Sudsy Kinetics

Introduction to Reaction Rates

Introduction

Teach kinetics concepts in a fun and sudsy way! This demonstration provides an interesting twist on the traditional "Old Foamey" or "Elephant Toothpaste" reaction. Not only will your students be amazed at the sudsy eruption—they will learn kinetics concepts along the way!

Concepts

- Kinetics
- Reaction intermediates
- Decomposition reaction
- Catalyst

Materials Needed

Chemicals

Hydrogen peroxide, H_2O_2, 30%, 20 mL

Hydrogen peroxide, H_2O_2, 10%, 20 mL

Hydrogen peroxide, H_2O_2, 3%, 20 mL

Alconox® detergent, 3–4 g

Sodium iodide solution, NaI, 2 M, 4–5 mL*

Tap water

Equipment

Graduated cylinders, 10-mL, 3

Graduated cylinders, 100-mL, 3

Graduated cylinders, 500-mL, 2
or Erlenmeyer flasks, 500-mL, 2

Large, plastic demonstration tray

Lighter or matches

Spoon or scoop

Wood splint

Safety Precautions

Hydrogen peroxide solution, 30%, is severely corrosive to the skin, eyes, and respiratory tract and is a very strong oxidant. It is a dangerous fire and explosion risk. ***Do not*** *heat 30% hydrogen peroxide. Sodium iodide is slightly toxic by ingestion. The decomposition reaction of 30% hydrogen peroxide is highly exothermic. Use only borosilicate glass graduated cylinders. Steam and oxygen are produced very quickly—do not stand over the reaction flask. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Avoid contact of all chemicals with eyes and skin. Wash hands thoroughly with soap and water before leaving the laboratory. Please review current Safety Data Sheets for additional safety, handling, and disposal information.*

Procedure

Part 1. Effect of Concentration on the Rate of the Reaction

1. Place three 100-mL graduated cylinders in a large, plastic demonstration tray or dishpan.
2. Add 20 mL of 30% hydrogen peroxide to the first cylinder, 20 mL of 10% hydrogen peroxide to the second cylinder, and 20 mL of 3% hydrogen peroxide to the third cylinder.
3. Add 1 small scoop (3–4 g) of solid Alconox® detergent to each cylinder and swirl to mix the detergent.
4. Measure out 5 mL of 2 M sodium iodide solution into each of three 10-mL graduated cylinders. Ask your students to predict the relative rate at which each hydrogen peroxide solution will react with potassium iodide.
5. Ask for three student volunteers. Make sure the students are wearing chemical splash goggles; warn them to step back as soon as they pour. Have the students simultaneously pour sodium iodide solution into the three individual cylinders containing differing concentrations of hydrogen peroxide. Make observations. White foam erupts from the cylinder with the 30% hydrogen peroxide the fastest, the 10% hydrogen peroxide next, and only slowly rises up from the cylinder containing 3% hydrogen peroxide.

Part 2. Old Foamey—Observing a Reaction Intermediate and Products

1. Place a 500-mL graduated cylinder on a large, plastic demonstration tray.
2. Measure out 20 mL of 30% hydrogen peroxide and add it to the cylinder.
3. Add 1 small scoop (3–4 g) of solid Alconox® detergent to the cylinder and swirl the mixture to dissolve the detergent.
4. Measure out 5 mL of 2 *M* sodium iodide solution and, quickly but carefully, pour this into the cylinder. In a few seconds, copious amounts of white foam will be produced. Observe closely at the beginning of the reaction. A brown foam is produced at first but then turns white before it erupts out of the cylinder. This is due to the presence of the free iodine produced by the oxidation of iodide ions by hydrogen peroxide.
5. Notice the steam coming off from the foam—this indicates that the decomposition reaction is very exothermic.
6. Light a wood splint and blow out the flame. Insert the glowing wood splint into the foam. The wood splint will re-ignite in the foam—this indicates that the gas in the foam is pure oxygen. Take the glowing splint out of the foam, re-insert it, and watch it re-ignite again. This can be repeated numerous times.

Part 3. Comparing the Rate of the Reaction with its Stoichiometry

Purpose: In this part, the total number of moles of peroxide is the same in each container, although one has been diluted with water. An equal volume of foam is produced by both but at different rates, with the more concentrated one reacting faster. The more dilute one will eventually produce an equal amount of product. This demonstrates that the *rate* at which the product is produced is not necessarily related to the *amount* of product.

1. Carefully measure out 15 mL of 30% hydrogen peroxide and add it to a 500-mL graduated cylinder or Erlenmeyer flask.
2. Carefully measure out a second 15 mL portion of 30% hydrogen peroxide and add it to a different 500-mL graduated cylinder or Erlenmeyer flask. To this second cylinder or flask, also add 30 mL of tap water.
3. Add a scoop (3–4 g) of Alconox® detergent to each cylinder or flask. Swirl to dissolve the detergent.
4. Place both containers in the center of a large, plastic demonstration tray.
5. Ask for two student volunteers. Again make sure they are wearing goggles and are warned to step back. Have them add 4 mL of 2 *M* sodium iodide solution to the two individual cylinders. The reaction will turn brown immediately and white foam will rise up out of each cylinder, with the more concentrated mixture rising more rapidly. However, keep observing! Compare the final volume of foam produced by each reaction. The diluted peroxide will eventually produce the same amount of foam since an equal number of moles of hydrogen peroxide were used in each reaction.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The foam and any solution left in the cylinder or on the plastic tray may be rinsed down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Tips

- Each part of the demonstration is designed to teach a different concept in chemistry. First perform Part 1 with the three concentrations of peroxide, discussing how rate is dependent on concentration. Ask students which one they would like to see again—they will surely choose the 30% one. Then perform Part 2 in a larger graduated cylinder, this time discussing the reactions that are occurring, the brown iodine intermediate, production of heat, and the formation of water and oxygen gas. Finally perform Part 3 in flasks. Discuss the stoichiometry of the decomposition reaction and use the ideal gas law ($PV = nRT$) to calculate the volume of gas that should be produced.
- The decomposition reaction is exothermic and the cylinder will become very hot. Be sure to let it cool before handling.
- If a demonstration tray is not available, use a dishpan or perform this demonstration in a laboratory sink.
- The safe products of this reaction, as well as the generous amount of detergent, make cleanup very easy.

Discussion

Hydrogen peroxide decomposes to produce oxygen and water according to the following overall equation.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g) + \text{Energy}$$

The reaction is quite slow unless catalyzed by a substance such as iodide ions, manganese metal, manganese dioxide, iron(III) ions, and many other substances such as yeast or even blood. A *catalyst* is a substance that, when added to a reaction mixture, participates in the reaction and speeds it up, but is not itself consumed in the reaction. The iodide ion is used as a catalyst in this demonstration. While the complete mechanism is not known, the observations of this reaction are consistent with the following reactions.

Step 1: Hydrogen peroxide and iodide mix to cause spontaneous formation of the brown color from the I_3^- intermediate with very little foam. This reaction shows that the catalyst is involved in the reaction.

$$H_2O_2(aq) + 3I^-(aq) \rightarrow 2OH^-(aq) + I_3^-(aq) \qquad \Delta H_{rxn} = –37.0 \text{ kcal}$$

$$\Delta G_{rxn} = –18.5 \text{ kcal}$$

Step 2: The intermediates then combine with additional hydrogen peroxide to cause the spontaneous disappearance of the brown color and the production of copious amounts of foam containing oxygen gas. The I^- is regenerated in the reaction, showing that the catalyst is not consumed in the reaction.

$$H_2O_2(aq) + I_3^-(aq) + 2OH^-(aq) \rightarrow 2H_2O(l) + 3I^-(aq) + O_2(g) \qquad \Delta H_{rxn} = –8.3 \text{ kcal}$$

$$\Delta G_{rxn} = –30.8 \text{ kcal}$$

Overall Reaction: Combining Steps 1 and 2 gives the overall reaction shown below. Notice that the enthalpy or heat of reaction (ΔH_{rxn}) is negative, indicating that the reaction is exothermic and releases heat. The free energy of the reaction (ΔG_{rxn}), which takes into account not only the enthalpy but also the entropy of the reaction, is also a negative value, indicating that the reaction takes place spontaneously. If the reaction occurs spontaneously, then why is a catalyst needed? The iodide catalyst causes the reaction to occur at a reasonable rate—without it, the reaction would occur, but so slowly that it would not be observable.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g) + \text{Energy} \qquad \Delta H_{rxn} = –45.3 \text{ kcal}$$

$$\Delta G_{rxn} = –49.3 \text{ kcal}$$

Why all the foam? A sample calculation is given below for the volume of oxygen released by the decomposition of 15 mL (as in Part 3) of 30% hydrogen peroxide. Hydrogen peroxide solution (30%) has a specific gravity of 1.11 g/mL. Therefore, the mass of solution can be determined

$$1.11 \text{ g/mL} \times 15 \text{ mL} = 16.7 \text{ g of solution}$$

Since only 30% of the total volume of solution is H_2O_2, then

$$30\% \text{ of } 16.7 \text{ g of solution} = 5.01 \text{ g of } H_2O_2$$

Since the molecular weight of H_2O_2 is 34.02 g/mol, the number of moles of H_2O_2 is

$$5.01 \text{ g} \times 1 \text{ mole}/34.02 \text{ g} = 0.147 \text{ mol of } H_2O_2 \text{ used}$$

From the balanced equation, there is a 2 to 1 ratio of hydrogen peroxide to oxygen gas. Thus, the number of moles of O_2 released can be determined

$$0.147 \text{ mol } H_2O_2 \times 1 \text{ mole } O_2/2 \text{ mol } H_2O_2 = 0.0736 \text{ mol } O_2$$

This shows that the reaction should produce 0.0736 moles of oxygen gas. To determine the volume of this amount of gas, use the ideal gas law, PV = nRT, assuming a reaction temperature of the steaming foam of approximately 100 °C (or 373 K) and standard pressure (1 atm). Solving for volume, V = nRT/P, where n = 0.0736 mol, R = ideal gas constant = 0.0821 L·atm/mol·K, T = 373 K and P = 1 atm, the volume of oxygen gas can be calculated

$$V = (0.0736 \text{ mol})(0.0821 \text{ L·atm/mol·K})(373 \text{ K})/1 \text{ atm} = 2.25 \text{ L } O_2.$$

The volume of oxygen expected, then, is 2.25 liters.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions, interactions of energy and matter

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Sudsy Kinetics* activity, presented by Irene Cesa, is available in *Introduction to Reaction Rates*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Sudsy Kinetics* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Sudsy Kinetics—Chemical Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP4866	Sudsy Kinetics—Chemical Demonstration Kit
AP5429	Demonstration Tray
H0008	Hydrogen Peroxide, 30% Reagent, 500 mL
H0009	Hydrogen Peroxide, 3%, Lab Grade, 500 mL
S0084	Sodium Iodide, Reagent, 100 g
A0126	Alconox® Detergent, 4 lb Carton
GP2020	Graduated Cylinder, Borosilicate Glass, 100 mL
GP2030	Graduated Cylinder, Borosilicate Glass, 500 mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.