Simulation

Use Simulation 3, ***Set 7***

- *Follow your teacher's demonstration on how to manipulate the simulation. You will create three unique trials in which you manipulate the pressure. Keep all other variables constant.*
- *For Trial 1, select a unique pressure by adjusting the volume of the container. Before starting the simulation, record the initial data and submicroscopic observations.*
- *Create a sketch of the submicroscopic concentration plot on the axes provided.*
- *Start the simulation and run for 10 seconds then pause.*
- *Record data and submicroscopic observations.*
- *Create a sketch of the concentration plot on the axes provided. Make sure to include a key to decode the plot.*
- *Reset and repeat for two more trials by adjusting pressure. You do not need initial submicroscopic sketches for Trials 2 and 3.*
- *Boyles' Law applies to this simulation. Pressure cannot be directly adjusted. Pressure can only be adjusted by increasing or decreasing volume.*

	Initial State 0 seconds	**Trial 1 - Final** 10 seconds
Submicroscopic Sketch		
Observations		

Data

[$ClNO_2$]		[NO]		[$ClNO_2$]		[NO]	
[ClNO]		[NO_2]		[ClNO]		[NO_2]	
Pressure		Temperature		Pressure		Temperature	
Volume				Volume			

Key	**Graph**

	Trial 2 - Final 10 seconds				Trial 3 - Final 10 seconds			
Submicroscopic Sketch								
Observations								
Data	$[ClNO_2]$		[NO]		$[ClNO_2]$		[NO]	
	[ClNO]		$[NO_2]$		[ClNO]		$[NO_2]$	
	Pressure		Temperature		Pressure		Temperature	
	Volume				Volume			

Graph

Graph

1. Pressure affects gases differently than it does solids and liquids. From a submicroscopic level, explain why gases react to differences in external pressure differently than solids and liquids. *Support your claims with evidence.*

2. During cellular metabolism in some organisms, a chemical reaction occurs between hydrogen gas and oxygen gas. How would the reaction rate be affected by having the gases inside a chamber which was being compressed? *Support your claims with evidence.*

3. Explain how the rate of the reaction changed, if at all, across the three trials. *Support your claim with evidence.*

4. Considering your observations, what is the relationship pressure and rate of the reaction?

5. Explain how the number of collisions between molecules is related to the pressure of the system. Provide evidence from the simulations at the submicroscopic level.

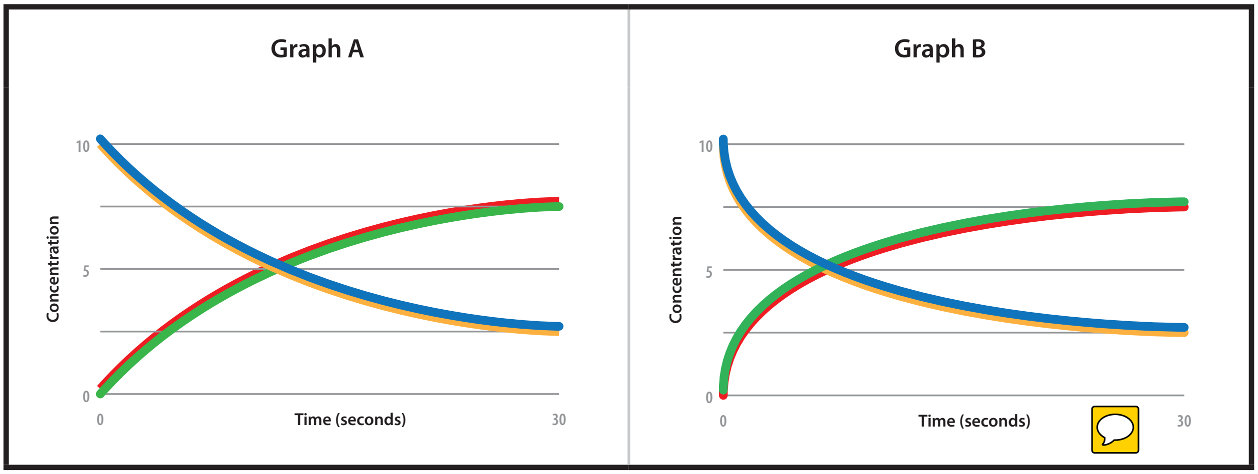
Lesson Reflection Question

6. Explain the factors that affect reaction rates using the submicroscopic level to describe why these

factors change the reaction rate.

Activity 9: Capstone

Part 1



1. Which graph shows a reaction with a slower average rate? *Support your claim with evidence.*

2. Which variable could have been directly manipulated to cause the difference in rate between graph A and B? Support your claim with evidence.

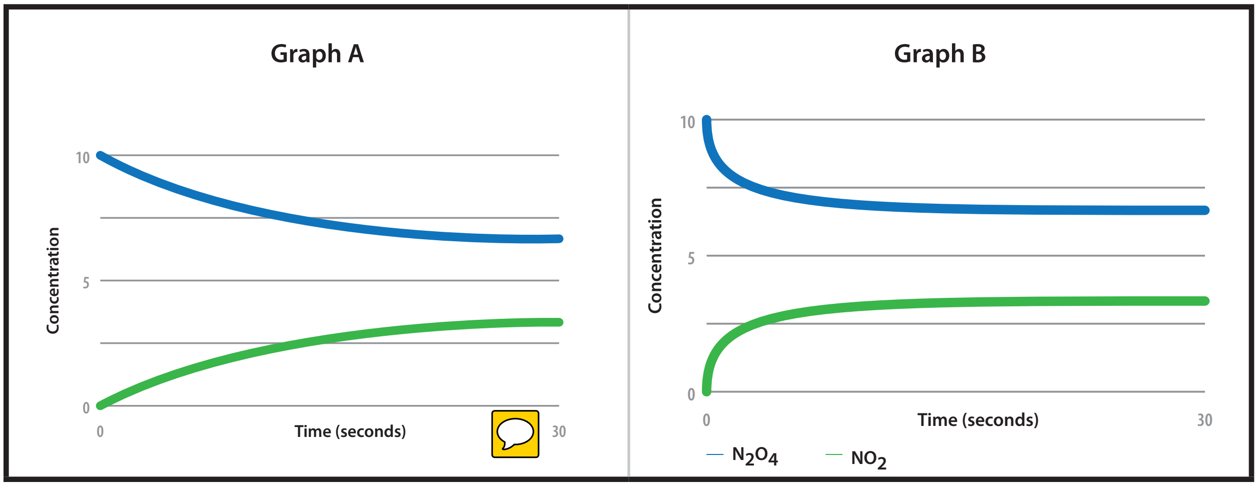
A. Concentration

B. Adding heat to change temperature

C. Adjusting volume to change pressure

D. Both B and C

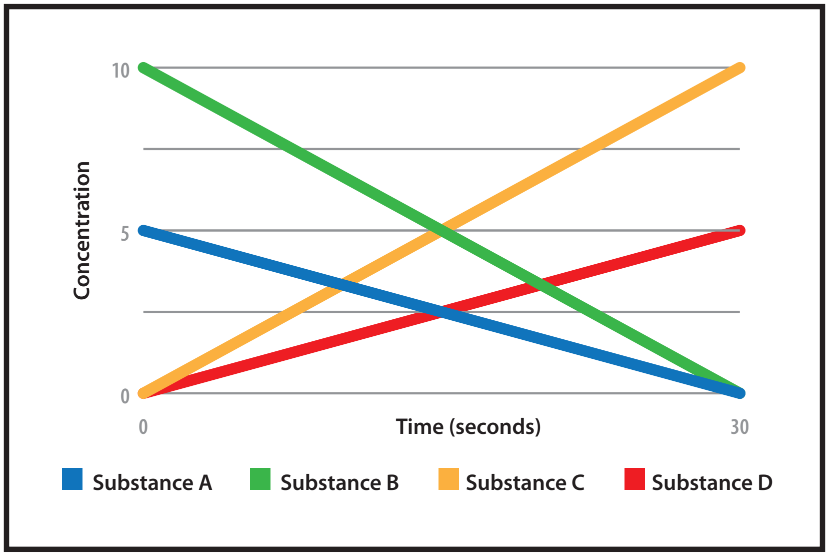
Part 2



3. Which graph shows a reaction with a faster average rate? *Support your claim with evidence.*

4. The plots above depict the same reaction under different conditions. Label each graph as to whether an inhibitor or a catalyst was added. *Support your claim with evidence.*

Part 3

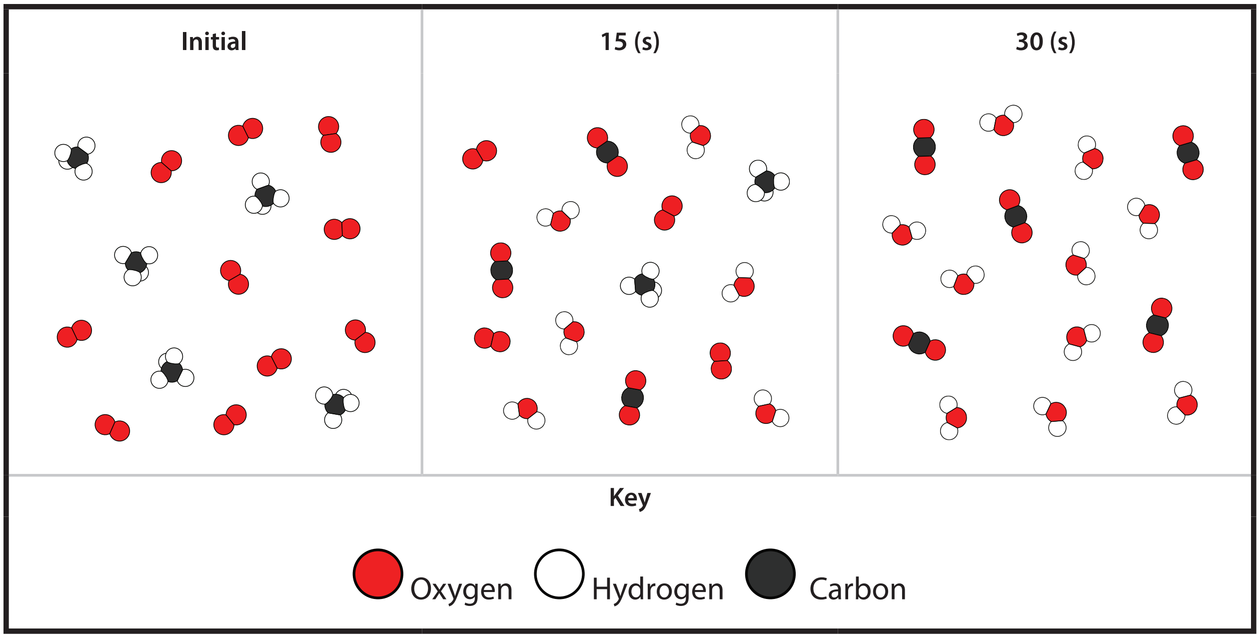


5. Which data table below matches the graph above? *Support your claim with evidence.*

Set	Substance	0 seconds	15 seconds	30 seconds
1	A	[10]	[5]	[0]
	B	[5]	[2.5]	[0]
	C	[0]	[5]	[10]
	D	[0]	[2.5]	[5]

Set	Substance	0 seconds	15 seconds	30 seconds
2	A	[10]	[2.5]	[0]
	B	[5]	[5]	[0]
	C	[0]	[2.5]	[10]
	D	[0]	[5]	[5]

Set	Substance	0 seconds	15 seconds	30 seconds
3	A	[0]	[5]	[10]
	B	[0]	[2.5]	[5]
	C	[10]	[5]	[0]
	D	[5]	[2.5]	[0]



6. Which data table below matches the series of submicroscopic pictures above? *Support your claim with evidence.*

Set	Substance	0 seconds	15 seconds	30 seconds
1	CH_4	[0.005]	[0.002]	[0]
	O_2	[0.005]	[0.005]	[0]
	CO_2	[0]	[0.003]	[0.005]
	H_2O	[0]	[0.006]	[0.005]

Set	Substance	0 seconds	15 seconds	30 seconds
2	CH_4	[0.005]	[0.002]	[0]
	O_2	[0.010]	[0.005]	[0]
	CO_2	[0]	[0.003]	[0.005]
	H_2O	[0]	[0.006]	

Set	Substance	0 seconds	15 seconds	30 seconds
3	CH_4	0	[0.002]	[0.005]
	O_2	0	[0.005]	[0.010]
	CO_2	[0.005]	[0.003]	0
	H_2O	[0.010]	[0.006]	0

Connected Chemistry

Kinetics Unit

Lesson 4: Exploring the Rate Law and Rate Order

Student's Lesson at a Glance

Lesson Summary

This lesson contains three activities. Students will be introduced to the rate law in the Connecting Activity. Students will learn that the exponent values in the rate law are determined by the rate order. Students will be given a chart that shows the relationship between rate order, rate equation, value of ***k*** as determined by slope and the graphic relationship. Using this information, students will determine the rate law and order for three reactions following a teacher demonstration of how to gather data and create concentration graphs.

SWBAT (Student will be able to)

- Define the rate law as rate = $k[A]^m[B]^n$
- Explain the difference between a zero, 1st and 2nd order reaction via calculations and graphic representations.

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.
- 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.
- Label all graphs so that you can accurately answer analysis questions.
- For help on calculating slope, look in the Appendix.

Notes

Homework

Upcoming Quizzes/ Tests

Activity 1: Connecting

Consider the following three scenarios:

- While buying a sports car a customer asks the salesman, "how fast does the car run?" The salesperson says it goes "really fast."
- A friend calls to say the line to buy tickets for her favorite band is slow.
- A radio announcer giving the traffic report says commute times are average for this time of day.

1. Are the descriptions of speed above qualitative or quantitative? *Support your claim with evidence.*

2. How easy is it to rank these scenarios from slowest to fastest?

By examining the change in concentration over time, we are able to make general statements about the "speed" of a reaction. However, chemists, chefs, hair stylists, doctors, and many others need to be more specific. For example, a chef must know the rate at which yeast converts sugars into carbon dioxide to make a proper loaf of bread and the rate at which food spoils to prevent illness. Hair stylists must know how long to leave chemical dyes on hair to produce long-lasting color, but not cause damage. To prevent unwanted side effects, doctors must understand how medications affect the rate of chemical reactions inside the body so that medicines can be administered long enough to treat disease without damaging the body.

3. Name at least two other careers that may be concerned with knowing the specific rate of chemical reactions. Explain why people working in these careers would find it useful to know about reaction rates.

4. What are factors that speed up a reaction?

5. What are factors that slow down a reaction?

Chemists have observed that the rate of a reaction can be calculated using the rate law. The **rate law** for a chemical reaction is an equation that expresses the reaction rate as a function of the concentrations of reactants and a constant. The rate law determines a quantitative value for a reaction that has qualitatively been described as "fast" or "slow". The equation below represents a generic rate law which will be explored further in this lesson:

$$rate = k\,[A]^m\,[B]^n$$

Recall that the brackets **[ ]** in the equation stand for concentration of the reactants. In many cases, the value of the exponents (m or n) are identical to the coefficients in the relevant chemical equation. The values of exponents (m or n) can only be determined through experimentation and may not be the values of the coefficients in the balanced chemical equation. The constant k is a proportional factor that is specific for any given reaction.

A chemical equation may have one or more reactants. The following simulations will focus on two reactants. For example:

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

In the simulations of the reactions, you will vary the concentration of reactant A while the keeping concentration of reactant B constant across three trials. In the rate law, the exponent values of m and n are usually 0, 1, or 2. These numbers come from what rate order the reaction is classified as.

- A **zero order reaction** has a rate that is independent of the concentration of the reactants.
- A **1st order reaction** is when the rate is directly proportional to the concentration of only one reactant.
- A **2nd order reaction** is when the rate is proportional to the square of the concentration of one reactant or two first-order reactants.

We can discover what order the reaction is by creating three graphs from data.

Whatever graph shows a linear relationship between concentration and time, determines the order and thus the exponent for the rate law equation.

Rate Order	Rate Equation	Value of k (See Appendix for help on calculating slope)	Graphic Relationship	Unit of Rate
0	rate = k	Negative slope	[A] vs. t	mole L^{-1} sec^{-1}
1	rate = k [A]	Negative slope	*ln* [A] vs. t	sec^{-1}
2	rate = $k(A)^2$	Positive slope	$\frac{1}{[A]}$ vs. t	mole L^{-1} sec^{-1}

6. If the concentration of A is doubled in a zero order reaction, how is the rate affected? *Support your claim with evidence.*

7. If the concentration of A is doubled in a 1st order reaction how is the rate affected? *Support your claim with evidence.*

8. If the concentration of A is doubled in a 2nd order reaction how is rate affected? *Support your claim with evidence.*

Activity 2: Demonstration of Rate Law and Rate Order

Simulation

Use Simulation 4, ***Set 1***

- *Your teacher will set up a reaction using the simulation.*
- *Create an initial submicroscopic sketch at time 0 seconds and a key. Record [A].*
- *Your teacher will then run the simulation, pausing at 3 specific times between 0 and 30 seconds. You will have a total of five trials. Collect values for [A] at the 3 unique times selected as well as 0 and 30 seconds. [A] is Ammonia (NH_3).*
- *Create a final submicroscopic sketch at 30 seconds and record observations.*
- *Calculate ln [A] for the five trials and record in table.*
- *Calculate* $\frac{1}{[A]}$ *for the five trials and record in table.*

Create a Submicroscopic Sketch of the Reaction at 0 Seconds	Create a Submicroscopic Sketch of the Reaction at 30 Seconds
Record Your Observations	**Record Your Observations**
Key	

Trial	Time (s)	[A] mol/L	ln [A]	$\frac{1}{[A]}$
1	0 s			
2	5 s			
3	10 s			
4	25 s			
5	30 s			

9. Write out the balanced equation for the reaction.

10. Create a graph of **[A] vs time** using data from the table.

11. Create a graph of **ln [A] vs time** using data from the table.

12. Create a graph of **1/[A] vs time** using data from the table.

13. Considering the graphs, what order is the reaction?

14. What is the rate law equation for the reaction?

Activity 3: Determining Rate Law and Rate Order

Simulation: Use Simulation 4, ***Set 2-3***

- *Set up a reaction using the* ***Simulation 1 Set 2****.*
- *Create an initial submicroscopic sketch at time 0 seconds and a key.* ***Record [A]****. In both activities, [A] is* NO_2*.*
- *Run the simulation, pausing at 3 unique times between 0 and 30 seconds. You will have a total of five trials. Collect values for [A] at the 3 unique times selected as well as 0 and 30 seconds.*
- *Create a final submicroscopic sketch at 30 seconds and record observations.*
- *Calculate ln [A] for the five trials and record in table.*
- *Calculate 1 / [A] for the five trials and record in table.*
- *Repeat procedure for reaction 2 using simulation 4 set 3.*

Reaction 1

Create a Submicroscopic Sketch of the Reaction at 0 Seconds	Create a Submicroscopic Sketch of the Reaction at 30 Seconds
Record Your Observations	**Record Your Observations**
Key	

Trial	Time (s)	[A] mol/L	ln [A]	$\frac{1}{[A]}$
1	0 s			
2	5 s			
3	10 s			
4	25 s			
5	30 s			

15. Write out the balanced equation for the reaction.

16. Create a graph of **[A] vs time** using data from the table.

17. Create a graph of **ln [A] vs time** using data from the table.

18. Create a graph of **1/[A] vs time** using data from the table.

19. Considering the graph, what order is the reaction?

20. What is the rate law equation for the reaction?

Reaction 2

Create a Submicroscopic Sketch of the Reaction at 0 Seconds	Create a Submicroscopic Sketch of the Reaction at 30 Seconds
Record Your Observations	**Record Your Observations**
Key	

Trial	Time (s)	[A] mol/L	ln [A]	$\frac{1}{[A]}$
1	0 s			
2	5 s			
3	10 s			
4	25 s			
5	30 s			

21. Write out the balanced equation for the reaction.

22. Create a graph of **[A] vs time** using data from the table.

23. Create a graph of **ln [A] vs time** using data from the table.

24. Create a graph of **1/[A] vs time** using data from the table.

25. Considering the graph, what order is the reaction?

26. What is the rate law equation for the reaction?

Connected Chemistry

Kinetics Unit

Lesson 5: Exploring Stepwise Reactions

Student's Lesson at a Glance

Lesson Summary

This lesson is a bridge for students who may be exploring kinetics further. CCC does not have technology at this time that show intermediate products formed during stepwise reactions.

SWBAT (Student will be able to)

- Define stepwise reactions
- Identify the steps for a multi-step reaction

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

- Use the vocabulary section and note section to take good notes so that studying for tests and quizzes is easier.
- Use vocabulary notes from previous sections to help refresh your understanding of concepts.
- Draw a key when you are sketching. Keys can help you and others decode your sketches at a later time.
- Create clear explanations of the sketches you create so they are usable at a later time to study.
- 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

Activity 1: Connecting

1. In your own words what does the term "deplete" mean?

____

____

CFC is the abbreviation for chlorofluorocarbons. It is an organic substance made from carbon, chlorine, and fluorine that was used in aerosol products. CFCs are nontoxic, nonflammable, and non-reactive with other chemical compounds. These safety characteristics made CFCs ideal for many uses in the home and commercially. CFCs could be found in coolants for refrigerators, aerosol beauty and hygiene products, and electronic cleaning sprays.

During the 1980s, scientists discovered that CFCs speed up a chemical reaction that was slowly destroying the ozone layer that protected the earth. This layer is composed of high concentrations of ozone (O_3) which helps filter out over 97% of the ultraviolet (UV) radiation coming from the sun. Too much UV radiation leads to sunburns, skin cancer, and eye damage. UV radiation can also affect food chains by killing crops, trees, and other microorganisms. This may limit the availability of food and oxygen for humans and other organisms in the food web. Because of ongoing research and federal regulation, companies found more environmentally friendly ways to manufacture aerosol products to prevent further damage to the ozone layer.

2. Are CFCs catalysts or inhibitors? *Support your claim with evidence from the text.*

____

____

3. How might a company that produces large amounts of CFCs annually impact the environment?

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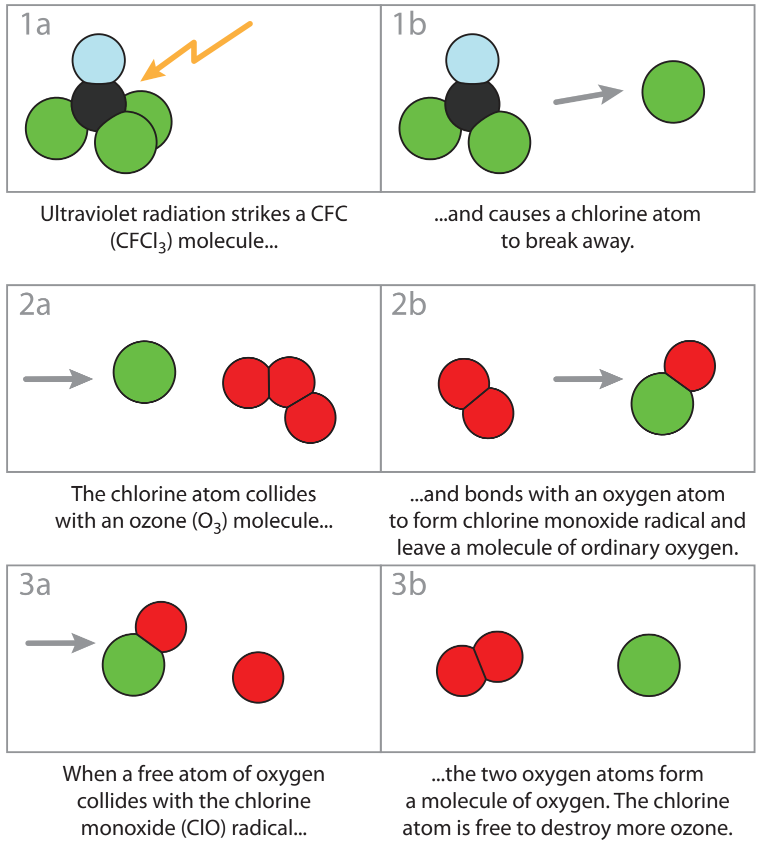
The chemical reaction between CFCs and ozone is represented in the following net equation:

$$2\,O_3(g) \longrightarrow 3\,O_2(g)$$



There seems to be a missing piece from this reaction. The CFCs are not represented because this is a net equation and in the reaction takes place in several steps. A **stepwise reaction** is a reaction with one or more *intermediate reactions*. These intermediate reactions produce unstable products that only last for a short time before they participate in another step of the reaction. Some of the steps are faster than others. The overall rate of the reaction is only as fast as the slowest step.

The panels on the right depict individual molecules. In Step 1, the UV radiation acts to break the bond between chlorine and carbon. The resulting free radical is efficient at removing ozone because it is a catalyst. A free radical is an atom with unpaired electrons that is very reactive. The reaction can be shown in the figure to the right. The chlorine radicals are not used by the reaction, but are recycled and continue to react with other ozone molecules to react with them as well (repeat Step 2). One CFC molecule can react with up to 100,000 ozone molecules, which leads to the depletion of the ozone.

4. Create a written equation for each step of the process.

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____

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5. What factors may influence the rate of this reaction?

____

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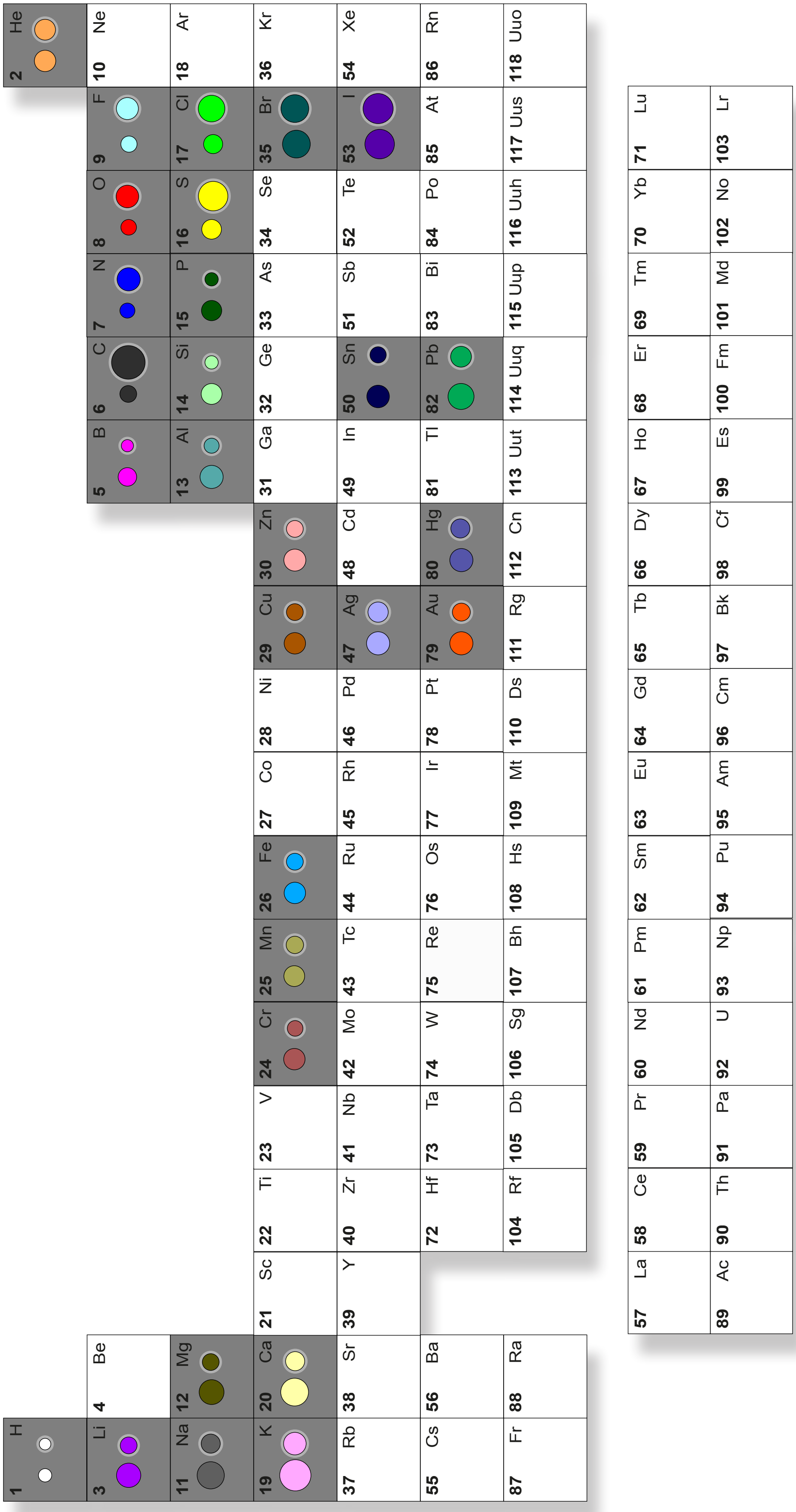
Elements Used in the Connected Chemistry Curriculum



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

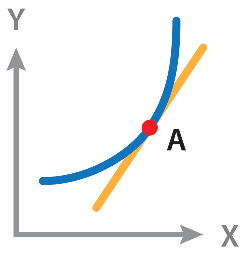
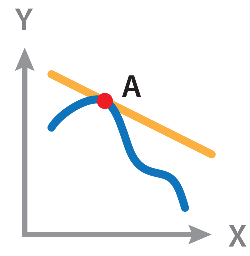
Supplement

Calculating the Slope of a Line

Remember that the slope of a line (linear relationship) is constant, but the slope of a non-linear curve (non linear relationship) changes from point to point.

In chemistry rate reactions, most reactions will have a non-linear relationship. This means that we will measure the slope at one point on the curve. This is done using a tangent line.

A tangent line is a line that touches a curve at a single point and does not cross through it. The slope of a curve at a point is equal to the slope of the line that is tangent to the curve at that point. You can fit a line to the curve by using a ruler or straight edge for accuracy.

Positive Slope	Negative Slope
	

$$\text{Slope} = \frac{\Delta y = (y_2 - y_1)}{\Delta x = (x_2 - x_1)}$$

To Determine the Slope of the Tangent Line

1. Identify two points on the line.
2. Select one to be (x_1, y_1) and the other to be (x_2, y_2).
3. Use the slope equation to calculate slope.

A line pointing up from left to right is positive.	A line pointing down from left to right is negative.	A straight horizontal line has a zero value slope.