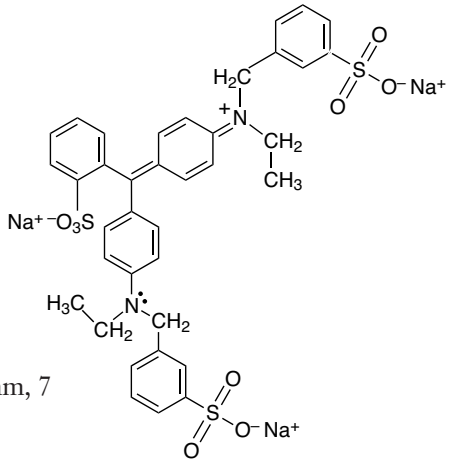
Rainbow out of the Blue

A Colorful Acid–Base Demonstration

FLINN SCIENTIFIC CHEMFAX!

Introduction

Let's make a rainbow out of the blue! Produce a whole spectrum of colors by simply adding blue food dye to varying concentrations of acid solutions.



Concepts

- Acid–base indicators
- Light absorption

Materials

Blue food dye, McCormick®, 7 drops

Hydrochloric acid solutions, HCl, 12 M, 6 M, 3 M, 1 M, 0.5 M, 0.1 M, 20 mL of each

Water, distilled or deionized, 20 mL

Marking pen

Stoppers, size 1, 7

Test tubes, 18 × 150 mm, 7

Test tube rack

Safety Precautions

Hydrochloric acid, both in concentrated form and as dilute solutions, is severely corrosive to all body tissues, especially skin and eyes; inhalation of the concentrated (12 M) vapor may cause lung and throat irritation; it is toxic by ingestion and inhalation. Avoid contact with eyes, skin, and clothing. 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. Label 7 test tubes as 12 M, 6 M, 3 M, 1 M, 0.5 M, 0.1 M, and W (for water). Place the tubes in a test tube rack in order from highest concentration (12 M HCl) to lowest concentration (water only).
2. Add 20 mL of each of the corresponding concentrations of hydrochloric acid solution to each labeled test tube. Add 20 mL of distilled or deionized water to the last test tube.
3. Add one equal-sized drop of McCormick® blue food dye to each tube. Cap each tube with a rubber stopper and invert several times to mix.
4. Observe the colors in the test tubes. A color gradient should be seen in the tubes from red (12 M HCl) to blue (water only) as listed below:

Concentration of HCl (M)	pH	Color
12	–1.1	Red
6	–0.8	Orange
3	–0.5	Yellow
1	0	Yellow–green
0.5	0.3	Green
0.1	1	Green–blue
0 (water)	7	Blue

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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. Dispose of the acid solutions by first diluting to 1 M or lower, neutralizing, and flushing down the drain with an excess of water according to Flinn Suggested Disposal Method #24b. Remember to add the acid to the water when diluting.

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

Tips

- McCormick® blue food dye can be purchased at a local grocer or supermarket. McCormick® blue food dye is the only dye we have found to give the full rainbow of colors, from red in 12 M HCl to blue in water. Other brands of blue food dye may also give a spectrum of colors; however, the ones we tested only gave a rainbow from yellow in 12 M HCl to blue in water.
- An interesting and unexpected phenomenon is observed when a drop of blue food coloring is put in 20 mL of a basic solution. Use any concentration of sodium hydroxide solution, such as 0.5 M, 1 M, or 6 M. Add one drop of blue food coloring. Observe that the solution stays blue for at least 5–10 minutes. After that time, the color begins to change to a violet color and then, oddly enough, to a peach color.

Discussion

The FD&C Blue No. 1 food dye, used in McCormick's blue food coloring, is a complex triphenylene molecule (see the figure on page 1). It reacts with hydrogen ions (H^+) like other more familiar acid–base indicators. The dye is blue in solutions with a pH of approximately 2–14; however, below a pH of 2, the color of the dye in solution begins to shift to the red end of the visible spectrum. As the solution becomes more acidic, the color changes to green to yellow to orange and finally to red at the lowest pH.

Polyenes (compounds containing multiple double bonds) with eight or more conjugated double bonds absorb light in the visible region of the spectrum, absorbing wavelengths of light between 400 and 750 nm. In fact, a general rule is that the greater the number of conjugated multiple bonds, the longer the wavelength at which the compound absorbs light. If a compound absorbs certain wavelengths of light, it transmits the complementary colors and those are the wavelengths that are perceived by the eye. For example, -carotene has a maximum absorption at 497 nm which is a blue–green color. Since this light is absorbed, the complementary color of blue–green, which is red–orange, is transmitted. Thus we perceive βcarotene as red–orange.

Observe the structure of the FD&C dye used in this demonstration (see figure on page 1). There are five active sites on this molecule—three anionic sulfonate groups and two amine groups. The conjugation of the ring system includes one of the sulfonate groups (on the middle ring) and both amine groups. The conjugated system is a resonance-stabilized structure with the two amine groups as the two ends of the conjugated system. One proposed mechanism for the observed color change is a sequential protonation of the three sulfonate groups and then the neutral amine group. The result is a decrease in resonance and a decrease in the number of conjugated double bonds. The smaller number of conjugated multiple bonds in the fully protonated species causes light at shorter wavelengths to be absorbed (see above general rule). Thus, light of longer wavelengths will be transmitted to the eye and, at lower pH values, we perceive the dye in the red end of the visible spectrum.

References

Ealy, J. B.; Ealy, J. L. *Visualizing Chemistry: Investigations for Teachers;* American Chemical Society: Washington, DC, 1995; pp 255–257.

Selinger, B. *Chemistry in the Marketplace*, 4th ed; Harcourt Brace: Sydney, Australia, 1994; pp 607, 611.

Solomons, T. W. G. *Organic Chemistry*, 3rd ed; John Wiley & Sons: New York, 1984; pp 423–426.

Materials for *Rainbow out of the Blue* are available from Flinn Scientific, Inc.

Catalog No.	Description
H0031	Hydrochloric Acid, 12 M, 100 mL
H0033	Hydrochloric Acid Solution, 6 M, 500 mL
H0034	Hydrochloric Acid Solution, 3 M, 500 mL
H0013	Hydrochloric Acid Solution, 1 M, 500 mL
H0035	Hydrochloric Acid Solution, 0.5 M, 500 mL
H0014	Hydrochloric Acid Solution, 0.1 M, 500 mL

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