The Roy G Biv Clock Reaction

Chemical Demonstration

Introduction

Take seven different dry chemical mixtures and add each to a separate beaker. Pour a clear liquid into each beaker and, in less than a minute, a rainbow of colors appears.

Concepts

- Clock reaction
- pH indicators
- Buffers

Materials (for each demonstration)

Formaldehyde, HCHO, 37% solution, 7 mL
Isopropyl alcohol, $(CH_3)_2CHOH$, 28%, 140 mL
meta-Nitrophenol, $O_2NC_6H_4OH$, 0.6 g
Phenolphthalein, 0.2 g
Sodium bisulfite, $NaHSO_3$, 60 g
Sodium sulfite, Na_2SO_3, 15 g
Thymolphthalein, 0.1 g
Distilled or deionized water
Beakers, 400-mL, 7
Erlenmeyer flask, 2000-mL
Graduated cylinder, 10-mL
Graduated cylinder, 25-mL
Graduated cylinder, 250-mL
Stirring rods, 7

Safety Precautions

Formaldehyde is a known carcinogen. Formaldehyde is a strong irritant; avoid breathing vapor and avoid skin contact. Formaldehyde is highly toxic by ingestion, inhalation, and skin absorption. This demonstration should be done in a fume hood. Sodium sulfite is moderately toxic and is a possible body tissue irritant. Sodium bisulfite is slightly toxic and a severe irritant to skin and tissue as an aqueous solution. meta-Nitrophenol is moderately toxic by ingestion, inhalation, and skin absorption. It is a body tissue irritant. Phenolphthalein acts as a laxative upon ingestion and is a body tissue irritant. Avoid body tissue contact. 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.

Preparation

To prepare the formaldehyde solution, dilute 7 mL of the 37% formaldehyde solution with 1.7 liters of deionized water in a 2000-mL Erlenmeyer flask. Stir the solution. The final formaldehyde solution concentration is approximately 0.05 M. Prepare this solution at least 2 hours before use in the demonstration.

Dry dye mixtures

- Each dry mixture is a 4-to-1 combination of sodium bisulfite powder, $NaHSO_3$, and sodium sulfite powder, Na_2SO_3, along with various amounts of three indicators: phenolphthalein, thymolphthalein, and *m*-nitrophenol.
- Below is a table lists the rainbow colors and the "recipes" of chemicals.

Color	Red	Orange	Yellow	Green	Blue	Indigo	Pink
Sodium bisulfite, $NaHSO_3$	8 g	8 g	8 g	8 g	8 g	8 g	8 g
Sodium sulfite, Na_2SO_3	2 g	2 g	2 g	2 g	2 g	2 g	2 g
Phenolphthalein	0.1 g	0.01 g	—	—	—	0.01 g	0.01 g
***m*-Nitrophenol**	0.15 g	0.15 g	0.15 g	0.15 g	—	—	—
Thymolphthalein	—	—	—	0.01 g	0.01 g	0.01 g	—

These quantities of dry dye mixtures are enough for at least ten demonstrations. If the amounts of indicator powders

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are too small to weigh, the amounts can be scaled up. The useful shelf life of these mixtures is at least three months or more.

28% Isopropyl alcohol solution

- Mix 60 mL of 70% isopropyl alcohol in a 250-mL graduated cylinder with sufficient deionized water to make 150 mL of solution.

Procedure

1. Set up the demonstration by placing the seven 400-mL beakers, each with a stirring rod, on display. Label the beakers 1–7.
2. Add, in the rainbow color order, 1 gram of each bisulfite/sulfite dry mixture to each 400-mL beaker. For example, add the dry mixture for red to beaker #1, add the dry mixture for orange to beaker #2, and so on.
3. Using a 25-mL graduated cylinder, measure 20 mL of the 28% isopropyl alcohol solution and transfer to each of the 400-mL beakers. Swirl each beaker to dissolve the solids.
4. Once all the solids have dissolved, quickly and carefully fill each beaker to the 250-mL mark with the dilute formaldehyde solution and stir each. The solutions should all be colorless.
5. In about one minute or less, the solutions in the beakers will change to the colors of the rainbow.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The reaction products may all be disposed of according to Flinn Suggested Disposal Method #26b. The formaldehyde solutions may be disposed of according to Flinn Suggested Disposal Method #2. Sodium sulfite/sodium bisulfite dry powder mixtures may be disposed of according to Flinn Suggested Disposal Method #12b. The isopropyl alcohol solutions may be disposed of according to Flinn Suggested Disposal Method #18a.

Tips

- The reaction starts as soon as the formaldehyde solution is added. Fill the remaining beakers as quickly as possible. This will keep the timing of the color changes in the seven beakers close. Another option is to have the formaldehyde solution in seven separate beakers to make the addition quicker.
- Place a white background behind the beakers or place the beakers on a light box to show the colors more effectively.
- A two-hour wait is needed to allow for a sufficient buildup of formaldehyde concentration in solution. In the 37% formaldehyde solution, formaldehyde undergoes polymerization to polyoxymethylene glycols, $HO(CH_2O)_nOH$. When this solution is diluted below a concentration of 4%, the methylene glycols slowly depolymerize to formaldehyde.

Discussion

In this clock reaction, formaldehyde reacts with sulfite ions to form hydroxymethyl sulfonate ions and hydroxide ions.

$$H_2O(l) + HCHO(aq) + SO_3^{2-}(aq) \rightarrow HOCH_2SO_3^-(aq) + OH^-(aq) \qquad \textit{Equation 1}$$

The bisulfite ion is a weak acid and it is in solution with its conjugate base, the bisulfite ion, setting up a buffer condition in the solution.

$$HSO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_3^{2-}(aq) \qquad K_a = 1.07 \times 10^{-7} \qquad \textit{Equation 2}$$

Initially, the solution is slightly acidic, with a pH of approximately 6.4. As the reaction proceeds (Equation 1), sulfite ions are consumed and hydroxide ions are produced. This reduction in sulfite ion concentration causes a shift to the right in Equation 2, producing sulfite ions and hydronium ions (H_3O^+). The hydronium ions, in turn, react with the hydroxide ions to produce water.

$$H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l) \qquad \textit{Equation 3}$$

This buffering action holds the pH of the solution relatively constant until all the bisulfite ions have been consumed. The hydroxide ion concentration then builds up causing a rapid rise in solution pH.

The color changes of the indicators in the solution all occur as the solution pH changes from 7 to 10. Phenolphthalein changes from colorless to red-purple in the pH range of 8.0–9.6, thymolphthalein changes from colorless to blue in the pH range of 9.3–10.6, and meta-nitrophenol changes from colorless to yellow in the pH range of 6.8–8.6. The seven colors of the final solutions are a result of the different combinations of these three indicators.

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 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

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Reference

Shakhashiri, B. Z., *Chemical Demonstrations: A Handbook for Teachers of Chemistry;* University of Wisconsin Press: Madison; 1985; Vol. 4, pp. 70–74.

Materials for *The Roy G Biv Clock Reactions* are available from Flinn Scientific, Inc. A Flinn Chemical Demonstration Kit with enough materials to perform the demonstration seven times is also available.

Catalog No.	Description
AP6280	The Roy G Biv Clock Reaction—Chemical Demonstration Kit
I0021	Isopropyl Alcohol, 70%, 500 mL
F0074	Formaldehyde, 37%, 100 mL
S0047	Sodium Bisulfite, 500 g
S0109	Sodium Sulfite, 100 g
P0017	Phenolphthalein, 25 g
N0088	meta-Nitrophenol, 25 g
T0072	Thymolphthalein, 1 g

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