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Demonstration

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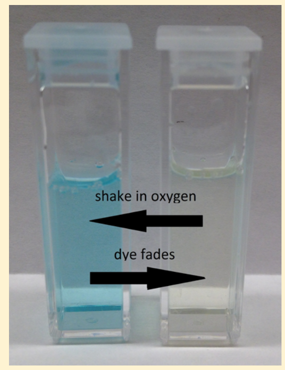
Variations on the "Blue-Bottle" Demonstration Using Food Items That Contain FD&C Blue #1

Felicia A. Staiger, Joshua P. Peterson, and Dean J. Campbell*

Mund-Lagowski Department of Chemistry and Biochemistry, Bradley University, Peoria, Illinois 61625, United States

ABSTRACT: Erioglaucine dye (FD&C Blue #1) can be used instead of methylene blue in the classic "blue-bottle" demonstration. Food items containing FD&C Blue #1 and reducing species such as sugars can therefore be used at the heart of this demonstration, which simply requires the addition of strong base such as sodium hydroxide lye.



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■ BACKGROUND

The "blue-bottle" experiment is a classic demonstration involving the air oxidation of sugars in a basic solution containing methylene or a similar dye, which becomes involved in the redox reaction.[1−4] The initial blue solution fades to colorless as the methylene blue dye is reduced by the sugar. When a bottle containing the faded dye is shaken in contact with air, the blue color temporarily reappears as the reduced form of the dye is reoxidized by oxygen from the air. The same reaction solution can be made to change between colored and colorless many times, enabling repeated observations of the same reaction mixture. Additionally, the demonstration has well-known kinetics that can be studied in high school or collegiate chemistry courses.[1,5,6] A related reaction, reduction of methylene blue by ascorbic acid in acidic media, has also been used to illustrate kinetics in an educational setting.[7,8]

Information about the blue-bottle demonstration was published in this *Journal* in 1963, but its origins extend back in time well before that.[1,3] Since 1963, a number of researchers have explored variations on the core blue-bottle demonstration. Other redox-active dyes have exhibited color changes,[2,9−12] ascorbic acid has been used as a reducing agent,[13] and a source of methylene blue has been identified from pet stores.[13]

Erioglaucine dye, Figure 1, also works well in the blue-bottle demonstration. This dye, also known as FD&C (Federal Food, Drug, and Cosmetic Act) Blue #1 and Brilliant Blue 1, can be present as a pigment in food items.[14] This enables some candies and beverages to be used in blue-bottle demonstrations as commercially available sources of both dye and reducing agents. Unlike most of the dyes traditionally used for this demonstration, FD&C Blue #1 is a triarylmethane dye, similar to dyes such as crystal violet and phenolphthalein. To the authors' knowledge, the only other triarylmethane dye that has been used for this type of demonstration is phenolphthalein.[10,11] The likely reducing agents in the candies and drinks are sugars, although some of these items also contain ascorbic acid. The appeal of these demonstration variations is that they are based on readily available items (e.g., those that can be purchased from grocery and hardware stores), and use of these familiar items can remove difficulties in assembling the demonstrations and can remove some of the mystique that can be associated with the demonstrations.

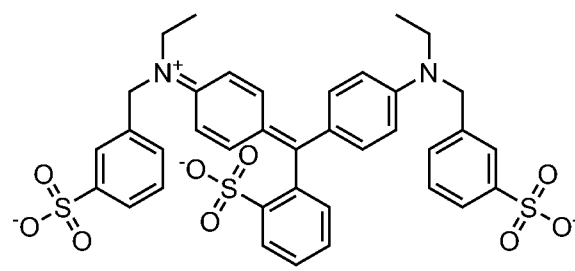

Figure 1. Erioglaucine ion.

■ DEMONSTRATIONS

General Setup

Except where noted, the following experiments were run in screw-top glass vials with a capacity of about 25 mL. The NaOH source and the food item containing both the Blue Dye #1 and the reducing agent were all combined in a capped vial. The total volume of the solutions placed into the vials was 10−

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15 mL so that there was sufficient room for the solutions and the oxygen in the headspace to mix well when the vial was shaken. The vial was initially shaken to disperse the Blue Dye #1 throughout the solution, where it was reduced to the colorless form over a period of several seconds to several minutes. Shaking the sealed vial containing the faded solution mixed in oxygen from the air and reoxidized the Blue Dye #1 back to blue. This cycle of blue fading to colorless and returning to blue by shaking was repeatable, although for each successive cycle, the color faded more quickly by reduction and returned to a less dark blue color upon shaking. Eventually, the Blue Dye #1 faded to the point where the blue color did not return. In many cases, the mixtures turned yellowish over time. This color has also been noted when using methylene blue for the blue-bottle demonstration.[5] One possible source of this color is that some of the sugars are transforming to caramel-type species similar to that observed in acidic conditions.[15] The yellowish solutions also fluoresced with a whitish color when excited with a 405 nm laser pointer, reminiscent of caramel compound fluorescence.[15] More detailed descriptions of specific demonstration experiments follow.

Blue Dye-Containing Drinks

5 mL of blue Gatorade sports drink (Fierce Blue Cherry and Fierce Grape flavors; produced by PepsiCo, Inc., Purchase, NY) and 5 mL of 3 M NaOH were added to a vial. The solution changed between aqua blue and colorless as described in the General Setup. Figure 2 shows a graph of the time-dependent absorbance of a mixture of 1.5 mL of blue Gatorade and 1.5 mL of 3 M NaOH solution in a plastic colorimeter cuvette. Data were collected at three-second intervals using a Vernier LabQuest 2 module[16] and an associated colorimeter set to 635 nm. Each time that the absorbance of the solution approached zero, the contents of the cuvette were mixed using a plastic pipet to reintroduce oxygen and restore the blue color of the mixture. Note the loss in intensity in maximum absorbance over successive mixings as well as the decreasing time intervals between mixings. The inset in Figure 2 illustrates the difference between the blue and faded solutions in the cuvettes.

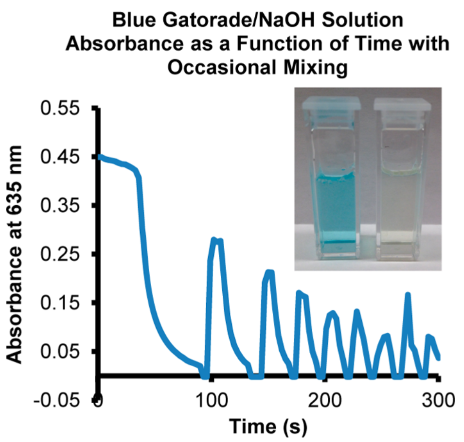

Figure 2. Time-dependent absorbance curve of a mixture of 1.5 mL of blue Gatorade and 1.5 mL of 3 M NaOH solution in a plastic colorimeter cuvette. Data were collected using a Vernier LabQuest 2 module[16] and colorimeter set to 635 nm. The inset shows two colorimeter cuvettes with the blue Gatorade/NaOH mixture: at left, the freshly shaken mixture has returned to blue, and at right, the mixture has turned colorless.

In an effort to maximize the use of household chemicals, sodium hydroxide lye (Rooto Corp., Howell, MI) was used instead of reagent-grade sodium hydroxide. The blue-bottle experiments worked well when (1) 1.5 g of lye was added directly to 50 mL of blue Gatorade, and (2) 1.5 g of lye was first dissolved in 25 mL of water, and then 25 mL of blue Gatorade was added. In both trials, the "colorless" state had a yellowish tint, which was more pronounced at the higher blue Gatorade concentration. When the blue Gatorade drink trials are scaled up from vials to wider bottles, any yellowish tint in the colorless state becomes more obvious to observers due to the greater path length of light through bottles than vials. Using vials or large test tubes diminishes these color tints and seems to make a more attractive demonstration.

Blue powdered Kool-Aid drink mix (blue Fruit Punch and blue Mixed Berry flavors, produced by Kraft Foods Group Inc., Northfield, IL) in NaOH solution also exhibited blue−colorless changes as described in the General Setup, but the mix exhibited inconsistent behavior in the small quantities used in these trials. This could be due to powder inhomogeneity or insufficient quantities of reducing agents in the sugar-free drink mixes. Blue food coloring containing Blue Dye #1 did not exhibit the blue to colorless reversible changes in basic solution unless a reducing agent (e.g., dextrose) was added.

Blue Dye-Containing Candy

One blue SweeTART candy piece (Nestlé Société Anonyme, Vevey, Switzerland) was crushed using a mortar and pestle into a fine powder. A sample of 0.375 g of the powder and 10 mL of 3 M NaOH were added to a vial, sealed, and shaken so that the SweeTART powder could dissolve. The solution changed between light blue and colorless as described in the General Setup.

A box of "rainbow" Nerds candies (Nestlé Société Anonyme, Vevey, Switzerland) was obtained, and the various candy colors were separated. About 6−8 dark green (watermelon-flavored) Nerds candies were then added to a vial along with 10 mL of 3 M NaOH. The vial was sealed and then briefly shaken so that the coating on the Nerds could start to dissolve and turn the solution green. The Blue Dye #1 component of the green solution was reduced to colorless form, but the yellow dye component was apparently unchanged, and so the green solution changed to a yellow color. Shaking the vial restored the blue component, and the solution turned back to green, so this particular system changed between green and yellow as described in the General Setup. When the system was agitated using nitrogen gas from a needle in a capped vial, the color changed from green to yellow and stayed yellow until the nitrogen gas was changed to air or oxygen, providing further support that oxygen was required to change the color back to green.

■ HAZARDS

The solutions of sodium hydroxide used in these demonstrations are typically in the 1−6 M range. Sodium hydroxide, both as a solid and in aqueous solution, is corrosive; contact with eyes can be avoided by wearing goggles, and contact with skin can be avoided by wearing gloves. Make sure that the vials are tightly capped while shaking so solutions do not leak out, and make sure not to accidentally strike anything with the glass vials while they are being shaken. Although the demonstrations

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use food items, spectators should be warned to never eat anything in the laboratory.

■ CONCLUSIONS

The demonstration experiments indicate that a variety of food items that contain Blue Dye #1 can be used in the blue-bottle demonstration. Of the variations explored, the dye-containing drinks are probably easiest to set up because the dyes and reducing agents are both already dissolved in aqueous media. Other relatively unreactive dyes present in the drinks can alter the overall colors in the demonstrations and illustrate that not all of the colors in these experiments are susceptible to fading. For example, combining equal parts green-colored Chillers juice drink (watermelon flavor, produced by Welch Foods Inc., Concord, MA) and 3 M NaOH solution showed color changes between green and yellow. The Blue Dye #1 component of the green solution was reduced to colorless form, but the yellow component (Yellow Dye #5) was apparently unchanged, and so the green solution changed to a yellow color. Shaking the vial restored the blue component, and the solution turned back to green. In a similar example, red food coloring was added to blue Gatorade and sodium hydroxide solution, and the resulting mixture changed between gray−purple and red.

The candy pieces are not already dissolved in solution like the drinks, which can be a drawback. However, the green and yellow color changes associated with the green watermelon Nerds are an attractive variation on the blue-bottle theme. Of course, the name "Nerds" could probably be used to inject humor into the demonstration (e.g., "Here is a Nerd-y demonstration we would like to present."). The green Nerds demonstration was the first to be explored and has been run successfully in multiple outreach settings.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: campbell@fsmail.bradley.edu.

Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) Campbell, J. A. Kinetics − Early and Often. *J. Chem. Educ.* **1963**, *40*, 578−583.
(2) Shakhashiri, B. Z. Reaction of Oxygen with Dextrose: "The Blue-Bottle Experiment". *Chemical Demonstrations: A Handbook for Teachers of Chemistry*; The University of Wisconsin Press: Madison, WI, 1985; pp 142−146.
(3) Lang, C. M.; Showalter, D. L.; Shulfer, G. J. *Yes Virginia...Learning Chemistry Can Be Fun*; University of Wisconsin: Stevens Point, WI, 1989; pp 18−19.
(4) *Tested Demonstrations in Chemistry*, 6th ed.; Alyea, H. H., Dutton, F., Eds.; Journal of Chemical Education; Easton, PA, 1965; p 187.
(5) Anderson, L.; Wittkopp, S. M.; Painter, C. J.; Liegel, J. J.; Schreiner, R.; Bell, J. A.; Shakhashiri, B. Z. What Is Happening When the Blue Bottle Bleaches: An Investigation of the Methylene Blue-Catalyzed Air Oxidation of Glucose. *J. Chem. Educ.* **2012**, *89*, 1425−1431.
(6) Engerer, S. C.; Cook, A. G. The Blue Bottle Reaction as a General Chemistry Experiment on Reaction Mechanisms. *J. Chem. Educ.* **1999**, *76*, 1519−1520.
(7) Mowry, S.; Ogren, P. J. Kinetics of Methylene Blue Reductions by Ascorbic Acid. *J. Chem. Educ.* **1999**, *76*, 970−973.
(8) Snehalatha, T.; Rajanna, K. C.; Saiprakash, P. K. Methylene Blue − Ascorbic Acid. *J. Chem. Educ.* **1997**, *74*, 228−233.
(9) Cook, A. G.; Tolliver, R. M.; Williams, J. E. The Blue Bottle Experiment Revisited. *J. Chem. Educ.* **1994**, *71*, 160−161.
(10) Vandaveer, W. R., IV; Mosher, M. The Blue Bottle Revisited. *J. Chem. Educ.* **1997**, *74*, 402.
(11) Vandaveer, W. R., IV; Mosher, M. Response to Letter to the Editor: The Blue Bottle Revisited. *J. Chem. Educ.* **1998**, *75*, 1067.
(12) North Carolina State University, Department of Chemistry. *Blue-Bottle and Traffic Light Oscillations*. http://ncsu.edu/project/chemistrydemos/Kinetics/Blue%20Bottle.pdf (accessed July 2015).
(13) Wellman, W. E.; Noble, M. E.; Healy, T. Greening the Blue Bottle. *J. Chem. Educ.* **2003**, *80*, 537−540.
(14) Wikipedia. *Brilliant Blue FCF*. http://en.wikipedia.org/wiki/Brilliant_Blue_FCF (accessed July 2015).
(15) Campbell, D. J.; Andrews, M. J.; Stevenson, K. J. New Nanotech from an Ancient Material: Chemistry Demonstrations involving Carbon-based Soot. *J. Chem. Educ.* **2012**, *89*, 1280−1287.
(16) Vernier Software & Technology, LLC. *LabQuest 2*. http://www.vernier.com/products/interfaces/labq2/ (accessed July 2015).

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