Lesson 2
Reaction Rate

Objectives

Students will

- understand the variety of speeds at which reactions occur
- discuss several factors affecting reaction rates
- be able to provide an example of each of these factors

Vocabulary

catalyst—a substance that increases the reaction rate without being permanently changed
inhibitor—a substance used to slow down or stop a chemical reaction
reaction rate—a measure of how rapidly a reaction takes place

Structuring the Curriculum

You may wish to set up some of the lesson activities and demonstrations as stations. You could conduct the demonstrations for some groups of students while others are doing the text reading assignment.

Preparation/Materials

Demonstrations: How Surface Area Affects the Reaction Rate

Option A

√ flour
√ spoon
√ mortar and pestle
√ Bunsen burner
√ plate
√ eyedropper with large bulb

Option B

√ tongs
√ steel utensil
√ steel wool
√ Bunsen burner

Demonstration: How Temperature Affects the Reaction Rate

√ beaker of cold water
√ beaker of room-temperature water
√ beaker of hot water
√ three antacid tablets

Demonstration: How Concentration Affects the Reaction Rate

√ two test tubes
√ dilute hydrochloric acid
√ concentrated hydrochloric acid
√ two strips of magnesium ribbon

Let's Find Out: How Do Catalysts Work?

√ safety goggles, one pair per student
√ 250-mL Erlenmeyer flasks, two per group
√ hot plates, two per group
√ distilled water, 100 mL per group
√ copper(II) sulfate solution, 100 mL per group. (Make the solution by dissolving 25 mL of copper(II) sulfate [$CuSO_4$ $5H_2O$] into 1 liter of distilled water.)
√ powdered copper, two 3.2 g-samples per group
√ powdered sulfur, two 0.6 g-samples per group
√ stirring rods, two per group

Background

The rate of a chemical reaction equals the change in concentration of products or reactants divided by the change in time. The rates of chemical reactions vary depending on the reaction. Some happen very slowly (corrosion, for example); others happen almost instantly.

Chemical kinetics is the study of reaction rates, how reaction rates change under varying conditions, and the mechanism by which the reaction proceeds. Different chemical reactions require varying times for completion. Chemical reactions, however, can be changed by physical factors such as the following.

- **The concentration of the reactants.** As a general rule, the more concentrated the reactant, the faster the reaction. In some cases concentration may not affect the rate; the reactant need only be present in a minimum concentration. In the case of gases, increasing the pressure increases concentration.
- **Temperature.** Reactions generally speed up as the temperature increases because the molecules move faster, they collide more often. As a general rule, the rate of many reactions will double or triple with a 10 °C temperature increase. The chemical accidents that happened at Seveso, Italy, in 1976 and in Bhopal, India, in December 1984 were both due to overheating.
- **Surface area.** The greater the surface area, the greater the reaction rate.
- **The presence (and concentration/physical form) of a catalyst or inhibitor.** A catalyst speeds up a reaction; an inhibitor slows it down. Catalysts lower a reaction's activation energy—the minimum energy needed for the reaction to occur—by providing a new mechanism or reaction path through which the reaction can proceed. If the new reaction path has a lower activation energy, the reaction rate increases. Such a reaction is said to be catalyzed. Emphasize to students that catalysts are not reactants in the equation. Enzymes are common, incredibly efficient catalysts found in nature. Most of the chemical reactions that occur in the human body and in other living things are high-energy reactions that would occur slowly, or not at all, without enzymes. For example, without catalysts it takes several weeks for starch to hydrolyze to glucose. But the

enzyme ptyalin, found in human saliva, accelerates the reaction so starches can be digested. (If you were to chew unripened grain—wheat or oats—you would notice a sweet taste within a few minutes. The ptyalin converts the grain starch to sugar.) Some enzymes increase reaction rates by a factor of one billion or more.

- In some cases, as in that of photographic film, light of a particular wavelength may speed up a reaction.

2 Reaction Rate

Chemical reactions are a very important part of the food we eat. The energy in all of our food can be traced to photosynthesis, a chemical reaction that occurs in plants. Ripening of fruits and vegetables involves many chemical reactions, many of them with oxygen as a reactant. And the preservatives and flavorings in foods are all based on chemical reactions. For example, 135 reactants are involved in the chemical reaction that produces artificial raspberry flavoring!

Understanding how fast chemical reactions happen is important. For example, food chemists must know how long a preservative is able to preserve a certain food. The **reaction rate** is a measure of how rapidly a reaction takes place. It is calculated by figuring out the amount of reactants that remain after a certain period of time.

Reaction rates vary widely. Some (such as burning) happen rapidly; others (such as rusting) may take years. To understand the speed of chemical reactions, it is necessary to understand the two conditions that must exist before a reaction can take place. First, the reactants' particles must come in contact with each other. Second, this contact must occur in such a way that the various particles can bond with each other. Thus, changing the conditions can change the speed with which the reactants contact each other and form a chemical bond. In other words, changing the conditions can change the reaction rate. Five factors affect reaction rates.

Ripening

Try This

Place a banana on a shelf at room temperature. Dissolve a spoonful of baking soda in a cup of water, and seal the cup and another banana in a sealable plastic bag. Which ripens faster? Why?

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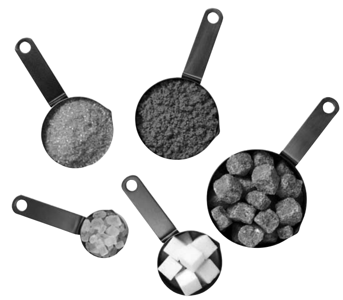
- **Temperature**. Often the easiest way to change the reaction rate is by changing the temperature of the reactants. Lowering the temperature decreases the reaction rate, and increasing the temperature speeds up the reaction rate. For example, frying an egg is a chemical reaction. Frying an egg on a low stove setting takes several minutes, but frying it on the highest setting takes only a minute or two. As the temperature increases, particles of the reactants move faster, colliding into each other more frequently. At higher temperatures particles also have more energy, which allows them to bond with each other more readily.

The higher you have the temperature, the faster these eggs will fry.

- **Surface area**. Increasing the surface area (amount of exposed surface) of a solid reactant increases the reaction rate. A reactant crushed or ground into smaller fragments has more exposed surface area than one larger piece. When more surface area is exposed, particles of the reactants come in contact and bond with each other more frequently. For example, solid zinc reacts with hydrochloric acid to form zinc chloride and hydrogen gas. Cubes of zinc measuring a centimeter on each side have only 6 cm^2 of zinc surface area exposed to the acid. But grinding the zinc into powder exposes 10,000 times more surface area to the acid. The larger surface area greatly speeds up the reaction rate.



The finer the sugar is ground, the more surface area is exposed.

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Discover

1. Use the following story to introduce the lesson. A restaurant hires three people to clear tables and stack dishes, one person to wash dishes, and three people to dry dishes. Ask the class why this hiring strategy is inefficient. (With only one dishwasher, the process of washing the restaurant's dishes will be slowed.) How could the restaurant's dishwashing process be made more efficient? (Answers will vary. Making one of the dryers a washer will speed up the process.)

2. Explain the concept of chemical reaction rates. Use the introductory story to explain the "reaction rate" of different combinations of dishwashing personnel. (The number of dishes washed in a minute is analogous to the reaction rate of a chemical reaction. Compare changing the conditions of a chemical reaction to increase the rate of reaction to the increase in the number of dishes cleared, washed, and dried when another dishwasher is added.)

3. Use the story of the restaurant personnel to explain why chemists are concerned with the speed of reactions. (To be profitable, products must be made as quickly as possible. Since most products made by mass production involve chemical reactions during one or more of steps of manufacturing, chemists are constantly searching for ways to speed up chemical reactions or slow down chemical reactions that are dangerous or undesirable. For example, chemists look for ways to slow down the aging of foods to retain crispness, color, odor, taste, and so on.)

- **Concentration of reactants**. The reaction rate generally increases when the concentration of the reactants is increased. This is because there are more particles available to bond and the particles collide more often. For example, substances such as coal burn much more rapidly in pure oxygen than in air because air is composed of only 20 percent oxygen. Since the combustion (burning) reaction requires oxygen, extra oxygen increases the speed of the reaction. But sometimes increasing the concentration of a reactant does not increase the reaction rate. Chemical reactions frequently take place in a series of simple steps called a reaction pathway. The slowest reaction along this pathway, called the rate determining step, determines the speed of the entire reaction pathway. Adding more of a reactant to one of the other pathway steps will not speed up the overall reaction. Picture the rate determining step this way. Imagine you and your friends are making sandwiches for a fundraiser. Three people are spreading mustard on the bread, three people are putting meat and cheese on the bread, and one person is wrapping the sandwiches in plastic wrap. Wrapping takes a long time, and only one person is wrapping. So the person who is wrapping determines the pace of the sandwich making. In other words, wrapping the sandwiches is the determining step. Recruiting more people to spread mustard or put meat and cheese on the bread will not speed up the overall sandwich making process.

- **Catalysts**. Some chemical reactions happen quite slowly and require the presence of another substance to speed up the reaction rate. A substance that increases the reaction rate without being permanently changed is called a **catalyst**. A catalyst is not part of the final product of a

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Let's Find Out

How Do Catalysts Work?

You will need
- ✓ safety goggles
- ✓ two 250-mL Erlenmeyer flasks
- ✓ two hot plates
- ✓ 100 mL of distilled water
- ✓ two 3.2-g samples powdered copper
- ✓ two 0.6-g samples powdered sulfur
- ✓ 100 mL of copper(II) sulfate solution

Do this
1. Wearing safety goggles, pour 100 mL of distilled water into one of the flasks.
2. Boil the water on the hot plate.
3. Mix a sample of powdered copper and powdered sulfur together, and stir the powder mixture into the distilled water.
4. Observe the results. Record your observations in your lab journal.
5. Pour 100 mL of the copper(II) sulfate solution into the second flask.
6. Slowly boil the solution on the hot plate.
7. Mix a sample of powdered copper and powdered sulfur together, and stir the powder mix into the copper(II) sulfate solution.

Questions
1. Explain what happened in the first flask.
2. Explain what happened in the second flask.
3. Why did a chemical reaction occur between the copper and sulfur powder in the second flask?

reaction. Sometimes chemists can even recover and reuse catalysts. Catalysts are common in the human body, usually in the form of enzymes, which are proteins. Enzymes can speed up chemical reactions in the human body by a factor of 10,000. For example, an enzyme in human saliva, acting as a catalyst, speeds up the conversion of starch into glucose so it can be digested immediately instead of several weeks later!

Digesting a potato chip would take weeks if God hadn't put a catalyst in our saliva.

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4. Explain that chemical reactions in the human body would occur very slowly without catalysts. Most reactions in living systems are speeded up many times their normal pace by catalysts. Modern day chemists are researching the speed at which the aging process occurs, hoping to find ways to slow it down.

Develop

1. Have students mention some chemical reactions with which they are familiar. (They may suggest burning, rusting, or photosynthesis.) Ask if there is anything that can be done to speed up or slow down chemical reactions or if a given chemical reaction always happens at the same rate.

   Tell students that several basic factors affect the rate of a chemical reaction. The lesson's demonstrations and activities will help them discover these factors.

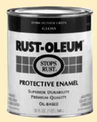
2. **Demonstration: How Surface Area Affects the Reaction Rate.** Demonstrate how surface area influences the rate of chemical reaction, using one or both of the following. In each case, encourage students to discover the influencing factor.

   Option A
   - Hold a spoonful of flour in a Bunsen burner flame to demonstrate that flour is normally not very flammable.
   - Mortar and pestle some flour, and put it onto a plate.

The Business of Rust

Stopping rust is big business. Cars receive a coat of rust-proofing when they are built in the factory. Metal lawn furniture is rust-proofed to lengthen the life of the paint. No one wants rust on their cars or metal lawn furniture so we look for inhibitors—products to slow down the process of rusting.

Rust-Oleum® is one such product. A sea captain named Robert Fergusson discovered that raw fish oil stopped the corrosion on rusty metal decks. He worked on a fish-oil based paint and in 1921 created a paint that stopped rust, didn't smell bad, and dried overnight. Today Rust-Oleum® is used to prevent rust at home and in industry.



- **Inhibitors**. Sometimes it is important that a chemical reaction happens more slowly than it naturally would. In these cases an **inhibitor**—a substance used to slow down or stop a chemical reaction—is used. Inhibitors interfere with the surface chemistry of two reactants, preventing them from rapidly bonding together. Preservatives added to food are inhibitors that slow down reactions in the bacteria or fungus that can spoil food.

This worker is mixing an oil-based primer before painting the Golden Gate Bridge.

Review

1. What conditions must exist before a chemical reaction can take place?
2. List five things that affect the reaction rate of a chemical reaction.
3. Name four ways a reaction can be slowed down.
4. Why does fruit ripen more slowly in the refrigerator?

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- Squeeze the bulb on an eyedropper (the bulb should be larger than a regular eyedropper bulb) to blow a fine mist of flour into the flame of the Bunsen burner. The flour will burn in an orange flame.
- Ask students what factor affected the rate of chemical reaction. (Surface area of the reactants affects their reaction rate. With more surface area exposed, more reactant is available to react, and reaction rates increase. This is the basis for dust explosions.)

Option B

- Using tongs, hold a steel utensil to a flame. Students will not expect it to burn.
- Using tongs, hold the steel wool in the flame. It will burn because of its increased surface area.

3. **Demonstration: How Temperature Affects the Reaction Rate**
   - Prepare a beaker of very cold water, a beaker of room temperature water, and a beaker of hot water.
   - Have three students simultaneously drop an antacid tablet into each beaker.
   - Which reacts faster, and why? (The tablet in the hot water reacts faster because the particles are moving faster, thus coming into more frequent contact with each other.)
4. **Demonstration: How Concentration Affects the Reaction Rate**
   - Fill one test tube with dilute hydrochloric acid and the other with concentrated hydrochloric acid.
   - Cut two strips of magnesium ribbon. Place one in each test tube.

- Which reacts faster, and why? (The more concentrated HCl will react faster because it has more particles to react with the magnesium.)

5. Have students complete **Let's Find Out: How Do Catalysts Work?** (page 177) in the student text to discover how the fourth factor, catalysts, affects the reaction rate.
   1. *Explain what happened in the first flask. (No reaction occurred.)*
   2. *Explain what happened in the second flask. (A black precipitate formed.)*
   3. *Why did a chemical reaction occur between the copper and sulfur powder in the second flask? (The copper(II) sulfate solution acted as a catalyst to make the reaction happen quickly enough to notice. Lab reaction: Cu (s) + S (s) [in the presence of $CuSo_4$] → CuS (s).)*

6. Have students read **Reaction Rate** (page 174) in the student text.

7. Discuss why each factor in the previous demonstrations or activities increased the speed of the reaction. Be sure to also discuss inhibitors.

8. Assign the section review questions (page 178) in the student text as homework.
   1. *What conditions must exist before a chemical reaction can take place? (The reactant's particles must come in contact with each other, and this contact must occur in such a way that the different particles can bond with each other.)*
   2. *List five things that affect the reaction rate of a chemical reaction. (Temperature, surface area, concentration, catalysts, and inhibitors.)*
   3. *Name four ways a reaction can be slowed down. (Decrease temperature, decrease surface area, decrease reactant concentrations, and add an inhibitor.)*
   4. *Why does fruit ripen more slowly in the refrigerator? (Heat changes the rate of a chemical reaction; the temperature in the refrigerator is lower.)*

Reinforce/Assess

1. Have students create analogies for the factors that affect the speed of a reaction. For example, they might compare a catalyst to a coach.

2. Have students state which factor affects the rate of the following chemical reactions.
   - A reaction will not occur in the gas supply to a Bunsen burner if it is turned on without a match. (Temperature.)
   - The grain dispersed in the air in a grain elevator will explode or burn if a spark or flame is present. (Surface area of grain exposed to oxygen.)
   - Hospital rooms or rest homes have no smoking signs in the rooms of patients who are receiving extra oxygen. (Increased concentration of oxygen raises the likelihood of combustion.)
   - Starch would not give us energy if our bodies did not have contain many different enzymes to first break up the large starch molecules into glucose for absorption into the bloodstream and later to release the energy of the glucose in our cells. (Catalysts.)

3. Have students find an additional example of each factor.

4. Have students design an experiment that shows how a chemical reaction rate can be changed.

5. Questions to ask:
   - How fast do chemical reactions occur? (They vary in speed. Some happen rapidly while others take years to complete.)
   - How does an increase in temperature generally change a reaction rate? (The reaction rate is generally increased because heat causes the particles to move faster, creating more collisions.)
   - Give an example of a reaction in your kitchen that can be increased by raising the temperature. (Frying an egg.)
   - The atmosphere is made of 20 percent oxygen. Explain why an increase in oxygen in the atmosphere to 50 percent would be dangerous to living things. (Oxygen is needed for the chemical reaction of burning. With a greater concentration of oxygen in the atmosphere, the reaction rate of burning forest fires would increase.)
   - What is a catalyst? (A substance that increases the rate of a reaction without being permanently changed.)
   - Why are catalysts important to us? (Most chemical reactions in the human body are speeded up by catalysts.)
   - Name a catalyst. (Enzymes.)

Extend

- To observe the rate of chemical reactions in ripening fruit, have students complete **Try This: Ripening** (page 174) in the student text. (The banana on the shelf outside of the bag ripened faster. The ripening was sped up with a chemical reaction involving oxygen. The baking soda and water produced carbon dioxide, which displaced the oxygen.)

- Have students read **The Business of Rust** (page 178) in the student text.

- Have students research the accidents at Seveso (Italy), Bhopal (India), Times Beach (Missouri), Love Canal (New York), Three Mile Island (Pennsylvania), and Chernobyl (Ukraine).

- Invite a chemist and/or a manufacturer to discuss the various methods they use to change the reaction rate.

- Arrange for a field trip to a chemical lab to observe how catalysts and other reaction-changing methods are used.

- Have students research reactions that take place inside the human body or that are used in industry that require the use of a catalyst.

2 Reaction Rate

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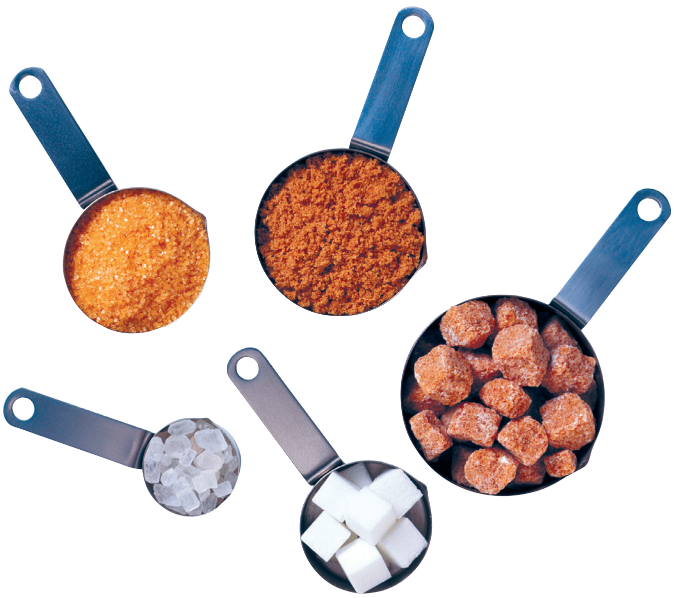

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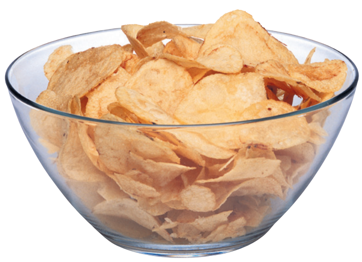

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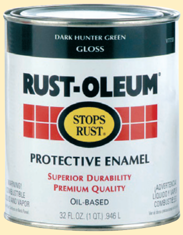

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