Reaction Kinetics in Blue

Effect of Temperature on Reaction Rates

FLINN SCIENTIFIC CHEM FAX!

Introduction

How fast will a chemical reaction occur? If a reaction is too slow, it may not be useful. If the reaction is too fast, it may be harmful or explosive. Measuring and controlling reaction rates makes it possible for chemists and engineers to create a variety of products, everything from antibiotics to fertilizers, in a safe and economical manner. The purpose of this experiment is to investigate how the rate of a reaction can be measured and how varying conditions can affect reaction rates.

Concepts

- Kinetics
- Collision theory
- Reaction rate
- Oxidation–reduction

Background

Kinetics is the study of the rates of chemical reactions. As reactants are transformed into products in a chemical reaction, the amount of reactants will decrease and the amount of products will increase. The rate of the reaction can be determined by measuring the concentration of reactants or products as a function of time. In some cases, it is possible to use a simple visual clue to determine a reaction rate. Thus, if one of the reactants is colored but the products are colorless, the rate of the reaction can be followed by measuring the time it takes for the color to disappear. The average rate of the reaction is then calculated by dividing the molar concentration (*M*) of the colored reactant by the time needed for the color to disappear. Depending on how fast the reaction occurs, the rate would be reported in units of either *M*/sec or *M*/min.

Reactions involving the organic dye methylene blue provide a convenient example to study reaction rates. Methylene blue (abbreviated MB) exists in two forms, a reduced form and an oxidized form. The reduced form of methylene blue (MB_{rd}) is colorless, while the oxidized form (MB_{ox}) is blue. The reduced form is easily converted to the oxidized form by mixing it with oxygen in the air (Reaction 1). The oxidized form, in turn, can be converted back to the reduced form by treatment with a reducing agent, such as dextrose, which is a reducing sugar.

$$\underset{\textit{Colorless}}{MB_{rd}} + O_2 \rightarrow \underset{\textit{Blue}}{MB_{ox}} \qquad \textit{Reaction 1}$$

In this experiment, the rate of reaction of the blue, oxidized form MB_{ox} with dextrose and potassium hydroxide to give the colorless, reduced form MB_{rd} (Reaction 2) will be studied. If the initial concentration of MB_{ox} in solution is known, the rate of the reaction can be determined by measuring the time needed for the blue color to disappear.

$$\underset{\textit{Blue}}{MB_{ox}} + \text{dextrose} + KOH \rightarrow \underset{\textit{Colorless}}{MB_{rd}} \qquad \textit{Reaction 2}$$

Materials

Dextrose solution, $C_6H_{12}O_6$, 0.1 *M*, 525 mL	Hot plate or warm water
Methylene blue solution, 0.1%, 5 mL	Ice or cold water
Potassium hydroxide solution, KOH, 3.0 *M*, 210 mL	Metric ruler
Water, distilled or deionized	Parafilm M®, to cover flasks
Beakers, to fit Erlenmeyer flasks, 600- or 1000-mL, 4	Rubber stoppers to fit Erlenmeyer flasks, 7
Erlenmeyer flasks, 250-mL, 7	Thermometer
Graduated cylinders, 25- or 30-mL, 2	

Safety Precautions

Potassium hydroxide solution is a corrosive liquid and is toxic by ingestion; it is particularly dangerous to eyes and may blister and burn skin. Avoid contact with eyes and skin and clean up all spills immediately. Keep citric acid on hand to neutralize any spills. Methylene *blue is slightly toxic by ingestion. Wear chemical splash goggles and chemical-resistant gloves and apron. Please consult current Material Safety Data Sheets for additional safety, handling, and disposal information. The dextrose (sugar) solution will attract ants. Rinse off work area with water. Wash hands thoroughly with soap and water before leaving the laboratory.*

Preparation of Solutions

"Blue Bottle" Solution: Prepare 600 mL of blue bottle solution by mixing 300 mL of 0.1 M dextrose solution, 60 mL of 3 M potassium hydroxide solution, 240 mL of distilled or deionized water, and 30 drops of 0.1% methylene blue. *Note:* The blue bottle solution should be prepared fresh at the beginning of the class period.

Procedure

Part A. Effect of Temperature

1. Obtain four 600- or 1000-mL beakers and make water baths at approximately the following temperatures: 10 °C, 20 °C, 30 °C, and 40 °C. In order to obtain easily measured reaction times, avoid temperatures above 40 °C or below 10 °C.
2. Obtain four Erlenmeyer flasks and fill each with about 150 mL of "Blue Bottle" solution.
3. Stopper each flask and cover the opening with a layer of Parafilm to ensure a tight seal.
4. Place one flask into each of the four water baths prepared in step 1. Let the flasks stand in the baths for about 5 minutes.
5. Select a student volunteer, and remove the flasks from the water baths. Simultaneously shake the flasks 10 times. Set the flasks down to observe the color change. *Note:* Consider practicing this with a student beforehand to ensure consistency of shaking.

Part B. Effect of Concentration

6. Obtain the remaining three flasks, rubber stoppers, and Parafilm.
7. Using a graduated cylinder, measure and add 75 mL of dextrose solution to each of the three flasks.
8. Add 3–4 drops of methylene blue solution to each test tube.
9. Using a clean, graduated cylinder, measure and add 25 mL of 3.0 M potassium hydroxide solution into one flask.
10. Measure and add 50 mL of distilled water to the same flask, giving a final volume of 150 mL. Stopper the flask and shake gently to mix the solutions.
11. Using a graduated cylinder, measure and add 50 mL of 3.0 M potassium hydroxide solution into the second flask.
12. Measure and add 25 mL of distilled water to the same flask, giving a final volume of 150 mL. Stopper the flask and shake gently to mix the solutions.
13. Using a graduated cylinder, measure and add 75 mL of 3.0 M potassium hydroxide solution into the third flask, giving a final volume of 150 mL. Stopper the flask and shake gently to mix the solutions.
14. Allow the flasks to sit undisturbed at room temperature until the blue color fades. *Note:* This may take a few minutes.
15. Check the temperature of the solutions to be sure they are all about the same temperature, then seal the openings with Parafilm M.
16. With the same student volunteer, simultaneously shake the flasks 10 times. Set the flasks down to observe the color change.

Disposal

Consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The waste solutions from Parts A and B may be flushed down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Tips

- Many students will think that the blue–colorless and colorless–blue reactions are the reverse of each other. This is not the case. There are two separate reactions occuring—oxidation of the colorless MB_{rd} form to the blue MB_{ox} form by reaction with oxygen, and reduction of the blue MB_{ox} back to the colorless MB_{rd} by reaction with dextrose.
- Reaction of dextrose with methylene blue in the presence of base results in oxidation of the sugar molecule. The aldehyde or hemiacetal functional group in dextrose is oxidized to a carboxylic acid derivative (gluconic acid or gluconolactone). Oxidation of dextrose in this reaction represents an application of the concept of "reducing sugars" that students may be familiar with from prior biology classes. Dextrose is called a reducing sugar because it acts as a reducing agent in reactions with Cu^{2+} or Ag^{+} ions (recall the Benedict's test and Tollen's test from carbohydrate chemistry). See the *Supplementary Information* section for the mechanism of oxidation of dextrose.
- The reaction times depend on the number of times the flask is shaken. Convenient reaction times are obtained if the pipet is shaken about 10 times. Shaking the flasks 10 or more times gives longer reaction times.
- Hot and cold running water should be suitable for preparing water baths in the 10–40 °C temperature range. Try to keep the temperature of the baths constant within ±1 °C by adding more hot or cold water, as needed.
- It may be helpful to review beforehand the idea that when the rate of reaction increases, the reaction time decreases. Using car travel as an analogy usually clarifies the relationship quite effectively.
- Other redox indicators may be used instead of methylene blue in this reaction. Indigo carmine is green in its oxidized form, yellow in its reduced form. It gives a green–red–yellow color transition with dextrose. (See the "Stop-n-Go Light—Demonstration Kit," Flinn Catalog No. AP2083.) Resazurin undergoes a reversible red–colorless reaction in the presence of dextrose. (See the "Vanishing Valentine Demonstration Kit," Flinn Catalog No. AP5929.)

Connecting to the National Standards

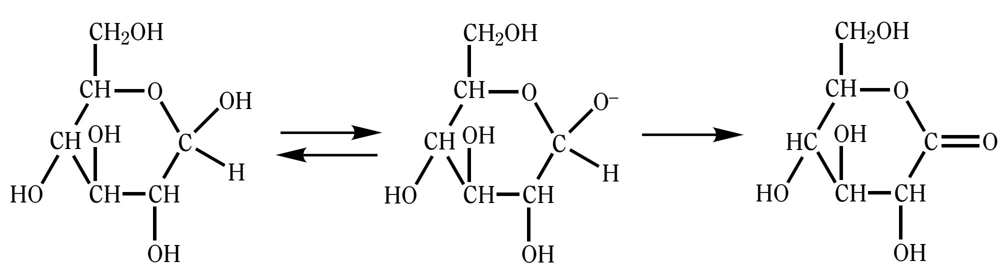
This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement

Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions

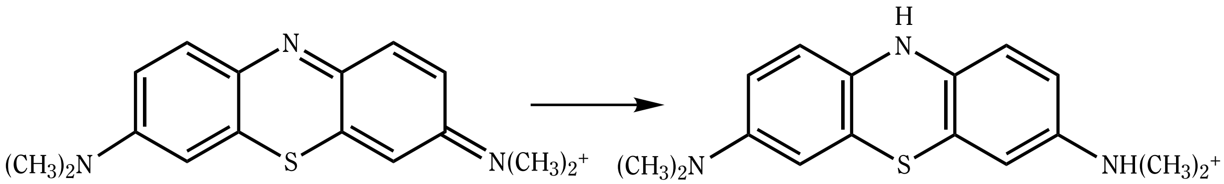
Supplementary Information

Oxidation of dextrose (glucose) in the presence of potassium hydroxide involves an initial acid–base reaction to form the glucoside anion, followed by $2e^-$ oxidation to gluconolactone.



D-Glucose   Glucoside Anion   D-Gluconolactone

The 2e⁻ oxidation of glucose is coupled with the 2e⁻ reduction of methylene blue (MB_{ox}).



Methylene Blue Oxidized Form (Blue)   Methylene Blue Reduced Form (Colorless)

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Reaction Kinetics in Blue* activity, presented by Jamie Benigna, is available in *Effect of Temperature on Reaction Rates*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Reaction Kinetics in Blue* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Introduction to Reaction Rates—The "Blue Bottle" Reaction* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP6446	Introduction to Reaction Rates—The "Blue Bottle" Reaction
AP8653	Feeling Blue Demonstration Kit
AP6049	Flinn Digital Pocket Thermometer, Economy Choice
D0002	Dextrose, Anhydrous, Reagent, 500 g
M0074	Methylene Blue Solution, 1%, 100 mL
P0058	Potassium Hydroxide, Reagent, 100 g

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