Activity 6

Reaction Rates

GOALS
In this activity you will:
• Discover conditions that make a reaction proceed faster or slower.
• Discuss explanations for why this happens at the molecular level.

What Do You Think?
Have you ever wondered why some chemical reactions, like the burning of a match, take place at a fast rate, while others, like the spoiling of milk, take place slowly? The rate of a chemical reaction is the speed at which the reactants are converted to products.

• What are some factors that influence the rate of a reaction?
• How could you make a reaction take place at a faster rate?
• How could you slow a reaction down?

Record your ideas about these questions in your Active Chemistry log. Be prepared to discuss your responses with your group and the class.

Investigate
1. Predict how the concentration (strength) of vinegar will affect how fast it will react with magnesium. One way to study the rate of a reaction is to time the reaction with a stopwatch. Try this!

Place 20 mL of vinegar into a large test tube.

To a second test tube, add 10 mL of vinegar and 10 mL of water. Mix well using a stirring rod.

In a third test tube, add 5 mL of vinegar to 15 mL of water. Mix.
Prepare three equal-sized pieces of polished magnesium ribbon. Set your stopwatch so that it is ready to start immediately.

Add a piece of polished magnesium ribbon to the first test tube, keeping track of the time the reaction takes.

- **a)** Record your observations and the reaction time on a data table. Repeat for the other two test tubes.

- **b)** In this step, you changed the concentration of one of the reactants (the vinegar). The vinegar was less concentrated (more dilute) in each successive test tube. Did this impact the reaction rate? If so, describe the relationship between the concentration of the vinegar and the resulting reaction rate.

- **c)** Compare your experimental results to the prediction you made before conducting the experiment.

**2.** Using the same reaction above, design a small-scale experiment using a well-plate and smaller amounts of reagents.

- **a)** Record your design. Include the equipment you will need, the amount of reactants, and any safety procedures.

- **b)** With the approval of your teacher, carry out the procedure. Record your data and results.

- **c)** How do the results compare with the reaction in Step 1?

**3.** Place 10 drops of 0.1 M HCl (weak concentration) into a small test tube and 10 drops of 1.0 M HCl (strong concentration) into a second test tube. Drop a small piece of polished zinc (equal size) into each test tube containing HCl.

- **a)** Record your observations.

- **b)** How do these results compare to your earlier results? Do these results support or refute the relationship you stated in Step 1 (c)?

**4.** Hydrogen peroxide (H$_2$O$_2$) is sold over the counter in pharmacies to be used as a disinfectant for minor injuries. Because hydrogen peroxide decomposes slowly to form oxygen and water, it is also a source of oxygen gas.

$$2\text{H}_2\text{O}_2(\text{aq}) + \text{light energy} \rightarrow \text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$$

Pour a small amount of hydrogen peroxide into each of two test tubes. Add a small amount of manganese dioxide to one of the test tubes.

- **a)** Record your observations.

The manganese dioxide did not actually react with the hydrogen peroxide; it simply acted as a catalyst for the decomposition of the hydrogen peroxide. A catalyst is a material that speeds up a reaction without being permanently changed itself. The chemical equation for this reaction is:

$$2\text{H}_2\text{O}_2(\text{l}) \xrightarrow{\text{MnO}_2} \text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$$

**5.** As an inquiry activity, design an investigation to prove that the manganese dioxide did not get used up in the reaction. Record your design. Include the equipment you will need, the amount of reagents, and any safety procedures.
a) Record your procedure in your *Active Chemistry* log.

b) With the approval of your teacher, carry out the experiment.

c) Record your data and results.

d) Describe the relationship between the use of a catalyst and the rate of a reaction.

6. Pour 200 mL hot water into one beaker and 200 mL ice water into another beaker. Add a tea bag to each.

a) Record your results.

b) Repeat the procedure using an effervescent antacid tablet in place of the tea bag. Record your observations.

c) Describe the relationship between temperature and the rate of reaction, based on the two situations you studied.

7. Prepare two beakers, each containing equal amounts (about 200 mL) of room temperature water. Obtain two effervescent antacid tablets. Crush one and leave the other whole. Simultaneously add the crushed tablet to one beaker and the whole tablet to the other beaker.

a) Record your observations. What factor was being studied in Step 7?

b) Describe the relationship between that factor and the rate of reaction.

8. Use the results of this activity to answer the following:

a) Describe how you could increase the rate of reaction by altering:
   - concentration
   - catalyst
   - temperature
   - surface area

9. Dispose of all chemicals as directed by your teacher. Clean and put away any equipment as instructed. Clean up your workstation.

10. Chemical systems that highlight reaction rates can be very interesting. Because time is a factor, these systems are often called clock reactions. Your teacher may do the following reaction as a demonstration. Your teacher will use the following solutions:
    
    Solution A = 0.1 M potassium iodate (KIO₃)
    
    Solution B = 1% starch solution
    
    Solution C = 0.25 M sodium hydrogen sulfite (NaHSO₃)

    Two rows of five beakers (all the same size!) will be arranged. The front row is shown here.
    
    Each beaker in the back row contains 20 mL of solution C and 130 mL of water. Your teacher will add the contents of one beaker from the back row to the contents of one of the beakers in the front row. Use a stopwatch and stop when a color change occurs. Your teacher will then combine the next set of beakers as you again use the stopwatch. She or he will continue down the row.

    a) Record the time and your observations about the change in each case.

    Wash your hands and arms thoroughly after the activity.
FACTORS AFFECTING THE RATE OF A REACTION

In this activity you investigated several common factors that influence reaction rate. The rate of reaction is the decrease in the concentration of reactants over time. This leads to a corresponding increase in products over time. The factors you investigated included surface area, concentration of reactants, temperature, and catalysts. On a molecular level, these factors either increase or decrease the collision frequency of the particles of the materials involved in the reaction or they lower the activation energy of the reaction.

Consider surface area. In water, a sugar cube dissolves at a much slower rate than if the same cube is first crushed. The crushed cube has a greater surface area. More parts of the sugar are in contact with the water. In a fireplace, wood chips burn faster than a pile of logs. In your activity, the crushed effervescent antacid tablet probably reacted faster. In all of these cases, the smaller pieces, with their increased surface area, allow the particles that are reacting to come in contact with each other more often. This increases the collision frequency.

Another factor that influences reaction rate is the concentration of the reactants. You investigated increases of concentration with vinegar and with hydrochloric acid. An increase in concentration means an increase in the number of particles in the reaction. This results in an increase in the collision frequency. If a chemist wants to increase the rate of a reaction, an increase in the concentration of one or more of the reactants will do the trick.

Altering collision frequency and efficiency can also be accomplished through temperature changes. According to the kinetic theory, particles move faster at higher temperatures and slower at lower temperatures. The faster motion of the particles increases the energy of the particles and increases the probability that particles will collide. In addition, increasing the temperature of the reactants increases the number of particles that have an energy that equals or exceeds the activation energy required for the reaction to take place. You probably noticed an

Chem Words
rate of reaction: the decrease in the concentration of reactants with a corresponding increase in products over time.
surface area: the physical property of a solid which measures its surface in square units. For example, a 1 cm sugar cube has a surface area of 6 cm².
increase in the reaction rate when you compared tea bags in hot and cold water. As a result of adding heat, the reaction rate increased.

**Catalysts** play an important role in many chemical reactions. A catalyst is a substance that speeds up a reaction without being permanently changed or consumed itself. The catalyst lowers the activation energy of the reaction. In the activity, you used manganese dioxide as a catalyst in the decomposition of hydrogen peroxide.

\[ 2\text{H}_2\text{O}_2(\text{l}) \xrightarrow{\text{MnO}_2} \text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \]

Many commercial reactions make use of catalysts, because the catalysts can be recovered and reused. You are probably familiar with the term catalytic converter. This is a device used in automobiles to convert the pollutants CO and NO into CO\(_2\) and N\(_2\). This lessens the environmental impact of the combustion products. The catalyst in this converter is platinum.

**What Do You Think Now?**

At the beginning of the activity you were asked:

- What are some factors that influence the rate of a reaction?
- How could you make a reaction take place at a faster rate?
- How could you slow a reaction down?

How would you answer these questions now that you have completed this activity?

Now think about these questions:

- Why do you think it takes a long time for a nail to rust?
- In what form are the reactants prepared in fireworks?
- Why do you think that food spoilage (chemical change) takes place more slowly in the refrigerator?

Record your answers in your *Active Chemistry* log.
Active Chemistry Cool Chemistry Show

**Chem Essential Questions**

**What does it mean?**

Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your *Active Chemistry* log.

<table>
<thead>
<tr>
<th>MACRO</th>
<th>NANO</th>
<th>SYMBOLIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explain what you observed when you changed different factors of the reaction, such as temperature, concentration, surface area, and catalyst.</td>
<td>How does collision theory help to explain that chemical reactions usually take place faster when hot reactants are used instead of cold reactants?</td>
<td>When hydrogen peroxide is decomposed in the presence of the catalyst manganese dioxide, oxygen gas and water are produced. Write a chemical equation for this reaction.</td>
</tr>
</tbody>
</table>

**How do you know?**

A pad of steel wool rusts out much faster than the hull of a steel ship. Why?

**Why do you believe?**

The process of digesting food is a chemical process. You sometimes hear that food must be chewed a certain number of times before being swallowed. Give a chemical explanation for why increasing your chewing aids in digestion.

**Why should you care?**

In your chemistry show, the goal is to entertain the audience at some level. Therefore, the reactions presented should actually take place during the show! (Hint: Try to avoid using the slow rusting of nails as a demonstration during the show!) You want to be able to control the reaction somehow to get the best effect. If a reaction is slow, what might you do to speed it up? If it takes place too fast, what might you do to slow it down?

**Reflecting on the Activity and the Challenge**

In this activity you have observed how different factors affect the rate of a reaction. This knowledge can be applied to the presentations you will make in the *Cool Chemistry Show*. If you need to cause a reaction to happen faster or slower, you now know what changes you can make. Of course, it is important for you to check with your teacher before making adjustments to any procedure you might be considering.
1. Explain each of the following in terms of the factors that influence reaction rate:
   a) Which will bake faster: cookies at 50ºC or at 150ºC?
   b) Bears (and many other animals) hibernate during the winter months. Scientists claim that low body temperature slows down the animal’s metabolism. Explain.
   c) Why does a sugar cube dissolve slower than the same amount of sugar in granulated form?
   d) Antacid tablets are used to neutralize acid in the stomach. Explain why two tablets are faster than one tablet in neutralizing the acid.
   e) If you tried to burn a sugar cube with a match, you would find it very difficult to get the sugar to burn. However, if you put some ash on the cube, the cube would then burn when you put a flame to it. Explain the purpose of the ash in changing the burning of the sugar cube.
   f) Why does powdered aspirin dissolve faster than an aspirin tablet in water?
   g) Sugar dissolves more readily in hot tea than in iced tea. Explain.
2. In most cases, if you increase the temperature, the reaction rate increases. Explain this in terms of the collision theory.
3. Imagine that you purchase a light-stick necklace or wristband at a social event and want to make it last as long as possible. What would you do? Why would it help?
4. Explain why the effervescent antacid tablet did not seem to react as fast when it was put in a more dilute solution of vinegar.
5. Explain in terms of the reaction-rate factors that you have studied why it is possible for a person who has been submerged in very cold ice water to survive. However, individuals who have been submerged in warmer water for the same length of time may not survive.
6. Grain elevators have been known to have explosions because of the production of fine grain powders. Explain in terms of the reaction-rate factors that you have studied as to why this could happen.
7. In each of the four beakers shown below, a 2.0-cm strip of magnesium ribbon reacts with 100 mL of HCl(aq) under the conditions shown. In which beaker will the reaction occur at the fastest rate?
8. Preparing for the Chapter Challenge

The factors affecting a reaction can be varied to achieve different reaction rates. How could you use this information in developing a presentation for the Cool Chemistry Show? Describe one possible scenario.

Inquiring Further

Quantifying the relationship between temperature and reaction rate

You have seen that temperature is a factor that influences the rate of reaction. In general, if the temperature increases, the reaction rate increases. When the temperature decreases, the reaction rate decreases. Can this relationship be quantified? Is there a mathematical relationship between temperature and reaction time? To answer these questions, explore the reaction between magnesium (Mg(s)) and vinegar (CH₃COOH(aq)).

Design and conduct an investigation that will use this reaction to show the relationship between temperature and reaction time in a quantitative way. Have your teacher approve your design before you begin. Remember—the point of the investigation is to see if the relationship between temperature and reaction time is quantifiable. You’ll need to monitor both the temperature and the time carefully. Plot your data on a graph to make the relationship explicit. In your notes, include the chemical equation for this reaction.