The Rate of a Chemical Reaction

Strand Nomenclature, Chemical Formulas, and Reactions

Topic Investigating chemical reactions and equations

Primary SOL CH.3 The student will investigate and understand how conservation of energy and matter is expressed in chemical formulas and balanced equations. Key concepts include
f) reaction rates, kinetics, and equilibrium.

Related SOL CH.1 The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include
a) designated laboratory techniques;
b) safe use of chemicals and equipment;
c) proper response to emergency situations.

Background Information

Chemical kinetics is the study of rates of chemical reactions and reaction mechanisms—when and how fast a chemical reaction occurs. Many factors influence reaction rate. Two of the most important are the nature and properties of the reactants themselves, including particle size (surface area). Other factors, such as concentration, temperature, pressure, or the presence of a catalyst, will also affect the rate of a reaction. Collision theory can explain how these factors affect reaction rate.

Collision-theory concepts:

- For a chemical change to occur, old bonds must be broken (an endothermic process) and new bonds must be formed (an exothermic process).
- The reactants must collide with each other to form products.
- The reactants must collide with each other at the correct angle and the correct molecular orientation.
- The collisions between reactants must be effective—i.e., they must have enough energy (called “activation energy”).
- Activation energy is the minimum energy needed for a reaction to occur.
- If the rate of collisions increases, the reaction rate increases.
- Anything that increases the chances of collisions between reactants also increases the number of collisions that are effective.
- If the percentage of effective collisions increases, the reaction rate increases.

Effect of concentration on reaction rate:

- An increase in the concentration of reactants results in an increase in the reaction rate. At higher concentrations, the molecules of the reactants are closer to each other; therefore, collisions occur more frequently, a higher percentage of collisions are effective, and the reaction rate increases.

Effect of surface area on reaction rate:

- In a solid, only surface particles can interact with the other reactants. If the solid is divided into smaller pieces, then there is greater surface area; therefore, more particles are able to react, and the reaction rate increases.

Effect of temperature on reaction rate:

- An increase in the temperature of reactants usually results in an increase in the reaction rate. At higher temperatures, the molecules of the reactants move faster; therefore, collisions occur more frequently, a higher percentage of collisions are effective, and the reaction rate increases. A general rule of thumb is that on average, the reaction rate doubles for every 10°C rise in temperature.

Effect of a catalyst on reaction rate:

- A catalyst is a substance that changes the reaction rate without being consumed by the reaction.
- A catalyst acts by lowering the activation energy required for a reaction to take place, thus allowing the reaction to occur more rapidly.

Materials

- Test tubes
- Ice water bath
- Hot water bath
- Distilled water
- 250-mL plastic bottle
- Steel wool
- Test tube rack
- Five 250-mL beakers
- *M*, 1.0 *M*, 3.0 *M*, and 6.0 *M* HCl solutions
- Small pieces of zinc
- Powdered zinc
- 3% H_2O_2 solution
- *M* $CaCl_2$ solution
- *M* NaCl solution
- *M* $FeCl_3$ solution
- *M* KNO_3 solution
- *M* $Fe(NO_3)_3$ solution
- Alka-Seltzer tablets
- Safety goggles

Vocabulary

activation energy, catalyst, chemical reaction, collision theory, concentration, constant temperature, endothermic, equation, exothermic, ion, kinetics, molecule, particle, reaction rate

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

Introduction

1. Ask students if the rate of a chemical reaction depends on the ability of molecules or ions to make consistent and effective collisions with each other. In this experiment, you will study various conditions and the effect they have on the collision of molecules. You will observe the effects of temperature, concentration, particle size (surface area), and catalysts on the rates of chemical reactions and then explain these effects in terms of the collision theory.

Procedure

Experiment 1: Effect of Temperature on Reaction Rate

1. Pour about 5 mL of 6.0 *M* HCl into each of three clean test tubes. Place one of the tubes in an ice water bath maintained at 0°C. Place another in a hot water bath maintained at 60°C. Maintain the third test tube at room temperature. Allow about 10 minutes for the tubes to reach equilibrium temperature.
2. Cut three small pieces of zinc to the same size (0.5 × 2.0 cm). Clean the pieces with steel wool, if necessary. Ask students why they would need to treat some pieces of zinc with steel wool and why others may not need it.
3. Note the time, and drop one piece of zinc into each of the three test tubes.
4. Watch the reactions, and note the time at which each reaction ceases. Which reaction was fastest? Which was slowest?

Experiment 2: Effect of a Catalyst on Reaction Rate

1. Measure 90 mL of distilled water into a clean 250-mL plastic bottle, and add 10 mL of 3% H_2O_2. Label the solution as 0.3% H_2O_2. This will be your test solution.
2. Rinse six clean test tubes and a 10-mL graduated cylinder with the 0.3% H_2O_2. Discard the rinsing.
3. Measure 5 mL of the H_2O_2 solution into each of the six test tubes, and place them in a test tube rack.
4. Add 5 drops of each of the following solutions to separate test tubes of H_2O_2:
   - 0.1 *M* $CaCl_2$
   - 6.0 *M* HCl
   - 0.1 *M* NaCl
   - 0.1 *M* $FeCl_3$
   - 0.1 *M* KNO_3
   - 0.1 *M* $Fe(NO_3)_3$
5. Ask students to set up a method for determining rate of gas evolution for each test.
6. Observe each solution, and report the rate of gas evolution from each, using the terms *fast, slow, very slow,* or *none* to describe the rate. Describe the catalytic effect as *high, low,* or *none*.

Experiment 3: Effect of Concentration on Reaction Rate (at Constant Temperature)

1. Pour 5 mL of each of the following HCl solutions into separate clean test tubes:

0.1 *M*
1.0 *M*
3.0 *M*
6.0 *M*.

2. Cut four small pieces of zinc (1 × 1 cm). Clean with steel wool, if necessary. Drop a piece of zinc into each of the acid solutions, and record the starting time and the ending time of each reaction. Compare the reaction times. Which was fastest? Which was slowest?

Experiment 4: Effect of Particle Size or Surface Area on Reaction Rate

1. Cut a piece of zinc (0.5 × 2.0 cm). Clean with steel wool, if necessary.
2. Determine the mass of the zinc to the nearest 0.01 g and record.
3. Place the piece of zinc in a clean, dry test tube.
4. Measure an equal mass of powdered zinc into a second clean, dry test tube.
5. Place both test tubes in a rack, and add 5 mL of 1.0 *M* HCl to each.
6. Observe the reactions for several minutes, and record your observations. Compare the reaction times. Which was fastest? Which was slowest?

Assessment

- **Questions**
  - Which ionic compounds used in Experiment 2 were effective catalysts? Using your data, identify the ion responsible for the catalytic activity.
  - Many reaction rates approximately double for every 10°C increase in temperature. Are the results obtained in Experiment 1 consistent with this general rule?
- **Journal/Writing Prompts**
  - Describe the effect of temperature on the reaction rate. Explain this effect in terms of the collision theory of reactions.
  - Describe the effect of concentration on the reaction rate. Explain this effect in terms of the collision theory of reactions.
  - Describe the effect of particle size or surface area on the reaction rate. Explain this effect in terms of the collision theory of reactions.
  - Describe the effect of a catalyst on the reaction rate. Explain this effect in terms of the collision theory of reactions. Rates of speed of chemical reactions depend on the ability of molecules to make consistent and effective collisions with each other. Explain the factors and the impact they have on rates of reactions.
- **Other**
  - Complete a lab report sheet and answer the questions.
  - Work in groups to do assigned parts of the lab and then present the results to the rest of the class as a demonstration.

Extensions and Connections (for all students)

- Have groups of students explore the following reaction to study further the effect of temperature on reaction rate:

  - Fill each of five 250-mL beakers with 100 mL of water adjusted to the following temperatures: 0°C, 10°C, 20°C, 30°C, and 40°C. Adjust the temperatures by using ice water, tap water, and hot water.
  - Add one Alka-Seltzer tablet to each beaker, and time the reaction until every last bit of the tablet stops fizzing. Record the results in a data table.
  - Using the data, construct a graph of the reaction time versus temperature.
  - How did the reaction rate vary with the temperature? Explain. A general rule of thumb is that on average, the reaction rate doubles for every 10°C rise in temperature. Does this rule hold true for this reaction?
- Have groups prepare an electronic presentation of their four experiments. Presentations should include photos of results and models/diagrams/animation that show how changing the variable in each experiment affects the ability of molecules to make consistent effective collisions with each other.

Strategies for Differentiation

- Have students take digital pictures of the reactants and results of each of four experiments.
- Color-code signs to label stations with corresponding color-coded directions for each experiment.
- Invite a local chemist to demonstrate chemical reactions by other means.
- Have students do this lesson as four separate minilabs. Set up separate stations for each of the four experiments, and have students work in groups of two or three. Put specific directions at each station. Have groups complete one experiment before moving to another station, but the order in which they move is not important.