NAME ______________________________

DATE ______________________________

Carolina Investigations® for AP Chemistry

Factors Affecting Reaction Rates

Guided Activity

Background

The quick booms and flashes of fireworks and the slow rusting of iron and corrosion of copper are all chemical reactions. The study of chemical kinetics centers on the reasons for the different rates at which chemical reactions occur. The primary theory behind chemical kinetics is the collision theory. According to this theory, reactant molecules must collide with enough force to achieve activation energy before a reaction can occur. Activation energy is the minimum amount of energy needed to break the chemical bonds of reactant molecules such that they form new products. While molecules collide continuously (according to the kinetic molecular theory), only those that meet or exceed their activation energy and collide in a favorable orientation will form new products with new bonds. The rate of chemical reactions can be influenced by temperature, concentration, and the surface area of the reactants as well as the presence of a catalyst.

Temperature

According to kinetic molecular theory, temperature is a measurement of the average kinetic energy of molecules. (In fact, the Kelvin temperature scale begins with 0 K, the temperature at which there is no molecular motion.) Increasing the temperature of a sample increases the average kinetic energy of the molecules, and decreasing the temperature reduces the average kinetic energy.

Concentration

Concentration is the number of molecules per volume. For example in 1 M hydrochloric acid, there is 1 mole of hydrochloric acid per liter of solution, whereas in 2 M hydrochloric acid there are 2 moles of hydrochloric acid per liter of solution (i.e., twice as many molecules of HCl in the same volume). Decreasing the volume of a gas in a closed system increases its concentration (because there are more molecules per volume).

Surface area

Surface area is the area of a substance that is exposed to a different substance. Surface area is especially important in chemical reactions when the reactants are in different phases. A liquid in a tall cylinder exposes a small surface area to a surrounding gas, whereas the same volume of the same liquid in a shallow pan exposes a large surface area. A solid substance in the shape of a cube exposes a smaller surface area to a surrounding liquid or gas than does a rectangular prism of the same volume.

Catalyst

A catalyst is a substance that increases the rate of a chemical reaction but is not chemically changed in the reaction. A catalyst provides a pathway for the reaction that lowers the activation energy normally required. For example, the decomposition reaction of H_2O_2 to O_2 and H_2O is greatly accelerated by the addition of platinum as a catalyst. This system is commonly used in the overnight disinfection of contact lenses. The H_2O_2 kills potentially infectious microorganisms but by morning has been decomposed to harmless water and oxygen before the lenses are put back onto the wearer's eyes. In this case, the platinum is a heterogenous catalyst (a catalyst in a different phase from the reactants—here, a solid in a liquid).

Homogeneous catalysts are those in the same phase as the reactants. Many critical physiological reactions are facilitated by homogeneous catalysts (involving liquid catalysts and liquid reactants).

In this laboratory activity, you will perform a reaction known as an iodine clock reaction. In this reaction, clear solutions that are poured together produce a dark blue-black product after a period of time. This timed color change makes it easy to observe how altering variables affects the rate of the reaction.

Pre-laboratory Questions

1. What are some examples of reactions that people may wish to speed up or slow down?

2. In each of the following three examples, explain how the molecules differ in the two items described:
   a. water at 70°C and water at 40°C

   b. 5 M glucose solution and 6 M glucose solution, both at room temperature

   c. a 64-cm^3 cube of sugar and a 2- × 8- × 4-cm rectangular prism of sugar

3. Read the laboratory procedure and diagram the steps, using illustrations and/or a flow chart. Label any diagrams with quantities and descriptions.

Materials

At the central materials station:

- 0.05 M potassium iodide, KI
- 0.10 M hydrochloric acid, HCl
- 0.01 M sodium thiosulfate $Na_2S_2O_3$
- 0.001 M copper(II) sulfate, $CuSO_4$
- 1% starch solution
- 3% hydrogen peroxide, H_2O_2
- labeled graduated cylinders
- potassium iodide, KI
- weigh boats

At each lab station:

- 24-well microplates
- 1-mL syringe
- stopwatch
- 5 disposable pipets
- hot plate*
- container of crushed ice
- thermometer
- mortar and pestle*
- paper towels
- 5 50-mL beakers
- 3 150-mL beakers
- chemical scoop
- balance (readable to 0.001 g)*
- test tube tongs
- 10 test tubes (13 × 100 mm)
- 3 small weigh boats
- 10-mL graduated cylinder
- water (deionized or distilled)

*Groups may share these items if there are not enough to place one at each station.

Procedure

Activity 1: Calibration

1. Orient your well plate so that there are four wells across by six wells down.
2. In the top left well, place 8 drops of KI.
3. Add 2 drops of HCl to the KI solution in the well.
4. Add 4 drops of starch to the solution in the well.
5. Add 4 drops of $Na_2S_2O_3$ (sodium thiosulfate) to the solution in the well.
6. Swirl the solution by moving the well plate in a small circle on the table.
7. With the syringe, draw up 0.4 mL of H_2O_2.
8. As the H_2O_2 is added to the solution in the well plate, begin timing.
9. Swirl the solution and monitor the color.
10. Record the amount of time it takes for the entire solution to turn a dark blue-black color.
11. If the solution took more than approximately 20 seconds to turn blue-black, repeat steps 1–10 in the next well in the row, this time with only 3 drops of $Na_2S_2O_3$. Continue trials, reducing the $Na_2S_2O_3$ by 1 drop each time, until it takes approximately 20 seconds for the dark color to appear.
12. If the solution took less than approximately 20 seconds to turn blue-black, repeat steps 1–10 in the next well in the row, this time adding 6 drops of $Na_2S_2O_3$ rather than 4. Continue trials, adding 2 more drops of $Na_2S_2O_3$ each time, until you find the number of drops that yields the color change at approximately 20 seconds.

13. When a solution takes approximately 20 seconds to turn dark, no additional trials are needed.
14. Record the number of drops of $Na_2S_2O_3$ used to achieve the 20-second change. This number will be used in all subsequent experiments.

Activity 2: Concentration

1. In the leftmost well of the next empty row, place 8 drops of KI.
2. Add 2 drops of HCl to the KI solution in the well.
3. Add 4 drops of starch.
4. Add the number of drops of sodium thiosulfate determined in Activity 1.
5. Swirl the solution by moving the well plate in a small circle on the table.
6. With the syringe, draw up 0.4 mL of H_2O_2.
7. As the H_2O_2 is added to the solution in the well plate, begin timing.
8. Swirl the solution and monitor the color.
9. Record the amount of time it takes for the entire solution to turn a dark blue-black color.
10. Repeat steps 1–9, using 6 drops of KI and 2 drops of distilled or deionized water in place of the 8 drops of KI.
11. Repeat steps 1–9, using 4 drops of KI and 4 drops of water in place of the 8 drops of KI.
12. Repeat steps 1–9, using 2 drops of KI and 6 drops of water in place of the 8 drops of KI.

	KI	H_2O (distilled or deionized)	HCl	Starch	$Na_2S_2O_3$	H_2O_2
Trial 1	8 drops	0 drops	2 drops	4 drops	Number of drops determined in Activity 1	0.4 mL
Trial 2	6 drops	2 drops	2 drops	4 drops	Number of drops determined in Activity 1	0.4 mL
Trial 3	4 drops	4 drops	2 drops	4 drops	Number of drops determined in Activity 1	0.4 mL
Trial 4	2 drops	6 drops	2 drops	4 drops	Number of drops determined in Activity 1	0.4 mL

Activity 3: Temperature

1. Prepare three water baths as follows:
   a. For a room-temperature water bath, place 125 mL water in a 150-mL beaker. Directly before using it, record the temperature of the water in the data table.
   b. For a hot water bath, place 125 mL water in a 150-mL beaker on a hot plate and set the temperature so that the water is at least 20°C above room temperature. Directly before using it, record the temperature of the water in the data table.
   c. For a cold water bath, half-fill a 150-mL beaker with ice and then add water to reach roughly the same level as in the other beakers. Directly before using the cold water bath, record its temperature in the data table.

2. Add 8 drops of KI to each of three test tubes.
3. Add 2 drops of HCl to the KI solution in each test tube.
4. Add 4 drops of starch to the solution in each test tube.
5. Add the number of drops of $Na_2S_2O_3$ determined in Activity 1 to the solution in each test tube.
6. Swirl the solution in each test tube.
7. With the syringe, place 0.4 mL H_2O_2 in each of three empty test tubes.
8. Mark each of the test tubes containing H_2O_2, using a wax pencil or permanent marker.
9. Place in each of the three prepared water baths one test tube containing the mixture of solutions and one test tube containing H_2O_2.
10. Allow the solutions to remain in the baths for 10 minutes so that each solution reaches the temperature of its water bath.
11. With test tube tongs, remove the test tube containing H_2O_2 from the room-temperature water bath. Pour the H_2O_2 into the tube containing the room-temperature mixture of solutions.
12. As the H_2O_2 is added, begin timing.
13. Swirl the solution and monitor the color.
14. Record the amount of time it takes for the room-temperature reactants to turn blue-black.
15. Repeat the mixing process with the pairs of tubes in both the hot and cold water baths.

Activity 4: Surface area

1. Add 4 drops HCl to each of two test tubes.
2. Add 5 drops of starch to the solution in each test tube.
3. Add 3 mL of sodium thiosulfate to the solution in each test tube.
4. Add 0.8 mL of H_2O_2 to the solution in each test tube.
5. Swirl the solution in each test tube.
6. Using a mortar and pestle, grind 0.5 g of KI crystals into a powder.
7. Place 0.02 g of the powdered KI crystals into an empty test tube. Mark it as test tube *P*.
8. Place 0.02 g KI crystals into an empty test tube. Mark it as test tube *C*.
9. Pour one of the mixtures of solutions into tube C with the KI crystals. Do not swirl.
10. As soon as the mixture is added, begin timing.
11. Monitor the color and record the amount of time it takes for the solution to turn blue-black.
12. Repeat steps 9–11 with tube P, containing the powdered KI.

Activity 5: Catalyst

1. On the well plate, place 8 drops of KI in the leftmost well of the next empty row.
2. Add 2 drops of HCl to the KI solution in the well.
3. Add 4 drops of starch.
4. Add the number of drops of sodium thiosulfate determined in Activity 1.
5. Add 2 drops of distilled or deionized water.
6. Swirl the solution by moving the well plate in a small circle on the table.
7. With the syringe, draw up 0.4 mL of H_2O_2.
8. As the H_2O_2 is added to the solution in the well plate, begin timing.
9. Swirl the solution and monitor the color.
10. Record the amount of time it takes for the entire solution to turn dark blue-black.
11. Repeat steps 1–10, this time using 2 drops of $CuSO_4$ instead of the water.

	KI	**HCl**	**Starch**	**NaS_2O_3**	**H_2O (distilled or deionized)**	**$CuSO_4$**	**H_2O_2**
Trial 1	8 drops	2 drops	4 drops	Number of drops determined in Activity 1	2 drops	0 drops	0.4 mL
Trial 2	8 drops	2 drops	4 drops	Number of drops determined in Activity 1	0 drops	2 drops	0.4 mL

Data

Table 1: Calibration

	Drops of $Na_2S_2O_3$	Time (min:sec)
Trial 1		
Trial 2		
Trial 3		
Trial 4		

How many drops will be used in the remaining experiments? ________________

Table 2: Concentration

	Drops of KI	Time (min:sec)
Trial 1		
Trial 2		
Trial 3		
Trial 4		

Table 3: Temperature

	Temperature of the Water Bath (°C)	Time (min:sec)
Cold Water Bath		
Room-temperature Water Bath		
Hot Water Bath		

Table 4: Surface Area

	Time (min:sec)
Solid KI	
Powdered KI	

Table 5: Catalyst

	Drops of $CuSO_4$	Time (min:sec)
Trial 1		
Trial 2		

Laboratory Questions

1. Explain how each treatment affected the rate of reaction. Describe the effect at a molecular level.
   a. Temperature:

   b. Surface Area:

   c. Concentration:

2. How did the addition of copper(II) sulfate affect the reaction rate?

3. Many fast-acting medications are sold as powders, sometimes inside soluble capsules. Why would these medications act faster than solid tablets?

4. Steel wool, mostly made of iron, is a very fine material used as an abrasive. This material rusts (oxidizes) readily in the presence of water and oxygen as do iron nails.
   a. How would the rate of rusting of a piece of steel wool compare with that of an iron nail? Explain.

   b. How would the rate of rusting be different in summer and in winter? Explain.