Fantastic Four-Color Oscillator

Chemical Demonstration

FLINN SCIENTIFIC CHEM FAX!

Introduction

You won't believe your eyes as you watch this amazing oscillating reaction! This four-color oscillator will get your students' undivided attention as they observe a solution flash from green to blue to purple to red. And that's not all—this four-color cycle will repeat itself for well over an hour!

Concepts

- Oscillating reactions
- Chemical equilibrium
- Kinetics/catalysts
- Reaction mechanisms
- Oxidation–reduction reactions

Materials (for each demonstration)

Solution A, 0.23 M potassium bromate, $KBrO_3$, 250 mL

Solution B, 0.31 M malonic acid, $CH_2(CO_2H)_2$ and 0.059 M potassium bromide, KBr, 250 mL

Solution C, 0.02 M cerium(IV) ammonium nitrate, $Ce(NH_4)_2(NO_3)_6$ and 2.7 M sulfuric acid, H_2SO_4, 250 mL

Solution D, 0.50% ferroin solution, 15 mL

Beaker, 1-L

Graduated cylinder, 250-mL and 25-mL

Magnetic stirring plate and stirring bar

Safety Precautions

A small amount of elemental bromine gas is released from the reactions in this demonstration; adequate ventilation is necessary. Potassium bromate is a strong oxidizing agent and poses a fire risk in contact with organic material; it is a strong irritant and moderately toxic. Malonic acid is a strong irritant, slightly toxic, and corrosive to eyes, skin, and respiratory tract. Potassium bromide is slightly toxic by ingestion and a severe body tissue irritant. Cerium(IV) ammonium nitrate is a strong oxidizer and a skin irritant. Ferrous sulfate is slightly toxic by ingestion and 1,10-phenanthroline is highly toxic by ingestion. Sulfuric acid solution is corrosive to eyes, skin, mucous membrane, and other body tissue. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Place a 1-L beaker on the magnetic stirring plate and place the magnetic stirring bar in the beaker.
2. Pour 250 mL of Solution A and 250 mL of Solution B into the 1-L beaker.
3. Adjust the stirrer to produce a vortex in the solution. The solution may become amber, and will turn colorless after about one minute.
4. Once the solution is colorless, add 250 mL of Solution C and 15 mL of Solution D. (Note: The solution composition is now 0.077 M BrO_3^-, 0.10 M malonic acid, 0.020 M Br^-, 0.0063 M Ce^{4+}, 0.90 M H_2SO_4, and 0.17 mM ferroin.)
5. Keep stirring the green cloudy mixture and it will become a green solution. Over a period of about a minute, the color of the solution will change from green to blue, then to violet, and finally to red-brown.
6. The color of the solution will suddenly return to green, and the cycle will repeat itself more than 20 times, lasting over an hour.

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Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The reaction mixture should be neutralized with sodium carbonate and flushed down the drain with excess water according to Flinn Suggested Disposal Method #24a.

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

Discussion

This oscillating reaction demonstrates the classic Belousov-Zhabotinsky (BZ) reaction which is a cerium-catalyzed bromate–malonic acid reaction. The overall reaction occurring in this demonstration is the cerium-catalyzed oxidation of malonic acid by bromate ions in dilute sulfuric acid. The bromate ions are reduced to bromide ions, while the malonic acid is oxidized to carbon dioxide and water. The overall reaction can be represented by *Equation 1*:

$$3CH_2(CO_2H)_2 + 4BrO_3^- \rightarrow 4Br^- + 9CO_2 + 6H_2O \qquad \textit{Equation 1}$$

The color changes occurring in this demonstration are quite complex. They arise from the oxidation–reduction of the ferroin and cerium ions. A simplified equation to help explain the color changes is shown below in *Equation 2:*

$$\underset{\textit{yellow}}{Ce(IV)} + \underset{\textit{red}}{Fe(II)} \rightleftarrows \underset{\textit{blue}}{Fe(III)} + \underset{\textit{colorless}}{Ce(III)} \qquad \textit{Equation 2}$$

A possible explanation for the appearance of the oscillating colors in solution is provided below; however, a more complete understanding of the color changes might be gained by reviewing the original references.

Green—The yellow Ce(IV) is oxidizing Fe(II) to blue Fe(III); a small amount of Fe(II) has been oxidized to the blue Fe(III) complex; thus, the mixture of yellow and blue forms a green solution. *Blue*—All Ce(IV) is reduced to colorless Ce(III); all Fe(II) is oxidized to the blue Fe(III) complex; thus, the solution is blue. *Violet*—The colorless Ce(III) is reducing the blue Fe(III) complex to the red Fe(II); the mixture of blue and red appears violet. *Red*—All of the blue Fe(III) is reduced to the red Fe(II) complex; colorless Ce(III) is present; the solution appears red.

References

Shakhashiri, B. Z. Chemical Demonstrations: A Handbook for Teachers of Chemistry; University of Wisconsin Press: Madison; 1985; Vol. 2, pp 257–261.

Materials for the *Fantastic Four-Color Oscillator* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP4833	Fantastic Four-Color Oscillator

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