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Classroom Activity Connections: Demonstrating Various Flame Tests Using Common Household Materials

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Members of our American Chemical Society local section student group at Spring Arbor University have presented a modification of Sanger's *JCE* Classroom Activity #67, "Flame Tests: Which Ion Causes the Color?" (*1*, see also *2*) to children at local schools and during our summer science camp. In Activity #67, students conduct flame tests by dipping cotton-tipped swabs saturated with dilute muriatic acid (3 M HCl) into household ionic salts and then burn the alcohol/salt mixture in a flame. After conducting a number of tests, students determine whether it is the cations or anions in the salts that are responsible for the colors observed. Because it is difficult for younger students to distinguish whether it is the cations or anions responsible for the flame colors, we have modified the activity to let children focus on the colors emitted by various elements when burned. We have also extended the activity by performing large-scale flame tests for children. While we are aware of (and have used) other methods to produce large-scale flames *(3−5)*, we usually perform these large-scale flame tests using only common household items to keep the demonstrations consistent with the theme of Activity #67. Below, we describe extensions to Sanger's activity that we have employed.

Hazards

The large-scale flame tests should only be performed in a well-ventilated area or in a hood. During the large-scale flame tests, some unreacted isopropyl alcohol falls onto the ground and should be wiped up with a paper towel. The paper towel should be rinsed with water and discarded in the trash. The audience should be at least 10 feet from the demonstrator; do not aim the spray at the audience.

Extension 1: Large-Scale Flame Tests with Household Items

To enable students to more easily see the colors emitted by various elements, we dissolve household materials in mixtures of water and isopropyl alcohol, and pour the resulting solution into a spray bottle. When the solution is sprayed as a very fine mist onto a flame generated by a wind-resistant grill lighter,[1] a large flame is produced. The flame color depends upon the element present in the household item dissolved in the isopropyl alcohol−water mixture (Table 1). We provide children with crayons and black and white copies of the periodic table (see the supporting information), and instruct students to color in the box of the element tested with the color of the flame observed. It should be noted that conducting large-scale flame tests in this manner using isopropyl alcohol is more challenging than the more commonly used methanol *(3)*. This is because methanol burns with a faint blue flame through which light emitted from elements is easily seen, while isopropyl alcohol burns with a bright, sooty, yellow flame that obscures light emitted from the elements.[5] This difference likely arises because methanol completely combusts in air, while isopropyl alcohol does not *(6)*. Because lower fuel/oxygen ratios support complete combustion *(7−11)*, we add water to the isopropyl alcohol solutions to lower this ratio, support more complete combustion, and enhance the visibility of the light emitted from elements. Unfortunately, competing effects are at work: higher amounts of water increase visibility of emission from the elements, but also tends to put out the flame from the lighter. Some adjustments to the specific ratio of isopropyl alcohol/water are occasionally required.

Extension 2: Iron in Sparklers

We have students dip cotton-tipped swabs that have been saturated with 70% isopropyl alcohol into a pile of iron filings,[6] and subsequently observe the burning of the iron on the swabs. The resulting flame releases orange-yellow sparks reminiscent of those given off by sparklers. (See Figure 1A for an example.) This extension allows students to correctly predict *(12)* that iron is contained in sparklers.

Extension 3: The Blue Flame

When discussing the chemistry of flame colors, students and parents alike often ask where the yellow-orange, blue, and purple colors in campfires or candle flames come from. We respond that these colors come from the element carbon.[5] We encourage students to observe these colors by examining the flame produced by a lit cotton-tipped swab that has been dipped in 70% isopropyl alcohol alone. To vividly illustrate the beautiful blue color emitted by flames produced by burning carbon-containing compounds, we light a portable propane torch for all to observe and discuss how propane and most fuels contain a large amount of carbon. We have also found it useful to spray a 50/50 mixture of 70% isopropyl alcohol and water (Table 1) onto a lighted grill lighter. Although the flame produced by the latter does contain a large proportion of yellow color, we almost always observe significant blue-purple color in the diluted isopropyl alcohol flame.

Extension 4: Festive Birthday Candles

Candles that burn with colored flames (Figure 1B−E) are available[7] *(13)*. One or more inorganic salts (Table 2) or other compounds are dissolved in these candles to produce a variety of colored flames *(14, 15)*. We have students light these candles and use the periodic tables they have previously colored (see Extension 1)

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Table 1. Preparation of Isopropyl Alcohol Solutions and Resulting Flame Colors

Element	Preparation: Materials and Steps	Flame Colors
Boron	1. Mix 2 tsp boric acid (H_3BO_3) and 1/2 cup of 91% isopropyl alcohol (C_3H_8O). 2. Spray lightly into flame. 3. Look for light green fringes when flame dies down.	Orange, yellow, and light green
Carbon	1. Mix equal amounts of 70% isopropyl alcohol (C_3H_8O) and water.	Orange, blue, and purple
Sodium	1. Mix equal amounts of 70% isopropyl alcohol (C_3H_8O) and water. 2. Saturate with baking soda ($NaHCO_3$).	Orange
Potassium	1. Mix equal amounts of 70% isopropyl alcohol (C_3H_8O) and water. 2. Saturate with cream of tartar ($KC_4H_5O_6$). 3. Add 1 Tbsp of vinegar.	Orange and lavender
Calcium	1. Mix equal amounts of 70% isopropyl alcohol (C_3H_8O) and water. 2. Saturate with deicer ($CaCl_2$).	Dark orange, perhaps a little red
Copper	1. Place 1 cup of ammonia and 1 copper (Cu) scouring pad in a closed container.[a,b] 2. Shake 1 min or until solution turns blue. 3. Add one part blue solution to two parts 70% isopropyl alcohol (C_3H_8O).	Light green, perhaps a little blue
Strontium	1. Mix equal amounts of 70% isopropyl alcohol (C_3H_8O) and water. 2. Mix in 1 strontium citrate supplement[c] [$Sr_3(C_6H_5O_7)_2$]. 3. Add 1 Tbsp of vinegar.	Red

[a] We have also used pennies as a source of copper for this reaction. If pennies are used, longer shaking times are required for the formation of the copper complex. See Note 2 in the text. [b] $CuSO_4$, which is sold in some hardware stores, may be used as a source of dissolved copper. See Note 3 in the text. [c] Strontium citrate tablets are available as nutritional supplements. See Note 4 in the text.

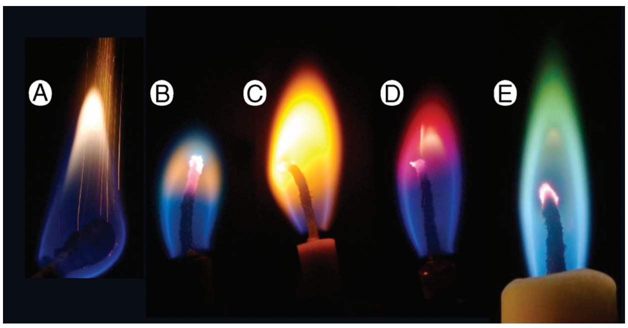

Figure 1. Flame colors produced from burning chemical elements as described in the text. (A) Isopropyl alcohol and iron filings mixture burned on a cotton swab. Flames of festive candles in B–E contain (B) cesium; (C) sodium; (D) lithium; and (E) copper. Elements in (B–E) were identified by collecting the emission spectrum of each candle's flame and finding the best match with line spectra data found at the NIST Atomic Spectra Database Lines Form Web site at http://physics.nist.gov/PhysRefData/ASD/lines_form.html (accessed Jun 2010).

to predict which element(s) might be responsible for the flame color.

Table 2. Possible Elements Used in Colored Flame Birthday Candles *(7, 8)*

Main Element Present	Flame Color
Lithium	Red/pink
Boron	Green
Sodium	Yellow/orange
Aluminum	Blue
Potassium	Lavender/orange
Calcium	Red-orange
Vanadium	White
Copper	Green/blue
Gallium	Purple
Rubidium	Red
Strontium	Red
Indium	Indigo-blue
Antimony	White
Cesium	Blue/purple
Barium	Yellow green

Notes

1. We have also placed a lighted tea light candle in an aluminum pie pan, which in turn is placed on a large plastic garbage bag on a table in a well-ventilated area and sprayed solutions on to the flame from a distance of 2 feet. The latter method works best to observe the light green boron flame.
2. The blue color is due to the tetraammine copper(II) complex formed in the reaction between copper and ammonia: $Cu^{2+} + 4NH_3 \rightarrow Cu(NH_3)_4^{2+}$ *(15, 16)*. We have also used pennies as a source of copper for this reaction. If pennies are used, longer shaking times are required for the formation of the copper complex. Students enjoy observing, participating in, and learning about the chemistry behind the preparation of this and many other solutions listed in Table 1.
3. One reviewer of this manuscript noted that $CuSO_4$, which is sold in some hardware stores, can be used as a source of dissolved copper, and that this may be especially useful to avoid spraying ammonia, with its irritating fumes, in front of a young audience.
4. Strontium citrate tablets are now being sold as supplements intended to promote the growth of strong, healthy bones. Many online purveyors offer these supplements; for one example, see Better Health International at http://betterhealthinternational.com/strontium.asp (accessed May 2010).
5. The orange-yellow color comes from light emitted by hot particles of soot produced in the burning process. The blue color results from a mixture of light given off from short-lived CH and C_2 radicals produced during the burning of carbon containing compounds *(7–11)*.

6. Fine steel wool that is cut into tiny pieces with a pair of scissors serves as a good source of iron filings.
7. If you cannot find these at your local grocery, crafts, or paper goods store, try ordering color flame candles online. Here are two possible vendors: Chinaberry, at http://www.chinaberry.com/prod.cfm/pgc/12100/sbc/12106/inv/11897/tid/808020803; or Wilton, at http://www.wilton.com/store/site/product.cfm?id=C7BDAA26-1E0B-C910-EA2602E19F87D70D&killnav=1 (both accessed May 2010).

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Supporting Information Available

A printable periodic table for students to add their observations is available. This material is availablevia the Internet at http://pubs.acs.org.

