Tested Demonstrations

Chemical Demonstrations with Consumer Chemicals: The Black and White Reaction

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Chemical reactions that produce color changes are popular with many audiences. They are especially effective when presented as "chemical magic" demonstrations to arouse interest in science with students or with public audiences of all ages. In connection with our ongoing effort to develop chemical demonstrations using consumer chemicals for public audiences, and particularly for primary and secondary school audiences, we have developed a new color-change reaction with good audience appeal. We wished to employ only consumer chemicals such as might be purchased at a supermarket and are commonly found in the home. Such a reaction would mitigate potential issues surrounding the transportation of chemicals, their use in a public setting, and the disposal of waste. Teachers or demonstrators at the elementary or secondary school level could also perform such a reaction. The use of consumer products also permits stimulating reactions to be carried out in distance learning situations.

The inspiration for this experiment was the "New South Africa" reaction that was published in this *Journal* (*1*). In that experiment, the contents of four beakers containing colored solutions (brown, black, red, and white) are combined simultaneously to afford a clear colorless solution. It seemed possible that a conceptually similar reaction might be produced using only household chemicals, and after some experimentation we were successful. In this demonstration, four glasses of clear, colorless liquids are presented to the audience. Two are combined to give a black mixture. The remaining two are combined to give a white mixture. After questioning the audience as to what might happen if the black and white mixtures are combined, the black and white mixtures are poured simultaneously into an empty glass to afford a clear colorless solution! This experiment is especially effective with younger audiences, particularly at Halloween, when accompanied by an improbable story of witches and ghosts.

The Reactions

Four solutions are prepared in beakers or disposable clear plastic cups. The solutions are designated A, B, C, and D. Solution A contains iodide ion and starch indicator in dilute acetic acid. Solution B contains a small amount of sodium hypochlorite. Solution C contains magnesium sulfate and ascorbic acid (vitamin C). Solution D is a dilute solution of ammonia in water.

When Solutions A and B are combined, iodide ion is oxidized by hypochlorite ion in acid solution to afford elemental iodine according to the following equation:

$$2I^-(aq) + OCl^-(aq) + 2H^+(aq) \rightarrow I_2(aq) + Cl^-(aq) + H_2O$$

The iodine combines with the starch present to yield the deep blue or black starch–iodine complex, resulting in a black mixture.

When Solutions C and D are combined, magnesium ion is precipitated as white magnesium hydroxide by aqueous ammonia according to the equation

$$Mg^{2+}(aq) + 2NH_3(aq) + 2H_2O \rightarrow Mg(OH)_2(s) + 2NH_4^+(aq)$$

Combination of the black (A + B) and white (C + D) mixtures allows the iodine present in the black mixture to be reduced to iodide ion by the excess of ascorbic acid that was originally present in Solution C:

$$I_2(aq) + C_6H_8O_6(aq) \rightarrow 2H^+(aq) + 2I^-(aq) + C_6H_6O_6(aq)$$

Ascorbic acid reacts rapidly and completely with iodine; in fact, the standard assay for ascorbic acid is iodometric titration (*2*). The black color of the starch–iodine complex is discharged as a result. Simultaneously, the magnesium hydroxide precipitate present in the white mixture (C + D) is dissolved by the excess of acetic acid originally present in Solution A:

$$Mg(OH)_2(s) + 2CH_3CO_2H(aq) \rightarrow Mg^{2+}(aq) + 2CH_3CO_2^-(aq) + 2H_2O$$

As a consequence, both the black and the white colors that were present disappear upon mixing, and a clear, colorless solution results.

The demonstration may be conducted either with laboratory reagents or with common consumer chemicals obtained from a supermarket or pharmacy. When consumer chemicals are used, the necessary source of iodide ion is tincture of iodine, sold as a topical disinfectant.[1] White vinegar (dilute acetic acid) provides a satisfactory acid solution for Solution A.[2] Household bleach serves as the source of the hypochlorite in Solution B used to oxidize iodide ion to iodine.[3] Solution C can be prepared from commercially available

vitamin C supplement tablets[4] and Epsom salt.[5] While vitamin C tablets contain some inert and insoluble excipients, the amount is relatively small and the presence of the excipients did not adversely affect the use of the tablets.[6] The vitamin C tablets were simply thoroughly crushed and dissolved in water. The ammonia required for Solution D may be obtained as so-called "clear ammonia", sold as a household cleaner.[7] Liquid laundry starch affords a satisfactory starch indicator. Various brands of laundry starch may be used successfully; however, slight modification of the experimental procedure may be required depending on the brand that is available and the concentration of starch in the particular brand.[8] Because of the potential for variability in the nature and quality of consumer chemicals, the demonstrator must rehearse the demonstration before presenting it to an audience.

Experimental Procedures

Tincture of iodine (USP, 2%), white vinegar (5% acidity), Clorox liquid chlorine laundry bleach, Epsom salt (USP), vitamin C supplement tablets, and liquid laundry starch solution were purchased from a local supermarket and used as purchased. Liquid volumes were measured using Nalgene polypropylene student-grade graduated cylinders or kitchen measuring implements. In addition, a medicine dropper is required for Procedure B. Ascorbic acid (vitamin C) solutions are degraded by oxidation when exposed to air. All solutions must be freshly prepared for best results. For best visibility, Solutions A, B, C, and D should be prepared in transparent containers of approximately 300- to 400-mL capacity. The black and white solutions can then be combined in a transparent container of approximately 500- to 600-mL capacity.

At the conclusion of the experiment, the clear colorless reaction mixture may be safely discharged to the sanitary drains. The reaction containers should be rinsed with water. Careful cleanup and audience control are essential for maximum safety, particularly with audiences of elementary school age.

Procedure A: Reaction Using Laboratory Reagents

A stock solution of household bleach diluted with water is prepared by diluting 15 mL of household liquid chlorine bleach with 45 mL of water. This solution is used in the preparation of Solution B.

Solution A: Dissolve 0.60 g of potassium iodide in 100 mL of 1 M aqueous acetic acid, then add 2.5 mL of 1% starch solution.

Solution B: Add 5 mL of the diluted bleach solution prepared above to 95 mL of water.

Solution C: Dissolve 2.50 g of magnesium sulfate heptahydrate in 100 mL of water, then dissolve 0.75 g of ascorbic acid in the solution.

Solution D: Use 100 mL of 1 M ammonium hydroxide solution.

To perform the experiment, pour Solution B into Solution A with stirring. A black mixture is formed immediately. Then pour Solution D into Solution C. A white mixture is formed in about 5 seconds. To complete the experiment, pour the black and white mixtures simultaneously into a larger container. The mixture will become clear and colorless, apparently identical to the starting solutions.

Procedure B: Reaction Using Consumer Chemicals

A stock solution of household bleach diluted with water is prepared by diluting 1 tablespoon (15 mL) of household liquid chlorine bleach with 3 tablespoons (45 mL) of water. This solution is used in the preparation of Solution B.

A stock solution of vitamin C is prepared by thoroughly crushing and dissolving a 1000-mg vitamin C supplement tablet in 2 tablespoons (30 mL) of water.[9] This solution is used in the preparation of Solutions A and C.

Solution A: Add 2 teaspoons (10 mL) of tincture of iodine to 6 tablespoons (90 mL) of white vinegar. Add dropwise with stirring just enough of the vitamin C stock solution to discharge the iodine color, then add $\frac{1}{2}$ teaspoon (2.5 mL) of starch solution.

Solution B: Add 1 teaspoon (5 mL) of the diluted bleach solution prepared above to 6 tablespoons (90 mL) of water.

Solution C: Dissolve $\frac{1}{2}$ teaspoon of Epsom salt in 5 tablespoons (75 mL) of water, then add the entire remaining quantity of the vitamin C stock solution.

Solution D: Use 7 tablespoons (105 mL) of clear household ammonia.

To perform the experiment, pour Solution B into Solution A with stirring. A black mixture is formed immediately. Then pour Solution D into Solution C. A white mixture is formed in about 5 seconds. To complete the experiment, pour the black and white mixtures simultaneously into a larger container. The mixture will become clear and colorless, apparently identical to the starting solutions.

Hazards

Tincture of iodine USP 2%, also known as "mild tincture of iodine", was used in these experiments.[10] Tincture of iodine, chlorine bleach, and ammonia are poisonous. Tincture of iodine contains 50% ethyl alcohol and is flammable. Tincture of iodine, chlorine bleach, and ammonia must not be combined with each other, or with any other chemicals in any way, other than *exactly* according to the means detailed in the procedures. Other combinations involving these chemicals could result in the formation of hazardous by-products or gases. All chemicals and the reaction mixtures must be kept away from the audience (particularly children) at all times. Safety glasses must be worn when handling these or any other chemicals. Adequate ventilation must be ensured when handling ammonia solutions.

Notes

1. Tincture of iodine 2% USP contains 0.08 M I_2 and 0.16 M sodium iodide in a solution of ethyl alcohol and water. It is prepared by dissolving 20 g of iodine and 24 g of sodium iodide in 500 mL of 95% ethyl alcohol and diluting the mixture to one liter with water.

2. White (clear) vinegar is a colorless dilute solution of acetic acid in water. A 5% concentration is typically marketed for kitchen use. This corresponds to 0.9 M acetic acid as determined by acidimetric titration. Other varieties of vinegar, such as wine vinegar and cider vinegar, are not colorless and are therefore not suitable.

3. Household liquid chlorine bleach is a 5.25% solution of sodium hypochlorite in water. This corresponds to 0.7 M sodium hypo-

chlorite by iodometric titration. Recently, household liquid chlorine bleaches containing 6% sodium hypochlorite have appeared on the retail market. This does not affect this demonstration because only a very small amount is used.

4. Tablets marked "chewable" or "flavored" should not be used. They contain much higher quantities of additives, including colors, sweeteners, and flavors, which could interfere with the reaction.

5. Epsom salt USP is essentially pure magnesium sulfate heptahydrate.

6. For example, a 250-mg nonchewable vitamin C tablet was found to have a mass of 295 mg. It contains 250 mg, or 1.4 mM, of ascorbic acid and 45 mg of excipients.

7. Household ammonia as sold for use as a general cleaner is a dilute solution of ammonia in water. For this demonstration, so-called "clear" ammonia should be used. It is a clear, colorless liquid with no added dyes, detergents, or fragrances. Ammonia solutions labeled "sudsy" or "scented" should not be used. The actual concentration of ammonia in household ammonia cleaner is usually not stated by the manufacturer. Acidimetric titration has shown that the concentration varies among brands from approximately 1 to 2 M. This has not had a noticeable effect on the outcome of the demonstration.

8. Linit brand laundry starch was used as purchased. "Concentrated" liquid starches, such as STA-FLO concentrated liquid starch, may be used if the amount of starch solution used in the preparation of Solution A is reduced to 5 drops. One checker was successful in using spray starch to prepare Solution A. A 1% or 0.5% laboratory starch solution may also be used. If starch solution is not available, a satisfactory solution may be prepared by stirring 5 g (1 to 2 tsp) of cornstarch with 30 mL (2 tbsp) of cold water until a uniform thin suspension is formed. This suspension is poured slowly into 500 mL (2 cups) of *vigorously* boiling water with stirring so that the boiling does *not stop*. The solution is allowed to cool before use.

9. A stronger solution, containing 7% iodine, may be available in some locales but is not suitable for use in this demonstration without modification of the experimental procedure. A product with a similar name, "tincture of iodides", also known as "decolorized iodine", is sold in some areas. It likewise is not suitable for this demonstration without modification of the experimental procedure.

10. If the vitamin C stock solution is unacceptably turbid after thorough crushing and stirring of the vitamin C tablet in water, the solution may be filtered. This is best accomplished by using a cone-style (Mellitta) coffee filter cut to a top opening diameter of about 3 to 4 cm to minimize the amount of solution lost in wetting the filter. Basket-style coffee filter papers do not work well.

Literature Cited

1. Ellsworth, J. F. *J. Chem. Educ.* **2000,** *77*, 484–485.
2. *The United States Pharmacopeia USP 24*; National Publishing: Philadelphia, PA, 1999; p 160.