Fifth Edition

YOU BE THE CHEMIST™

ACTIVITY GUIDES

Hands-on Science for Grade K-8 Students

Powered by Chemical Educational Foundation®
www.chemed.org

Chemical Reactions: Reaction Rates & Catalysts

Activity Guides:

SETZER REACTION RATES | **ELEPHANT TOOTHPASTE** | **AGELESS APPLES**

Chemical Reactions: Reaction Rates & Catalysts

All matter in the universe is made up of atoms. There are 118 different types of atoms called **elements**, which are shown on the periodic table. These 118 different types of atoms can be combined in millions of different ways to form unique substances.

Table sugar is made of a molecule called sucrose. Sucrose is composed of 12 carbon atoms, 22 hydrogen atoms, and 11 oxygen atoms bonded together in a specific way. Smartphone screens respond to your finger because of a layer of indium tin oxide, which conducts electricity and is transparent. Some smartphones have more than 60 different elements in them!

Sucrose, the molecule in table sugar, contains carbon, hydrogen, and oxygen: $C_{12}H_{22}O_{11}$

Indium tin oxide, used in smartphone screens, is made up of indium, tin, and oxygen *ITO*

A **chemical change** or **chemical reaction** is a change that takes place when the atoms of a substance are rearranged. During a reaction the bonds between atoms are broken or formed. All the substances that are present at the beginning of a reaction are the **reactants**. All the new substances that are produced during the reaction are the **products**. The products are different from the reactants, and have different physical and chemical properties than those of the reactants.

Chemical reaction
Reactants → Products

On a molecular level, a chemical reaction takes place when particles of the reactants run into each other. For particles to react when they collide, the particles also need to have enough energy and must collide with the right orientation. The rate of a reaction depends on how often particles run into each other and react. This is called **collision theory**.

Scientists often manipulate reactions rates. Some ways to change the rate of a reaction are:

Higher concentration of reactants → faster reaction rate
A higher concentration of the reactants means that particles are more likely to run into each other. Since there are more collisions, the reaction happens faster.

Higher temperature → faster reaction rate
Temperature measures how fast the particles in a substance are moving around (this is called kinetic energy). At a higher temperature, particles have more energy, they are moving faster, and are more likely to collide and react.

Add a catalyst → either faster OR slower reaction rate
A catalyst is a substance that changes the rate of a reaction, but isn't used up during the reaction. Scientists usually use catalysts to increase a reaction rate.

The rate of a reaction also depends on what the reactants are and how they have to change. Every reaction needs some energy to get started. Think of pulling a sled up a hill. For every reaction, there is an "energy hill" of some size that it needs to climb before it can go forward. The harder it is to climb this hill, the slower the reaction is. The amount of energy needed to start a reaction, the size of the "energy hill" it needs to climb, is called the **activation energy**.

A reaction needs activation energy because the reactants have to pass through a very high-energy, unstable state called the **transition state**. In the transition state, the bonds in the reactants are in the process of breaking while the bonds in the products are in the process of forming. Since the transition state is so unstable, all chemical reactions need a bit of a push (activation energy) to get through it. The top of the sledding hill is like the transition state, and the energy needed to get there is like the activation energy.

For some reactions this energy hill is so big, and the reaction takes place so slowly, that it basically doesn't happen at all. For example, diamonds and graphite (in pencils) are made of the same thing: both are different forms of pure carbon. A diamond could just spontaneously change into graphite. However, the activation energy for this reaction is so high that it is practically impossible to start the reaction.

Let's experiment with some of the ways you can change the rate of a chemical reaction!

ENGAGE YOUR STUDENTS

Before beginning any of these activities, use the following ideas to engage your students in learning about chemical reactions:

- Start with an overview of physical versus chemical changes, including their definitions and how we distinguish them. Show students a variety of pictures, video clips, or demos and ask them whether a physical or chemical change has occurred, and the evidence they have for their answer. Some examples of physical changes could be melting an ice cube, mixing sand and salt, shredding paper, crushing a can, or chopping wood. Examples of chemical changes could be roasting a marshmallow, baking a cake, cooking an egg, food rotting, iron rusting, a match burning, or digesting food.

- Chemical reactions are all around us! Encourage students to discuss and come up with examples of chemical reactions, where the substances that you start with undergo an irreversible change.

Seltzer Reaction Rates

Section **CHEMICAL REACTIONS** *Topic* **REACTION RATES & CATALYSTS**

Estimated Time Setup: 5 minutes; Procedure: 5-10 minutes

OVERVIEW

Students explore how temperature affects reaction rates in this simple, bubbly experiment.

In this activity, students place seltzer tablets into samples of water at different temperatures. Higher temperatures often mean reactions proceed faster, and students will see that the seltzer tablets in the hot water bubble and fizz at a high higher rate than tablets in the cold water. This chemical reaction is also endothermic – meaning it absorbs heat – and students can feel the water cooling as the reaction comes to completion.

INQUIRY QUESTIONS

Getting Started:
- Is the change that occurs in this reaction a chemical or physical change? What evidence do we have for either case?

Learning More:
- What effect does temperature have on the rate of a reaction?

Diving Deeper:
- What happens at the molecular level when the temperature of a reaction is increased or decreased, and how does this change the rate of reaction?

CONTENT TOPICS

This activity covers the following content topics: properties of matter, chemical reactions, chemical change, temperature, reaction rate, energy (temperature, kinetic), endothermic and exothermic reactions, acid-base reactions

This activity can be extended to discuss: equilibrium, reversible and irreversible reactions, conservation of matter and mass, density

NGSS CONNECTIONS

This activity can be used to achieve the following Performance Expectations of the Next Generation Science Standards:
- **5-PS1-4:** Conduct an investigation to determine whether the mixing of two or more substances results in new substances.
- **MS-PS1-2:** Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

MATERIALS

For one setup:
- 3 seltzer tablets
- 3 clear glass or thick plastic cups
- Hot, cold, and room temperature water

Optional materials:
- Stopwatch
- Thermometer

ACTIVITY NOTES

This activity is good for:
- Individuals
- Pairs
- Small groups

Safety Tips & Reminders:
- Seltzer tablets are used as a medicine; be sure to pour the product down the drain after the reaction is complete.
- Review the Safety First section in the Resource Guide for additional information

Fun Fact #1

Alka-Seltzer, the original seltzer tablet brand, was invented in 1931 by A. R. "Hub" Beardsley, the president of a laboratory in Indiana. He found that during a flu epidemic in Elkhart, Indiana, none of the employees of a local paper got sick. He found that the editor of the paper made his staff drink a mixture of aspirin and bicarbonate of soda each day. Beardsley worked with his staff to develop this concoction into a pill, which later became Alka-Seltzer!

ENGAGE

Use the following ideas to engage your students in learning about chemical reactions:

- Start with an overview of physical versus chemical changes, including their definitions and how we distinguish them. Show students a variety of pictures, video clips, or demos and ask them whether a physical or chemical change has occurred, and the evidence they have for their answer. Some examples of physical changes could be melting an ice cube, mixing sand and salt, shredding paper, crushing a can, or chopping wood. Examples of chemical changes could be roasting a marshmallow, baking a cake, cooking an egg, food rotting, iron rusting, a match burning, or digesting food.

See more ideas for engagement in the Reaction Rates & Catalysts Background section! You can also look at the Elaborate section of this activity for other ideas to engage your students.

Fun Fact #2

Baking soda, or sodium bicarbonate,can be used to put out small electrical or grease fires because it helps smother the flames.

EXPLORE

Procedure:

1. Fill three cups with the same amount of water: one with hot water, one with room temperature water, and one with ice-cold water.
   Optional: Take the temperature of each sample and record.
2. Label each cup as “hot,” “room temperature,” or “cold”
3. At the same time, drop a seltzer tablet into each cup. Observe and record your findings.

Alternate method:

1. Fill three cups with the same amount of water: one with hot water, one with room temperature water, and one with ice-cold water. Label each cup accordingly.
   Optional: Take the temperature of each sample and record.
2. Drop the seltzer tablet in the cold water and start the stopwatch immediately.
3. Stop the stopwatch when bubbles stop forming and record the time.
4. Take the temperature of the water solution at the end of the reaction and record.
5. Repeat for the other two samples of water: room temperature and hot.

DATA COLLECTION & ANALYSIS

Analyze and discuss the results of this activity using the following questions:

- What are the physical properties of the seltzer tablet? How do you think it works?
- Write your observations: what was happening in each cup? What was different between each sample? Why do you think that is?
- If you timed the experiment, how long did it take the bubbles to stop forming in the hot water? The room temperature water? The cold water? What does this tell you? Graph your data to look for a pattern.
- In which cup was the reaction the slowest? The fastest? Why?
- Where do you think the bubbles were coming from? What are the bubbles composed of?
- Was this a chemical or physical change? How do you know? What evidence do you have?
- Feel each cup at the end of the experiment. Do they feel warmer or cooler than at the start? Or, if you measured the temperature, did it change from the start to the end of the experiment? What does this mean?

EXPLAIN

What's happening in this Activity?

First review the Reaction Rates & Catalysts Background section to gain a deeper understanding of the scientific principles behind this activity.

Seltzer tablets are used to treat a variety of symptoms—including fever, heartburn, acid reflux, indigestion, and stomachaches. These tablets do all of this by reacting with excess acid in the stomach and neutralizing it.

People take these tables by first dissolving it in water and then drinking the solution. When a tablet is put in water, it doesn't just a dissolve—a chemical reaction takes place! We can see this because bubbles are forming, which is often a sign of a chemical reaction. Alka-Seltzer tablets contain three different compounds: sodium bicarbonate, citric acid, and aspirin.

When the tablet is put in water, the sodium bicarbonate and the citric acid react. The reaction produces carbon dioxide gas, CO_2, which forms bubbles and floats to the top. The other products of the reaction are sodium citrate and water. Sodium citrate, $C_6H_5Na_3O_7$, is the compound that neutralizes stomach acid when someone takes an Alka-Seltzer tablet. These kinds of compounds are called antacids.

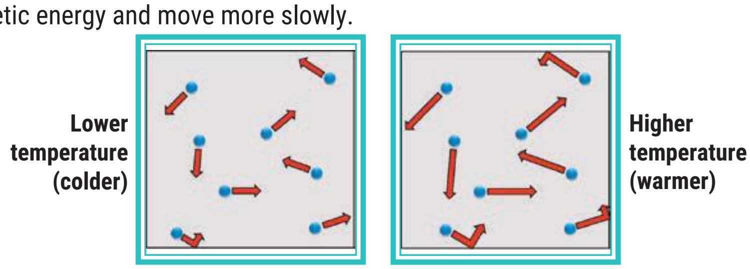
Reactants			→	Products				
Sodium bicarbonate	+	Citric acid	→	Carbon dioxide gas	+	Sodium citrate	+	Water
$3NaHCO_3$	+	$C_6H_8O_7$	→	$3CO_2$	+	$C_6H_5Na_3O_7$	+	$3H_2O$

How fast the bubbles are produced depends on how fast the reaction takes place. One factor that can change the rate of a chemical reaction is temperature. Generally, increasing the temperature increases the rate of a chemical reaction. The warmer the water, the faster the Alka-Seltzer tablet reacts.

A chemical reaction occurs when particles of the reactants run into each other. The Alka-Seltzer produces a gas because of millions of tiny collisions between sodium bicarbonate molecules and citric acid molecules, each of which produces carbon dioxide gas molecules. The particles collide because all particles have something called kinetic energy. **Kinetic energy** is the energy of motion. Anything that is moving has kinetic energy—whether it is a baseball, a car, or a cheetah.

Because particles have kinetic energy, they are always in random motion. The air particles in a room are constantly zooming around and colliding with each other, the walls, and objects in the room (unlike in Alta-Seltzer, these collisions don't cause a reaction).

Temperature is a measure of the average kinetic energy of particles in a substance. Think of temperature as how fast particles are moving around. The higher the temperature, the more kinetic energy particles have, and the faster they move. Most people think of temperature as a measure of hot and cold. If something feels "hot," that means its particles have high kinetic energy and move more quickly. If something feels "cold" its particles have low kinetic energy and move more slowly.



Each arrow shows the motion of a particle. The length of the arrow shows how fast the particle is moving—the longer the arrow, the faster it is moving. When the particles are moving faster they collide with things around them more often.

Notes

EXPLAIN continued

How does this fit in with chemical reactions? Increasing the temperature increases the rate of a reaction in two ways.

More collisions! When particles are moving faster, they are more likely to collide. Since collisions happen more often, particles react more often and the reaction goes faster.

Higher energy collisions! Not every collision results in a reaction. For two particles to react when they collide, they need to have a certain amount of energy—if they don't have enough energy, they will just collide and not react. Increasing the temperature means that particles have higher kinetic energy, and more particles have enough energy to react when they collide. This is the main way that increasing temperature increases the reaction rate.

Increasing the temperature makes the particles collide more often and makes it more likely that particles react when they collide. We can see this by putting Alka-Seltzer tablets in water at different temperatures and watching how fast the carbon dioxide bubbles are produced. The tablet in hot water produces bubbles the fastest. The tablet in cold water produces bubbles the slowest.

During this reaction, the glasses of water feel cold to the touch. This is because the reaction in Alka-Seltzer is **endothermic**, meaning that it takes in or absorbs energy from its surroundings. The feeling of "cold" is energy being transferred from your hand to the reaction mixture. Other types of reactions release energy and feel warm to the touch. These are **exothermic reactions**.

Differentiation for Younger or More Advanced Students

You can differentiate this activity for students of different grade levels by focusing on the concepts outlined below.

GETTING STARTED	DIVING DEEPER
For younger students, emphasize the following concepts: • Compounds can react with the body in certain ways based on their chemical properties • During a chemical reaction the original substances are used up, and a new substance is formed • Changing temperature changes the rate of a chemical reaction	**For more advanced students, emphasize the following concepts:** • Kinetic energy is the energy of motion, and temperature measures average kinetic energy • All particles have kinetic energy and are in constant random motion • A chemical reaction takes place when particles collide with sufficient energy

ELABORATE

Elaborate on your students' new ideas and encourage them to apply them to different situations. The section below provides some alternative methods, modifications, and extensions for this activity.

- What are other ways we could speed up a reaction? What about ways we could slow it down? Have students brainstorm some ideas and test them out. What worked and what didn't work? Why? (Hint: try the experiment again, but this time use water all at the same temperature but keep one seltzer tablet whole, break one into a few pieces, and crush the final one into a fine powder. What happens? What does this tell us about surface area and reaction rates?)
- What are some ways we could slow down the rate of reaction? Ask students to brainstorm some ideas, then test them out. Which worked? Why do they think that is? (Hint: less water, coating the tablet in something like an oil to prevent it from reacting, decreasing surface area, or cooling the water even more will all slow down the process!)
- Make a homemade lava lamp! Fill a jar 3/4 with oil and 1/4 with water. Mix in a few drops of food coloring, then drop in small pieces of seltzer tablets. Watch as the CO_2 bubbles pull the colored water up and down through the oil. Seal the jar and use again and again!
- To better understand how changes in temperature affect reaction rates, set up multiple trials at different temperatures. Students can decide how they want to display their data and add each trial they complete to a class data set, then graph the results. How does the reaction rate change as temperature changes in either direction?
- For more advanced students: look up the chemical formulas for the reactants. Can you predict any of the products? Can you balance the equation? (Sodium bicarbonate is $NaHCO_3$ and citric acid is $C_6H_8O_7$, which are the two reactants. The bubbles rising in the reaction are CO_2, which is one of the products. The other two products are sodium citrate, $C_6H_5Na_3O_7$, and water, H_2O. The unbalanced chemical equation is $NaHCO_3 + C_6H_8O_7 \rightarrow C_6H_5Na_3O_7 + CO_2 + H_2O$. The balanced chemical equation is $3NaHCO_3 + C_6H_8O_7 \rightarrow C_6H_5Na_3O_7 + 3CO_2 + 3H_2O$)

CHEMISTRY IN ACTION

Share the following real-world connections with your students to demonstrate how chemistry is all around us.

Real-World Applications·

Glowsticks glow because of a chemical reaction called chemiluminescence that produces light. Temperature affects how quickly this reaction happens, so putting a glowstick in a cool environment can slow down the reaction, making the glow last longer, whereas a glowstick in a hot environment will wear out faster.

A different type of endothermic reaction is also used for pain to help people find relief. Instant cold packs consist of two bags, one of which has water in it, while a second bag around the first contains ammonium nitrate, calcium ammonium nitrate or urea. To activate the reaction, the inner bag of water is broken (from the user squeezing the package). The water then dissolves the solid around it through an endothermic reaction, creating the desired cold temperature.

Careers in Chemistry

- Seltzer tablets, like many medicines today, were created by chemists! By learning what home remedies people were using to fight illness, then replicating and testing them in the laboratory, chemists have been able to develop thousands of substances that we can easily access at the pharmacy to cure our aches and pains!
- Chemistry is important for pharmacists to know. When they advise patients on medications to take – both prescribed and over-the-counter – they need to know the molecules in each drug in detail, and how they might react with other chemicals in the body. This helps them to share information about potential uses, side effects, and any drug combinations that could be dangerous.

EVALUATE

- Ask students to try one of the simulations for temperature and reaction rate (see the examples in the Elaborate section). Ask them to explain what happens to the particles when the temperature increases or decreases? What effect does this have once the reaction starts? What do they notice when particles collide? How does temperature change the rate of collisions? What can they do to make the reaction go faster? Slower? Can they relate this to what they saw with the experiment they tried?
- If students graphed out their results, provide them with a different scenario and ask what results they would get. For example, what might be the reaction time if the water were at 2 °C? What about 97 °C? Or, provide them with a reaction time and ask what the temperature of the water likely was.
- Can students think of any reactions at home, school, or in their community where the rate changes based on temperature? Ask them to brainstorm some ideas or record their ideas throughout the week in a journal or in voice memos. Have them share their findings the next week with the class and explain the reaction, how temperature was involved, and what they noticed about the rate of reaction.

Elephant Toothpaste

Section **CHEMICAL REACTIONS** *Topic* **REACTION RATES & CATALYSTS**

Estimated Time Setup: 5-10 minutes; Procedure: 10 minutes

OVERVIEW

Students will mix household products to make an 'elephant-size' chemical reaction!

In this activity, students mix hydrogen peroxide, liquid dish soap, and active yeast to create new products through a chemical reaction. Students explore how catalysts work in a decomposition reaction, how reactants change to products in a chemical reaction, and thermal energy changes in this fun, colorful experiment.

INQUIRY QUESTIONS

Getting Started:

- How do we know a chemical reaction or change has occurred?

Learning More:

- What is the purpose of a catalyst and how does it work?

Diving Deeper:

- What happens in a decomposition reaction? What role does each reactant play in forming the products?

CONTENT TOPICS

This activity covers the following content topics: chemical reactions, chemical changes, catalysts, energy, exothermic reactions, decomposition reactions

This activity can be extended to discuss: chemical formulas, balancing equations

NGSS CONNECTIONS

This activity can be used to achieve the following Performance Expectations of the Next Generation Science Standards::

- **5-PS1-4:** Conduct an investigation to determine whether the mixing of two or more substances results in new substances.
- **MS-PS1-2:** Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

MATERIALS

For one setup:

- Empty, 16-oz. plastic soda pop bottle
- Foil cake pan with 2-inch sides (or a bin, sink)
- 3% or 6% Hydrogen peroxide
- Dawn® Ultra dishwashing liquid
- Active yeast
- Funnel
- Warm water
- Cup or bowl
- ½ cup liquid measurer
- Spoon
- Food coloring

ACTIVITY NOTES

This activity is good for:

- Large groups
- Demonstrations

Safety Tips & Reminders:

- Do this experiment in a bin, pan, sink, or outside since it can get messy!
- Safety goggles are recommended.
- If the water you use is too hot it will kill the yeast and the experiment will not work as well. Be sure to follow the instructions on the yeast container or packet.
- The reaction works much better with 6% hydrogen peroxide solution, though stores usually sell 3%. You can get 6% solution online or from a hair salon for a bigger reaction.
- Review the Safety First section in the Resource Guide for additional information

ENGAGE

Use the following ideas to engage your students in learning about chemical reactions:

- There are tons of fun, exciting videos of this reaction – many using more powerful ingredients than in this experiment. Check out some online and show them to students before they try the experiment themselves.
- For 'explosive' experiments like this, sometimes the best engagement is the demo itself!

See more ideas for engagement in the Reaction Rates & Catalysts Background section! You can also look at the Elaborate section of this activity for other ideas to engage your students.

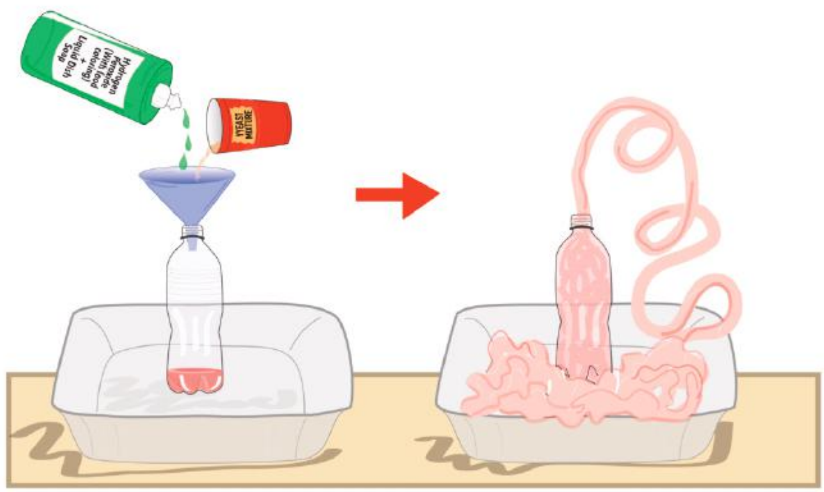
Fun Fact #1

Hydrogen peroxide naturally decomposes over time, especially if it is exposed to light or high temperatures. For this reason, hydrogen peroxide is stored in opaque bottles and is often refrigerated.

EXPLORE

Procedure:

1. Place empty soda pop bottle in the center of the cake pan with the funnel in the opening of the bottle.
2. Pour ½ cup of hydrogen peroxide through the funnel and into the bottle.
3. Add about one tablespoon of Dawn® Ultra dishwashing liquid to the bottle along with a few drops of food coloring.
4. In the cup or bowl, mix one packet of yeast with warm water (be sure to follow the activation instructions on the yeast label).
5. Pour the yeast mixture into the bottle, quickly remove the funnel, and step back!



Notes

____

____

____

____

____

____

____

____

____

____

____

DATA COLLECTION & ANALYSIS

Analyze and discuss the results of this activity using the following questions:

- Describe each reactant and their physical properties. What do you think is the purpose of each reactant in this experiment?
- Describe the products. Did a chemical reaction or change occur? Use evidence to explain why or why not.
- Feel the bottle at the end of the experiment. Does it feel warm or cool? What does that mean?
- Draw a diagram of the reaction in process and label the components.

Notes

EXPLAIN

What's happening in this Activity?

First review the Reaction Rates & Catalysts Background section to gain a deeper understanding of the scientific principles behind this activity.

During a chemical reaction the reactants change into new substances known as the products, and bonds between atoms are broken or formed. This is true of all chemical reactions, but not all reactions occur the same way. Some types of chemical reactions are synthesis reactions, decomposition reactions, and displacement reactions.

During a **decomposition reaction**, a larger molecule breaks down into two or more smaller molecules. There is only one reactant, and bonds in the reactant compound are broken to form two or more product compounds.

$$AB \longrightarrow A + B$$

In this experiment, we see the decomposition of hydrogen peroxide, H_2O_2. This reaction produces water, H_2O, and oxygen gas, O_2.

$$2H_2O_2\ (l) \longrightarrow 2H_2O\ (l) + O_2\ (g)$$

Because breaking chemical bonds requires energy, the decomposition of hydrogen peroxide happens very slowly under normal conditions. If you go to a grocery store, you can find bottles of hydrogen peroxide solution sitting on shelves—the hydrogen peroxide stays as hydrogen peroxide and doesn't react to turn into water and oxygen gas.

One way to make hydrogen peroxide decompose faster is to add a catalyst. A **catalyst** is a substance that changes the rate of a reaction but doesn't get used up during the reaction. In this case, we use yeast as a catalyst to make the hydrogen peroxide break down faster. This produces a lot of oxygen gas very quickly, which we can see in a big explosion of foam!

We can see the oxygen gas because we added soap to the hydrogen peroxide. The bubbles of oxygen that are produced are trapped in the soap, creating a foam. A **foam** is made of tiny bubbles of gas spread throughout a liquid or a solid. In this case, the foam is oxygen gas spread throughout soapy water. Some other examples of foams are seafoam, whipped cream marshmallows, and sponges.

With yeast, hydrogen peroxide decomposes so quickly and releases so much gas that pressure builds up inside the bottle, and foam explodes out of the top—just like toothpaste being squeezed out of a tube. The yeast makes the reaction happen more quickly by helping to position the reactants so that when they collide, they have the right orientation to react. This means the reaction doesn't need as much energy to get started—it has a lower **activation energy**.

During this experiment, the bottle feels warm to the touch because the decomposition of hydrogen peroxide releases energy. Any reaction that releases energy is an **exothermic reaction**. The products (in this case, water and oxygen gas) are lower in energy than the reactants (hydrogen peroxide). On the other hand, an **endothermic reaction** requires or takes in energy. In an endothermic reaction, the products are higher in energy than the reactants. Energy is put into the reaction, and stored in the chemical bonds that are formed.

The overall change in energy during a chemical reaction is different than the amount of energy the reaction needs to get started. We need to put in energy to get hydrogen peroxide to start decomposing, but once the reaction starts it produces energy. Another example is the combustion reaction that causes burning. You need a spark to start a fire. This spark provides the activation energy. Once the fire starts, it gives off energy in the form of heat because it is an exothermic reaction.

EXPLAIN continued

Differentiation for Younger or More Advanced Students

You can differentiate this activity for students of different grade levels by focusing on the concepts outlined below.

GETTING STARTED

For younger students, emphasize the following concepts:

- There are different types of chemical reactions
- A decomposition reaction breaks down a larger molecule into smaller ones
- Catalysts change the rate of a chemical reaction without being used up

DIVING DEEPER

For more advanced students, emphasize the following concepts:

- Exothermic reactions release energy, and endothermic reactions absorb energy
- A reaction's overall change in energy is different than the amount of energy it needs to get started

Fun Fact #2

Yeast is a living organism – a single-celled fungus – which is why it is important to not use water that is too hot, which could kill the sample.

ELABORATE

Elaborate on your students' new ideas and encourage them to apply them to different situations. The section below provides some alternative methods, modifications, and extensions for this activity.

- The foam produced is not toxic or dangerous, so students can touch and feel it (though if you added food dye this might get messy!). This is one way to feel the temperature difference.
- Want rainbow or glittery toothpaste? Add a few drops of different colors or glitter in step 3!
- Ask students whether the amount of each reactant matters in this experiment. Try the experiment a few more times, each time changing the amount of each reactant. Do they see a pattern? Which reactant limits the amount of product that can be made?
- Explore whether Elephant Toothpaste is a physical or chemical change. What is the definition of a physical change? Chemical change? What are some examples? What is the evidence that shows what type of change occurred?
- What happens if the experiment is done in a smaller bottle? What about a graduated cylinder? We find the experiment works best with a bottle that has a narrow neck. Why might that be the case? Make predictions and try the experiment using different containers.
- Lead a discussion about what each reactant does in this reaction. Which one could we increase (in amount of concentration) to make the reaction bigger? Record their predictions and then test a few of their ideas.
- What happens if some of the reactants are removed? For example, would the reaction happen without the yeast catalyst? Or without the soap to see the gas released? Lead a discussion of what students' predictions are and then try some out!
- Yeast is used as a catalyst in this reaction, but there are lots of other catalysts in the world around us! Design a research project for students to investigate catalysts in their body, home, school, environment, and more. Students can share their findings with the class.
- There are tons of videos of this reaction online! Ask students to find the most "elephant"-sized ones to share with the class. What did the experimenters do differently in their procedure? What might that have changed about the reaction?
- The catalyst in this reaction, yeast, is a living organism that is used in a number of different ways at home and in the laboratory. Ask students to find some fun facts about yeast, including how we use it in our everyday lives and in science research.
- For more advanced students: write out the chemical formulas for the reactants and products. Ask students to balance the equation.
- For more advanced students: a way to test for the presence of oxygen – which is a product in this reaction – is by bringing a glowing split near the foam. If oxygen is present, it will reignite.

CHEMISTRY IN ACTION

Share the following real-world connections with your students to demonstrate how chemistry is all around us.

Real-World Applications·

Hydrogen peroxide has many uses, including acting as a bleaching agent, disinfectant, and in high concentrations it has even been used as a propellant for rockets!

Yeast is used to leaven bread, ferment food and drink, as a nutritional supplement, and as a way to study genetics in the laboratory since it is easy to grow, maintain, and manipulate. Yeast is even being studied as a potential biofuel!

Humans need catalysts! Your body burns fuel (in the form of food), just like a car's engine burns fuel. The reactions in our bodies that digest food and turn it into fuel require energy. There are special catalysts in the body called enzymes that help these reactions to start. The slowest known biological reaction would take 1 trillion years without an enzyme. With enzymes, the reaction can occur in just 10 milliseconds

Careers in Chemistry

- Thinking of a career in the automotive industry? The invention of airbags relies on rapid decomposition reactions to save lives! Sodium azide ($Na(N_3)_2$) decomposes rapidly into nitrogen gas (N_2) and sodium (Na) upon impact, which causes airbags to instantly fill with gas.

Notes

____

____

____

____

____

____

____

____

EVALUATE

- Add some art and creativity to the experiment: ask students to make a video, comic, or advertisement selling Elephant Toothpaste. In their work they should explain how the product is made. You can also add in other sections like safety warnings, recommended usage, and more!
- Can students prove whether a chemical reaction took place? Provide vocabulary words learned throughout this unit and ask students to write what they observed and whether a chemical or physical change took place using new vocabulary and evidence from their experiences. They can present their writing to a peer to review and provide feedback, or share their thoughts orally with the class.
- Ask students to plan a presentation to younger students in the school. They should be prepared to introduce the experiment, perform it, explain what is happening, and answer questions from the audience.

Ageless Apples

Section **CHEMICAL REACTIONS** *Topic* **REACTION RATES & CATALYSTS**

Estimated Time Setup: 5-10 minutes; Procedure: 1 day

OVERVIEW

Students explore the chemistry of browning apples and a simple acid-base reaction that affects this process.

In this activity, students place apple slices into solutions that are acids, bases, or neutral. A day later, they examine the apples and can see dramatic differences in how much each of the slices browned or decayed. Students can explore how acidity changes reaction rates and the chemistry of food preservation.

INQUIRY QUESTIONS

Getting Started:
- How do we know if a chemical or physical change has occurred?

Learning More:
- What is an acid and a base, and how do they affect the rate at which an apple browns?

Diving Deeper:
- What chemical reaction causes apples to brown and how can we slow this process using our knowledge of acids and bases?

CONTENT TOPICS

This activity covers the following content topics: acids, bases, pH scale, enzymes, chemical change, chemical reaction, catalysts

This activity can be extended to discuss: enzyme, protein, amino acids, food preservation

NGSS CONNECTIONS

This activity can be used to achieve the following Performance Expectations of the Next Generation Science Standards:
- **5-PS1-4:** Conduct an investigation to determine whether the mixing of two or more substances results in new substances.
- **MS-PS1-2:** Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

MATERIALS

For one setup:
- ¼ cup lemon juice
- 1 tbsp. baking soda
- ½ cup water (distilled, if possible)
- 1 apple
- 3 sealable sandwich bags (or small bowls with lids)
- Permanent marker
- ¼ and ½ cup measurer, tablespoon
- Knife or apple slicer

ACTIVITY NOTES

This activity is good for:
- Individual
- Pairs
- Small group
- Large group
- Demonstration

Safety Tips & Reminders:
- An adult should cut the apple for students.
- Although household acids and bases are diluted, they can still pose risks. Follow proper safety procedures like wearing a lab coat, safety goggles, and gloves for protection.
- There is no eating or drinking in the lab, even when we are working with normally edible materials.
- Review the Safety First section in the Resource Guide for additional information

Fun Fact **#1**

Will an apple float or sink in water? (Hint: think of bobbing for apples!) An apple is actually 25% air by volume and easily floats in water.

ENGAGE

Use the following ideas to engage your students in learning about chemical reactions:

- Start by having students observe fruits – cut and whole – over time (or show videos and pictures if you cannot have samples in the room). What do students observe happens over time? Why do they think this might be? Do they have any ideas about what might be causing this and how to slow or stop the process?
- Ask students to brainstorm ways in which humans preserve their food. What do we add to food to keep it fresh? How do we store food to keep it from going bad? Do they know why food goes bad over time?
- If you test out the experiment in advance, start by showing them the three samples but do not label which solution they were put in. Can students guess what happened and why some samples browned while others did not? Turn this into a "20 Questions" game where students can only ask questions that can be answered with "yes" or "no," and see if they can figure out what you did!

See more ideas for engagement in the Reaction Rates & Catalysts Background section! You can also look at the Elaborate section of this activity for other ideas to engage your students.

Fun Fact #2

There are over 2,500 varieties of apples, ranging in size, taste, color, and appearance. But the only apple native to the US is the crabapple.

EXPLORE

Procedure:

1. Using the marker, add one of the following labels to each plastic bag: "lemon juice," "baking soda," and "water."
2. Pour ¼ cup lemon juice into the bag labeled "lemon juice."
3. Mix ¼ cup water with 1 tbsp. baking soda in the bag labeled "baking soda."
4. Pour ¼ cup water into the plastic bag labeled "water."
5. Have an adult cut an apple into 6-12 evenly-sliced pieces.
6. Place 2-4 apple slices into each bag, seal, and gently shake to ensure the apple slice is completely coated in the liquid.
7. Carefully remove the apple slices from each bag and place them on top of the sealed bag they came out of, or on a labeled plate or bowl.
8. Observe immediately and check in over the next few hours or day and note any changes between the apple samples.

DATA COLLECTION & ANALYSIS

Analyze and discuss the results of this activity using the following questions:

- At the start of the experiment, describe each liquid being used: water, lemon juice, baking soda solution. What are the physical properties? How are they similar or different?
- Draw and label of diagram of an apple slice at the start.
- Make a hypothesis: what effect do you think each of the liquids will have on the apple? Draw what you think each sample will look like tomorrow.
- Describe and draw any changes you notice between the three samples over time. This can be every hour, every few hours, or over the course of a few days. What differences can you observe?
- Do you think this is an example of a chemical or physical change? What is your evidence?
- Which of the liquids used could help keep apples fresh for longer? Why?

EXPLAIN

What's happening in this Activity?

First review the Reaction Rates & Catalysts Background section to gain a deeper understanding of the scientific principles behind this activity.

During a chemical reaction the reactants change into the completely new substances called the products, and bonds between atoms are broken or formed. Chemical reactions occur all around us—even in our food! Apples that we eat ripen because of chemical reactions. When an apple is cut open and turns brown, that is also because of a chemical reaction.

When an apple is cut open, it releases a molecule called polyphenol oxidase (PPO). Once PPO is released, the apple reacts with oxygen in the air and turns brown. The brown color of the apple is a defense mechanism, meant to make the plant less appealing so it is less likely to be eaten by other animals.

This change in color is due to an oxidation reaction. **Oxidation reactions** are chemical reaction that involve the transfer of electrons. The brown rust that forms on metal is also the result of an oxidation reaction (see the Cleaning Pennies activities for more!).

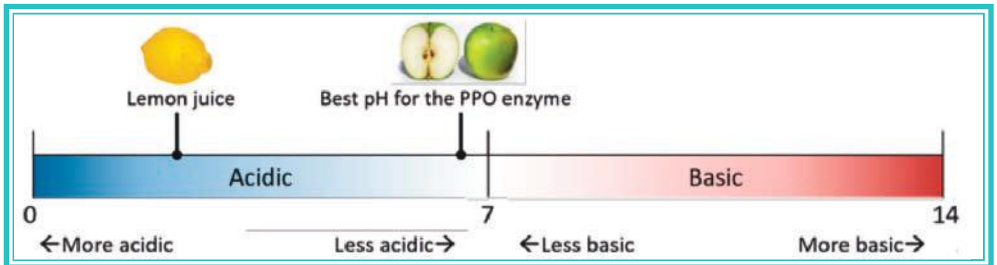
PPO is actually a catalyst. A **catalyst** is a substance that changes the rate of a reaction, but is not used up during the reaction. In this case, PPO makes other compounds in the apple react with oxygen in the air faster, so the apple turns brown faster. PPO itself does not react with anything. PPO is also the enzyme that makes guacamole turn brown over time, and is found in apples and other plants like mushrooms and lettuce. Catalysts make a reaction happen more quickly by decreasing the activation energy. **Activation energy** is the amount of energy needed to start a reaction, or the size of the "energy hill" the reaction has to climb. Since catalysts make it easier for the reaction to occur, it happens more quickly.

Enzymes are catalyst in living things that help to speed up biological reactions. In humans, enzymes help us with things like digesting food, generating energy, and staying healthy. The slowest known biological reaction, which is part of creating our DNA, would like 1 trillion years without a catalyst. With an enzyme, this reaction happens in just 10 milliseconds!

One way to change the rate of a reaction is to add or remove a catalyst. Another way is to change how a catalyst behaves. Whether or not a catalyst is active depends on a number of conditions, like temperature, acidity, and concentration. One of the reasons enzymes work in our bodies is our temperature. Most enzymes in the human body work best at normal body temperature (about 98 °F).

Another thing that can affect a catalyst is pH. The **pH scale** measures how acidic or basic something is. What this depends on is the concentration of hydrogen ions, H^+. pH can range from 0 to 14. **Acids** are substances with a pH less than 7. **Bases** are substances with a pH greater than 7.

Every enzyme has an ideal pH, or balance between acidic and basic, where it works best. PPO works best when the pH is around 6.5. When the pH drops below 2.5, PPO stops working at all. If the PPO in an apple becomes inactive, the oxidation reaction that turns apples brown happens much slower (barely at all!).
Adding lemon juice to apples deactivates the PPO enzyme in a few ways.



Notes

EXPLAIN continued

Vitamin C: Lemons are a great source of vitamin C, also known as ascorbic acid. When ascorbic acid is on an apple, oxygen in the air reacts with ascorbic acid before it reacts with the apple. Instead of the apple being oxidized, the ascorbic acid is oxidized. But this doesn't work forever—once the ascorbic acid has all reacted, the apple with start to oxidize and turn brown.

Low pH: Lemons are very acidic because they contain compounds like citric acid. The pH of lemon juice is 2.0, which is low enough to make the PPO enzyme inactive. Unlike ascorbic acid, the acidity doesn't "run out," so it prevents browning for longer.

Because lemon juice makes the PPO less active, the apple slices that were in lemon juice solution will turn brown slower than the apple slices that were in either baking soda solution or water.

Differentiation for Younger or More Advanced Students

You can differentiate this activity for students of different grade levels by focusing on the concepts outlined below.

GETTING STARTED

For younger students, emphasize the following concepts:

- There are different types of chemical reactions
- Catalysts change the rate of a chemical reaction without being used up
- Enzymes are catalysts in living things

DIVING DEEPER

For more advanced students, emphasize the following concepts:

- Catalysts behave differently depending on conditions like temperature and pH
- pH measures the concentration of hydrogen ions, H+, which determines whether something is an acid or a base

ELABORATE

Elaborate on your students' new ideas and encourage them to apply them to different situations. The section below provides some alternative methods, modifications, and extensions for this activity.

- Add another control: keep a few apple slices out and compare with the other samples. Students might see that even dipping the apple in water slowed the browning slightly. Why do they think that is? (Hint: with water covering the sample, can oxygen reach the fruit as easily?)
- Try this experiment again, but use a variety of acids, bases, and neutral substances, such as vinegar, milk, soda, saltwater, seltzer, orange or cranberry juice, milk of magnesia, tonic water, and more. Which works the best? Why?
- For students who are learning more about acids and bases, get some pH paper and measure the pH of each liquid used in the experiment. Graph the pH versus the level or browning. What is the relation? Now ask students to test the pH of other unknown liquids and make an informed guess of where it will fall on the graph. Test it out and see if they are correct!
- Students can graph their results and run multiple trials to determine which household preservative works the best. On the y-axis they can create a scale for brownness, and on the x-axis they can write what type of treatment they used. With a keen eye, close observation, and a stopwatch, they can also graph the time at which the apple started to brown on the y-axis instead.
- How does storage method affect browning? In this experiment, students learned that oxygen is what causes the enzymes to react. Can they design a way to store apples that limits the amount of oxygen? Or try the experiment again but keep each trial in a different storage container: out in the open, in a Tupperware, in a clean plastic bag. Which worked best?
- Does this work for other fruits or vegetables? Students can run the experiment again with bananas, pears, avocados, potatoes, peaches – whichever other produce items they can think of that brown like apples.
- If you are doing the experiment in the summer or fall in an area where there are apple orchards, pair this activity with a field trip. Learn about how apples are grown, the life cycle, farming, distribution, and the properties of each type of apple. Have students interview the farmers and orchard workers. How do they keep their produce fresh? What processes and products do they use to grow fresh, delicious apples? After students return to the classroom, do this experiment as part of a discussion about how food is produced and ends up in local grocery stores, restaurants, and in their homes. Why might experiments like these be important for the farming industry?
- Do different types of apples brown at different rates? Depending on the type of apple and the maturity, different levels of polyphenol oxidase (PPO) will be present, resulting in different levels of browning. Test it out!
- There are many theories to the evolutionary advantage of browning: perhaps the unappealing appearance keeps animals away from damaged fruit on a tree, or maybe it is a signal to them that the fruit is rotten and should be avoided. What do students think might be the evolutionary advantage to a fruit that can brown when open or damaged?
- Does temperature affect the rate of browning? Try putting one apple in the freezer, one in the refrigerator, one at room temperature, and one in a warm or sunny spot for a few hours. Cut a slice from each and observe. Did they brown at the same rate?

EVALUATE

- Provide groups of students with a mystery sample that is an acid, base, or neutral. Ask them to write a list of the physical properties. If pH paper is available, have them test the pH of their sample, or provide the estimated pH to each group. Using what they learned in this experiment, do they think this will be effective in preventing browning in an apple? Have them test it out, then make a guess as to what their mystery liquid could have been. Provide them with a bank of options (either samples they can look at and test the pH, or a chart) and guess which substance they had. They can then explain the evidence for their answer to their peers and see if everyone correctly guessed their samples.

- Ask students to visit a local grocery store or look at their food at home. What preservation techniques are applied on produce? You can provide scaffolding with various prompts: how are they displayed? Are they in packaging? Do you notice anything that could have been done to the produce to keep it fresh (i.e. think of the wax on apples!)? When reading labels on prepared or packaged produce, can they find the names of any preservatives? The next day, students can share out their findings and make a list of the ways we ensure our food stays fresh and edible.

- Genetically modified foods – like the non-browning Artic Apple – have caused lots of debate in recent years. For older learners, set up a debate using the Artic Apple as the case study. Students should be assigned one side of the debate (pro-genetically modified foods or against – or add in other stakeholders like perhaps a group that wants to treat conventional fruit with acidic solutions instead), conduct research and compile evidence for their argument, then hold a debate in class. Encourage students to think about the pros and cons from the point of view of scientists, farmers, grocers, consumers, the government, and more. What did they learn? Which side was more convincing? What is the role of a scientist in these types of debates?

Notes

CHEMISTRY IN ACTION

Share the following real-world connections with your students to demonstrate how chemistry is all around us.

Real-World Applications

Some grocery stores and fast food locations regularly sell bags of sliced apples – but how do they keep them looking and tasting fresh? This is made possible thanks to chemist Attila Pavlath, who developed a formula of salts and vitamin C (the same acid found in lemon juice!) that can keep a sliced apple as good as new for 21 days!

There are a number of methods used to preserve fruit and prevent it from rotting. One method explored in this experiment is dipping or spraying fruit with an acidic solution. Fruit is sometimes dried to remove moisture, which preserves its shelf life, or dipped in sulfur or honey solutions, which can act as a preservative. Cooking or blanching – dipping in boiling water – also destroys the enzyme that causes fruit to brown, but this changes the taste and texture it might not be a desirable option.

Careers in Chemistry

- Americans waste around 50% of their produce, which equates to around 60 million tons or $160,000,000,000 annually (which is around $1,600 per four-person household)! A big reason for this is that produce that is bruised, browned, or deemed ‘damaged’ in some way is thrown away – even if it is perfectly edible! This waste has spurred on a number of careers: commercial composting, marketing campaigns for ‘ugly fruit,’ repurposing slightly damaged produce to solve food insecurity issues, developing more scientific protocol for determining accurate expiration dates, and big business in finding safe, efficient, and effective ways to grow, harvest, package, and transport produce around the world.