Yellow–Blue Switcheroo

Reaction Pathways

Introduction

Three colorless solutions are mixed to produce a yellow solution that suddenly turns blue and then yellow again. The solution will oscillate between yellow and blue for several minutes. Competing reaction pathways give rise to the regular and repeating color changes. Teachers' favorite!

Concepts

- Oscillating reactions
- Reaction pathways

Materials

Hydrogen peroxide, H_2O_2, 8.6%, 40 mL	Beaker, 250-mL
Potassium iodate solution (acidified), KIO_3, 0.2 M, 40 mL	Graduated cylinders, 50-mL, 3
Starch–malonic acid–manganous sulfate solution, 40 mL	Stirring rod or magnetic stirrer with stir bar

Safety Precautions

Hydrogen peroxide solution is an oxidizer and a skin and eye irritant. Potassium iodate is an oxidizer; the soluton is acidified and contains sulfuric acid. Sulfuric acid is severely corrosive to eyes, skin and other tissue. Starch–malonic acid–manganous sulfate solution is a strong irritant, moderately toxic and corrosive to eyes, skin and respiratory tract. The reaction produces iodine in solution, in suspension and as a vapor above the reaction mixture. The solid iodine is toxic by inhalation. Iodine in solution is irritating to eyes, skin, and respiratory tract. Perform demonstration in well-ventilated room. Avoid all body tissue contact. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Materials Safety Data Sheets for additional safety information.

Preparation

1. Prepare 8.6% hydrogen peroxide solution by diluting 29 mL of 30% H_2O_2 to 100 mL with distilled or deionized water.
2. Prepare 0.2 M acidified potassium iodate solution by adding 10 mL of 1 M sulfuric acid, H_2SO_4, to 90 mL distilled water. Add 4.3 g solid KIO_3 to the diluted acid solution and stir to dissolve.
3. Prepare starch–malonic acid–manganese(II) sulfate solution by boiling 100 mL of distilled water. Add 0.1 g soluble starch to about 5 mL of the boiling water. Stir. Add the resulting starch paste to the remaining boiling water. Stir continuously and boil for 5 more minutes. Allow the solution to cool and then add 1.5 g of malonic acid and 0.4 g manganese(II) sulfate monohydrate, $MnSO_4{\cdot}H_2O$. Stir to dissolve.

Procedure

1. Using a 50-mL graduated cylinder, measure out 40 mL of 8.6% hydrogen peroxide solution and transfer it to a 250-mL beaker.
2. Using a clean 50-mL graduated cylinder, measure out 40 mL of the 0.2 M potassium iodate acidified solution and add it to the beaker. Stir using a stirring rod or magnetic stirrer.
3. Using the third 50-mL graduated cylinder, measure out 40 mL of the starch–malonic acid–manganous sulfate solution. Add this solution to the beaker and stir.
4. Bubbles will begin to appear. In a short period of time, the solution will turn yellow, then blue, and finally colorless. The entire process repeats itself over and over again. The yellow to blue to colorless oscillations will continue for about 10 minutes.

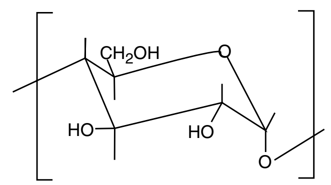
Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The final solution contains iodine and may be disposed of by reduction according to Flinn Suggested Disposal Method #12a.

Tips

- The reaction can also be done using 3% hydrogen peroxide, although the color changes will not be as sharp. Therefore an 8–9% solution is recommended for this demonstration.
- A magnetic stirrer may be used to stir the solution throughout the entire demonstration. Alternatively, mix the solutions well at the beginning and then simply enjoy the oscillations.
- Use only distilled or deionized water. Chloride ions from tap water will contaminate the reaction and stop the oscillations.

Discussion



amylose

This oscillating reaction is known as the Briggs-Rauscher (BR) Reaction and was developed by Thomas S. Briggs and Warren C. Rauscher of Galileo High School in San Francisco. The reaction mechanism is very complex. During the reaction, oscillations occur in the concentration of iodine and iodide ions. The yellowish color is attributed to the rise in I_2 concentration; the blue-black color of the starch–iodine complex results from the rise in both I^- and I_2 concentrations. The colorless solution is caused by the decline in I_2 concentration and the continued rise in I^- concentration.

The blue-black starch iodine complex is amylose-iodine. Amylose is the linear starch fraction that is composed of chains of 1,4 linked α-glucose units as shown above. The color of the complex, blue-black, comes from the pentaiodide anion, I_5^- formed when I_2 and I^- concentration are elevated. Though normally an unstable anion, it becomes stable as a part of the starch complex.

The overall equation for the BR reaction is:

$$IO_3^-(aq) + 2H_2O_2(aq) + CH_2(CO_2H)_2(aq) + H^+(aq) \rightarrow ICH(CO_2H)_2(aq) + 2O_2(aq) + 3H_2O(l)$$

This reaction consists of two component reactions that create an intermediate molecule HOI.

$$IO_3^-(aq) + 2H_2O_2(aq) + H^+(aq) \rightarrow HOI(aq) + 2O_2(g) + 2H_2O(l) \qquad \textit{Equation 1}$$

$$HOI(aq) + CH_2(CO_2H)_2(aq) \rightarrow ICH(CO_2H)_2(aq) + H_2O(l) \qquad \textit{Equation 2}$$

The two reactions are themselves very complex, consisting of ten steps. Iodine (I_2) and iodide ions (I^-) are produced as intermediates in various steps of these reactions.

In the proposed reaction mechanism, the concentration of HOI rises and falls, triggering oscillations in the I^- and I_2 concentrations in solution. When I_2 and I^- concentrations are high, the solution is blue; when I_2 is high and I^- is low, the solution is yellow; and when I_2 is low and I^- is high, the solution is clear.

The oscillations continue until either malonic acid or iodate ions are consumed. A detailed explanation of the reaction is included in the attachment.

Connecting to the National Standards

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

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

Answers to Worksheet Questions

1. Describe what happened in this demonstration.

   Hydrogen peroxide, potassium iodate, and starch-malonic acid-manganous sulfate solution are all added to a beaker. The colorless solution starts to bubble and soon it turns yellow. The solution then turns blue and then colorless, and the process repeats itself for about 10 minutes.

2. This reaction can be divided into two component reactions. Write the equation for each reaction described below.

   a. Iodate ions reacting with hydrogen peroxide and hydrogen ions to form the intermediate molecule HOI.

   $$IO_3^-(aq) + 2H_2O_2(aq) + H^+(aq) \rightarrow HOI(aq) + 2O_2(aq) + 2H_2O(l)$$

   b. The reaction between HOI and malonic acid.

   $$HOI(aq) + CH_2(CO_2H)_2(aq) \rightarrow ICH(CO_2H)_2(aq) + H_2O(l)$$

3. The color of the solution depends on the concentrations of iodine (I_2) and iodide ions (I^-). What color is the solution when:

   a, I_2 is high, I^- is high

   The solution is blue.

   b, I_2 is high, I^- is low

   The solution is yellow.

   c.I_2 is low, I- is high

   The solution is clear.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Yellow–Blue Switcheroo* activity, presented by Irene Cesa, is available in *Reaction Pathways*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Yellow–Blue Switcheroo* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *The Yellow and Blue Switcheroo—Chemical Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP8660	The Yellow and Blue Switcheroo—Chemical Demonstration Kit
H0037	Hydrogen Peroxide, 30%, Reagent, 100 mL
P0064	Potassium Iodate, Reagent, 100 g
S0122	Starch, Soluble, Potato, 100 g
M0091	Malonic Acid, 25 g
M0030	Manganese(II) Sulfate, Reagent, 100 g

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

Detailed Reaction Mechanism

The overall reaction involves the production of HOI, hypoiodous acid, as an intermediate, as shown below.

$$IO_3^-(aq) + 2H_2O_2(aq) + H^+(aq) \rightarrow HOI(aq) + 2O_2(g) + 2H_2O(l) \qquad (1)$$

$$HOI(aq) + CH_2(CO_2H)_2(aq) \rightarrow ICH(CO_2H)(aq) + H_2O(l) \qquad (2)$$

In reaction 1, iodate is reduced by peroxide. There are two competing mechanisms for this reaction: a radical mechanism, 1a, and a non-radical one, 1b.

1a — Radical Mechanism

i. $2IO_3^- + 2HIO_2 + 2H^+ \rightarrow 4IO_2\bullet + 2H_2O$

ii. $4IO_2\bullet + 4Mn^{2+} + 4H_2O \rightarrow 4HIO_2 + 4Mn(OH)^{2+}$

iii. $4Mn(OH)^{2+} + 4H_2O_2 \rightarrow 4Mn^{2+} + 4H_2O + 4HOO\bullet$

iv. $4HOO\bullet \rightarrow 2H_2O_2 + 2O_2$

v. $2HIO_2 \rightarrow IO_3^- + HOI + H^+$

1b — Non-radical Mechanism

i. $IO_3^- + I^- + 2H^+ \rightarrow HIO_2 + HOI$

ii. $HIO_2 + I^- + H^+ \rightarrow 2HOI$

iii. $2HOI + 2H_2O_2 \rightarrow 2I^- + 2O_2 + 2H^+ + 2H_2O$

Reaction 2 takes place by a two-step reaction sequence.

Reaction 2 Mechanism

i. $I^- + HOI + H^+ \rightarrow I_2 + H_2O$

ii. $I_2 + CH_2(CO_2H)_2 \rightarrow ICH(CO_2H)_2 + H^+ + I^-$

When the reactants are mixed, IO_3^- reacts with H_2O_2 to produce a little HIO_2. Once HIO_2, iodous acid. appears, the radical mechanism, 1a, begins. Steps i, ii, and v are fast, resulting in rapid production of hydroiodous acid, HOI. Since reaction 1a is faster than reaction 2 and [I⁻] is low, [HOI] builds up. ❶ HOI can now trigger the production of I⁻ and I_2 (see Figure 1).

HOI is reduced by H_2O_2, (reaction iii of 1b), to produce I⁻. As [I⁻] is produced, ❷, HOI reacts with I⁻, (reaction i of 2), to form I_2. At this point, the solution is still colorless, since I_2 concentration is still low.

As HOI concentration falls, I⁻ and I_2 concentrations continue to increase. [I_2] rises first, turning the solution yellow. As [I⁻] increases, its reaction rate with HIO_2, (ii of 1b) exceeds the rate for radical steps i and ii and the radical process shuts off. Now [I⁻] and [I_2] are high and the solution turns blue, ❸ as I⁻ and I_2 form a complex with starch.

The non-radical process, along with the second step of reaction 2, depletes both I_2 and HOI. As [I⁻] builds up, the solution turns colorless. ❹ At low levels of I_2 and HOI, I⁻ is consumed in steps i and ii of 1b.

At low [I⁻], the rate for steps i and ii of the radical reaction mechanism exceed that for step i of the non-radical one and the radical mechanism takes over. ❺ The process repeats itself and the oscillations continue until either malonic acid or iodate is consumed.

For a more complete discussion of the reaction mechanism, see Shakhashiri and the references therein.

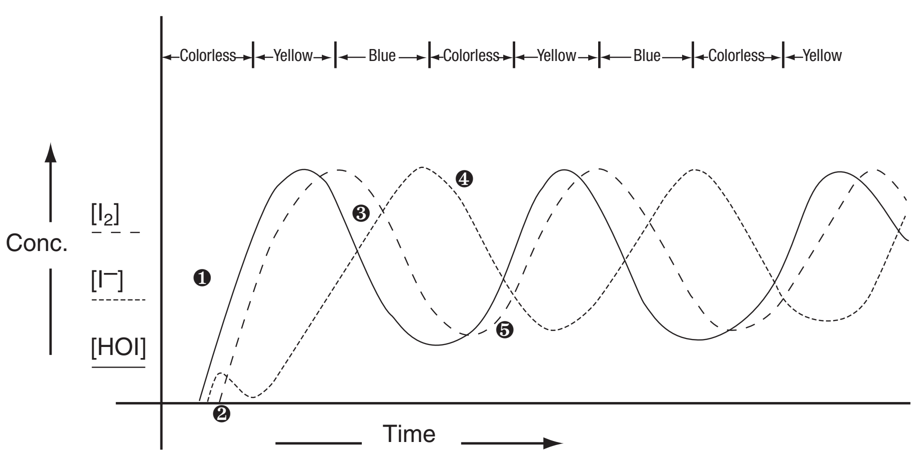


Figure 1.

Yellow–Blue Switcheroo Worksheet

Discussion Questions

1. Describe what happened in this demonstration.

2. This reaction can be divided into two component reactions. Write the equation for each reaction described below.

   a. Iodate ions reacting with hydrogen peroxide and hydrogen ions to form the intermediate molecule HOI.

   b. The reaction between HOI and malonic acid.

3. The color of the solution depends on the concentrations of iodine (I_2) and iodide ions (I^-). What color is the solution when:

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   c.I_2 is low, I- is high