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The Color-Changing Sports Drink: An Ingestible Demonstration

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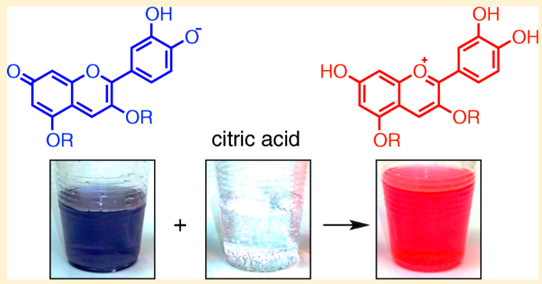
Supporting Information

ABSTRACT: Red cabbage (*Brassica oleracea*) contains anthocyanins that dissolve in water, have antioxidant properties, and have a fairly wide range of color changes owing to changing pH. These characteristics not only make red cabbage useful as an acid–base indicator for pH demonstrations in the classroom but can also be made into a visually dynamic, color-changing, hypotonic "sports drink" that is safe to consume at the end of the experiment. When combined with readily available kitchen ingredients, this experiment is inexpensive, visually compelling, and easily scaled up to allow classroom participation.



KEYWORDS: *General Public, Elementary/Middle School Science, High School/Introductory Chemistry, Public Understanding/Outreach, Acids/Bases*

■ BACKGROUND

Anthocyanins, which are counted among a class of compounds known as flavonoids, are believed to have health benefits, can be used as sunscreens, and are known antioxidants.[1] They are present in the leaves and petals of plants and are highly conjugated, instilling those leaves and flowers with brilliant colors.[2] Anthocyanins also contain hydroxyl groups, which hydrogen bond to other colorless flavonoids present in the plant, serving to modify their colors.[3] Red cabbage contains anthocyanins such as cyanidin, which readily changes color over a wide pH range as its hydroxyl groups are protonated and deprotonated.[4] The four different forms of cyanidin produce a range of colors that change with a change in pH. A solution containing anthocyanins is green at high pH and changes to blue then purple then pink then red as the pH decreases (Figure 1).

The properties of red cabbage as acid–base indicator have been employed in many educational demonstrations over the years,[5] including painting environmentally friendly artwork,[6] making natural dyes,[7] generating colorful patterns,[8] visualizing the electrolysis of water,[9] and producing noxious gases.[10] This particular version relies on the fact that all the chemicals used are commonly found in the kitchen, and so the experiment—like the result of all good recipes—can be safely consumed once complete. When green or red, cabbage solutions are too basic or acidic to consume, respectively, but the middle of the range is quite drinkable. A pinch of baking soda makes the solution a vivid blue, carbonic acid is enough to turn it back to purple, and citric acid will make it pink. Use a colorless soft drink as the source of the carbonic acid, and the end result is a faintly salty, sweet drink with an unusual flavor and a slight acid bite. It has similar ingredients to that of a hypotonic sports drink, and at the end of the experiment, it is perfectly safe to drink as such.

The experiment can be extended by using other plant extracts as the indicator. Mebane and Rybolt have published a very useful table detailing the color changes with pH of 15 natural indicators, including beets; blueberries; cherries; grapes; onions; tomatoes; and the skins of apples, peaches, pears, radishes, rhubarb, and turnip.[11] Herbal teas have been similarly documented.[12]

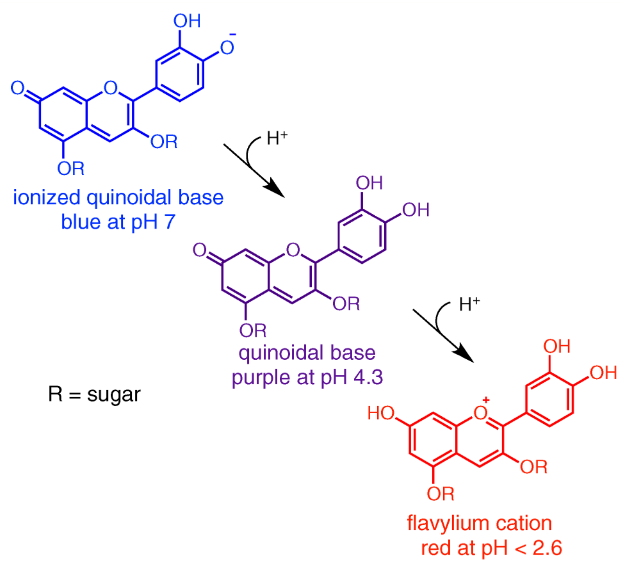


Figure 1. pH-caused transitional forms of cyanidin in red cabbage.

The pK_a of citric acid is 3.09,[13] and the pK_b of sodium bicarbonate is 7.65. The anthocyanins in red cabbage are pink at 3.5 < pH < 4, and blue at 6 < pH < 7. Another good candidate for a color change using kitchen ingredients is blueberries (green to purple at pH ∼5.5), which also perhaps provide a more appropriate flavor for a hypotonic sports drink.

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OVERVIEW

In this experiment, the dramatic color change occurring in the student-made sports drink is a vivid indication that a pH change is transpiring. The indicator may be added to the basic solution in the first glass, while the acidic solution in the other glass remains clear (or vice versa). The students then mix the solutions together and witness the various colors emerging, demonstrating the properties of acid–base mixtures. The students are told that they may consume their newly made beverage. The buffering effect of the citric acid and sodium bicarbonate will prevent the mixture from tasting unbearably tart.

Chemicals and Glassware

All the ingredients and glassware can be bought from a supermarket. Obtain red cabbage, clear soft drink (e.g., Sprite, 7-Up), baking soda, citric acid, two clear glasses for each experimenter, and tap water. Disposable clear plastic cups work well. A list of the required materials for both the red cabbage and blueberry indicator experiments is included in the Supporting Information.

DEMONSTRATION

Extract the color from the red cabbage by chopping up a leaf and adding hot water. This step can be done in a microwave. A purple solution will result. Add 5–20 mL of the indicator solution to one of the glasses, and make up to 1/3 full with water. Add a pinch of baking soda, just enough to make the solution go bright blue. Half-fill the other glass with the clear soft drink, and dissolve about 0.5 g of citric acid in this solution.

The contents of the two glasses can now be mixed in any order and at any speed desired (Figure 2). The clear and the blue solutions combine to make a pink solution, which may be safely consumed by the experimenter. The students should be encouraged to experiment: What happens if they add blue to clear versus clear to blue? What happens if they add the solutions very slowly? What happens if they leave out an ingredient? The full list of required materials and instructions for making the indicator solution is available in the Supporting Information.

Figure 2. The three solutions used in the red cabbage experiment: blue + clear = pink.

Blueberries

With blueberries, the solution is purple in regular tap water and requires the addition of baking soda to lift the pH to induce a color change to green. Soda should be avoided as it is acidic, so the contents of the two glasses should be water and blueberry juice in one, and water, sugar, and baking soda in the other (Figure 3). Much more baking soda is used in this experiment than with the cabbage.

Figure 3. The three solutions used in the blueberry experiment: purple + clear = green.

In addition to cyanidin, blueberries also possess peonidin, delphinidin, petunidin, and malvidin, all of which share the three-ring backbone, and with various sugars attached, the majority of these compounds are water-soluble.[14]

An Authentic Hypotonic Sports Drink

A useful exercise for older students is to get them to work out the concentrations required to make the final solution the equivalent of a commercial hypotonic sports drink.[15] Gatorade is one such drink, and it contains 14 g of sugar per 240 mL. Sprite contains 15.9 g per 150 mL, so to get the same sugar concentration as Gatorade, 130 mL of Sprite (approximately 1/3 of a can) and 110 mL of water should be used. Gatorade also contains 110 mg of sodium per 240 mL, requiring 400 mg of sodium bicarbonate. (Note: This is much more $NaHCO_3$ than required to make the red cabbage extract go blue.) The citric acid must be present in excess to overcome the buffering effect. Perceptive students will notice another ingredient, potassium. This component is not present in any of the ingredients of the color-changing sports drink, and so requires a nonfunctional adulterant. Commercial "lite salt" is a good source of potassium, consisting of approximately equal portions of KCl and NaCl. Because 30 mg of potassium is required, adding the KCl–NaCl mixture will provide some sodium to help offset the amount of sodium bicarbonate needed.

SAFETY

No safety precautions are necessary for this experiment, and it is quite suitable for a kitchen or classroom environment. It should be stressed, however, that this experiment is *not* typical of that performed in most laboratories, and that in a laboratory nothing should be consumed under any circumstances.

VARIANTS

Dry ice will make the blue cabbage solution slowly turn purple, as the carbonic acid neutralizes the sodium bicarbonate. Visually, the color change is subtle, yet the bubbling and fuming of the dry ice is entertaining and it brings home the fact that CO_2 in water is a weak acid. It also makes the drink cold, of course. This experiment should be done as a demonstration only, given the hazards associated with handling the cryogen.

ASSOCIATED CONTENT

Supporting Information

Notes for preparing and using two types of indicators; list of required materials for each experimenter.This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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