Final version published as: Canal, J. P., Sharma, R. D., & Tailor, H. N. (2019). A Convenient, Effective, and Safer Flame Demonstration. *Journal of Chemical Education*. DOI: 10.1021/acs.jchemed.8b01010

A Convenient, Effective, and Safer Flame Demonstration

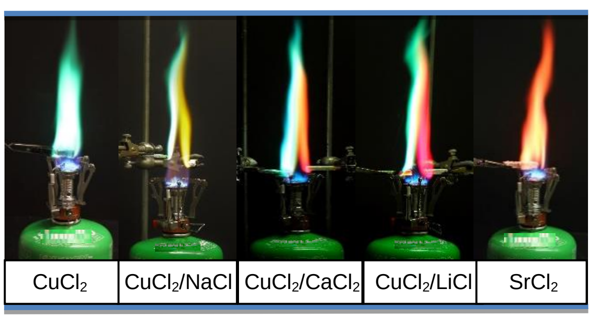
John P. Canal*, Rajendra Dev Sharma, Hamel N. Tailor

Department of Chemistry, Simon Fraser University, Burnaby, British Columbia, V5A 1S6

ABSTRACT

The well-described flame demonstration illustrates different aspects of energy, electronic transition, atomic structure, and the electromagnetic spectrum. Burning salts dissolved in a solvent produces visually appealing and vividly colored flames but many incidents have been reported from improper use of solvents and further use of this method has been strongly discouraged. Although alternative approaches have been developed to address some of the safety concerns, they do not match the convenience of use and vibrant colors produced using this new method. Presented, is a new approach on the standard flame demonstration that mitigates all concern regarding solvent use and restores the convenient aspects and brilliance of color of the traditional flame demonstration without compromising safety.

GRAPHICAL ABSTRACT



KEYWORDS

Audience: High School/Introductory Chemistry, First-Year Undergraduate/General, Second-Year Undergraduate

Domain: Demonstration, Inorganic Chemistry, Public Understanding/ Outreach, Safety/Hazards

Topics: Atomic Spectroscopy, Descriptive Chemistry

INTRODUCTION

The flame demonstration has a long history with many variations on the procedure. The flame demonstration, also known as the rainbow demonstration or rainbow flame test, is visually appealing and used by instructors to display atomic emission phenomena that occurs in common items such as neon lights and fireworks.[1,2] Topics of quantum theory of matter, descriptive chemistry, and elemental analysis are also reinforced by this demonstration.[3] In their work on the student understanding of atomic emissions, Bretz and Mayo reported that between 1928 and 2015, the *Journal Chemical Education* alone published 32 different methods for this test.[4]

A review of the methods listed illustrated that all variations of the demonstration rely on the same principle: a salt is introduced into a flame to generate the atomic emission (or colored flame).[4] The differences lie in the source of the flame and the matrix holding the salt. The most common method requires an accelerant such as methanol to be used.[5] A small amount of salt and ~10 mL of methanol is placed on a Petri or ceramic dish and the methanol is ignited. Although this method results in a strongly colored and visually appealing flame, its use has been strongly discouraged due to the numerous incidents with injuries that have occurred.[6,7] In a thorough review of the safety concerns on this demonstration, Sigmann reported that between 1998-2017, there were 32 documented accidents with 164 people injured.[6,7] To address and improve the safety, the *American Chemical Society* released a video highlighting a method that removed methanol but this approach only allows for showing one color at a time.[8,9] A recent publication in *Education in Chemistry* promoted the replacement of methanol with ethanol, but incidents resulting in injury have also been reported using this solvent.[7,10]

CRITERIA

To make this flame demonstration practical and safe, we devised a list of criteria.

Controlled Burning: The flame should be controlled, meaning a flame that can be extinguished by a “flip of a switch” and not only through fire suppression methods. The demonstration should also be easy to start and stop.

Low Risk: The salt matrix should not be a solvent.

Brilliant Color: The demonstration should have a brightly colored flame, visible by all audience members and all colors are observable simultaneously to emulate a "rainbow".

Convenient setup/cleanup: The demonstration should be quickly prepared with an easy post demonstration clean up.

Portable: The materials for the demonstration should be compact and easily handled and transported, allowing the demonstration to be performed outside of the university chemistry lecture or laboratory setting.

Long lasting: The demonstration should produce observable color for a relatively long time (i.e. more than 2 minutes).

Embrace Green Chemistry Principles: The demonstration should embrace principles of green chemistry such as generating little to no waste and preventing unwanted safety incidents.[11]

The alternative method presented here satisfies the above criteria. Our new method uses strips of an insulating firebrick as the matrix to support the salt, and the source of the flame is either an ultralight camping stove or a refillable butane micro burner (See Figure 1).

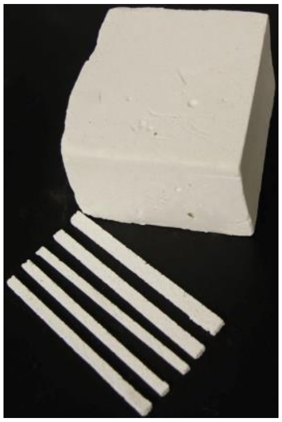


Figure 1. Porous ceramic brick cut into strips.

MATERIALS

The supplies required for this demonstration are readily available, inexpensive, and include:

- Soft insulating aluminosilicate firebrick cut into strips
- Hacksaw and dust mask

- Ultralight camping stove with a replaceable mixed butane/isobutene/propane fuel bottle or a refillable butane micro burner (The term "burner" will be used to mean either device)
- Saturated aqueous solutions of lithium chloride (LiCl), sodium chloride (NaCl), potassium chloride (KCl), calcium chloride ($CaCl_2$), copper chloride ($CuCl_2$), and strontium chloride ($SrCl_2$).
- Self-closing tweezers
- Pipettes/dropper bottles (Glass pipettes/droppers required if placed in the flame)
- Lab stand, clamp, matches/flint torch striker (optional)
- An appropriate (BC or ABC) fire extinguisher should be available with any demonstration involving a flame.

The micro burner, butane refill cylinder and the ultralight camping stove can be purchased through www.amazon.ca.[12-14] The soft insulating aluminosilicate firebrick are common in fireplace masonry and can be purchased through www.amazon.ca or at most local home centers.[15] The brick should be tested to ensure that it does not give any competing background emissions. The hacksaw and blade is available at any local home center.[16] The local availability of the fuel bottle for the ultralight camping stove is listed on the manufacture's website.[17]

PREPARATION

An aluminosilicate firebrick was chosen as the substrate since it did not interfere with the emission color. The optimal dimensions of the firebrick strips are 0.4 cm (d) x 1.0 cm (w) x 3.0 cm (l). These dimensions are obtained by cutting a slice of the smallest face of the firebrick and then cutting that piece into strips. A length of 3.0 cm is easy to handle and not prone to breakage. The strips may be stored in individually labelled plastic tubes (such as centrifuge tubes) to prevent breakage and cross contamination for reuse. Preparation time is minimal (eight strips in 10 minutes).

Saturated stock test solutions were prepared and stored in labeled plastic bottles. The approximate masses of salt dissolved in distilled water required to create saturated solutions are: 80 g $CaCl_2$, 150 g $CuCl_2$, 115 g LiCl, 44 g KCl, 45 g NaCl and 200 g $SrCl_2$ per 100 mL of water.[9] Barium chloride ($BaCl_2$) was not used in our study due to its increased toxicity but others might not find its use objectionable.[9]

Using a labelled pipette, 5-8 drops of the specific saturated salt solutions were applied to a firebrick strip. Drops were added until the strip was saturated but not dripping. The strips were either left to air dry for later use or immediately placed in the flame. As the strip is porous and all sides becomes saturated, the orientation of the 0.4 cm or 1.0 cm face in the flame is irrelevant.

Alternately, solid salt crystals can be placed directly on a wider strip using a scoopula and replaces the need for saturated solutions. Both methods generate equally brilliant flames, but when using the dry set up care must be taken not to spill the salt. Dampening the strip with distilled water can aid in adhesion of the dry salt crystals to the strip. The firebrick strip can be hand held in the flame using the self-closing tweezer or by using a lab stand and clamp (Figure 2).

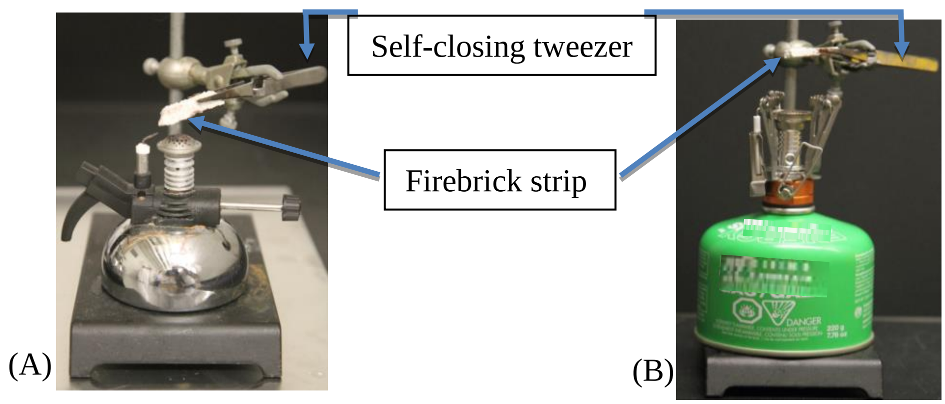


Figure 2. (A) The butane micro burner setup and (B) the ultralight camping stove setup.

The strips can be easily “recharged” by adding more drops of the specific saturated solution (or solid salt crystals) after removing them from the flame. Complete cooling of the strip is recommended and the “charged” strip can be immediately returned to the flame. Charging strips while they are in the flame should be avoided as drops landing on the burner will evaporate and clog the burner head. After the demonstration, the burner should be turned off and everything allowed to cool prior to storage. All items can be placed in a storage box for future use.

PRESENTATION

The demonstration is appropriate for both large and small audiences. The smaller micro burners have successfully been used in a lecture hall with a capacity of 60 people. With its much larger flame, the ultralight camping stove is suitable for larger spaces and audiences. If only one burner is available, different salts can be introduced into the flame one at a time. If resources permit, six burners can be placed side-by-side and colored flames emulating a rainbow can be generated simultaneously. (See Supporting Information for a side-by-side video). The duration of the emissions varied but typically lasts for at least two minutes. The colors generated are fuchsia (LiCl), yellow (NaCl), lilac (KCl), orange/red ($CaCl_2$), blue/green ($CuCl_2$) and red ($SrCl_2$), as shown in Figure 3 and 4.

Figure 3. The colored flame in the order of fuchsia (LiCl), yellow (NaCl), lilac (KCl), orange/red ($CaCl_2$), blue/green ($CuCl_2$) and red ($SrCl_2$) (via the ultralight camping stove)

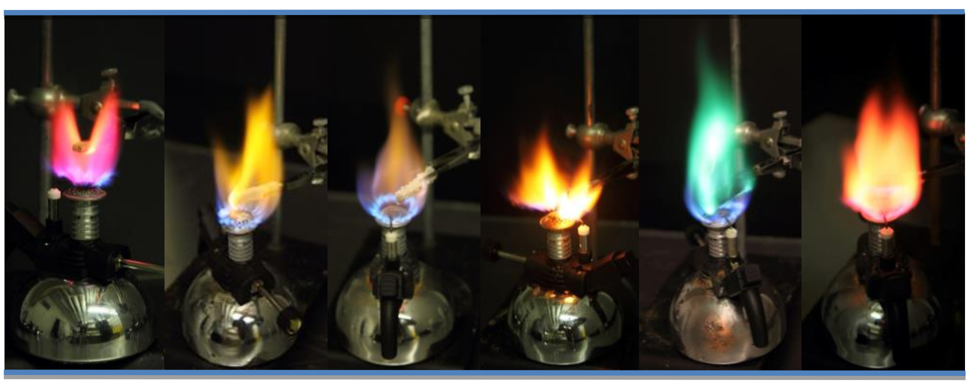


Figure 4. The colored flame in the order of fuchsia (LiCl), yellow (NaCl), lilac (KCl), orange/red ($CaCl_2$), blue/green ($CuCl_2$) and red ($SrCl_2$) (via the micro burner)

Multi-colored Flame

In a modified procedure, two firebrick sticks each containing a different salt were simultaneously exposed to the flame, resulting in a two-colored flame (See Figure 5). Mixing various salts in this

Figure 5. The mixed colored flame from saturated firebrick sticks containing $CuCl_2$ (blue/green)/NaCl (yellow), $CuCl_2$ (blue/green)/$CaCl_2$ (orange/red), $CuCl_2$ (blue/green)/LiCl (fuchsia), LiCl (fuchsia)/$SrCl_2$(red), NaCl (yellow)/LiCl (fuchsia), NaCl(yellow)/$CaCl_2$ (orange/red).

manner can generate a third color as seen with $CuCl_2$ (blue/green)/LiCl (fuchsia) (Figure 6). The blue/green of the $CuCl_2$ emission combine with the fuchsia emission of LiCl to generate the yellow color at their boundary. A multi-colored flame is not possible with many previously published methods.

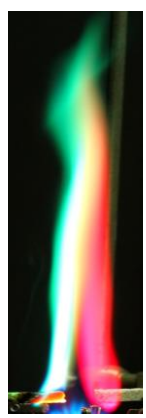


Figure 6. The three-colored flame (green/ blue, yellow and fuchsia) from saturated firebrick sticks containing $CuCl_2$ (blue/green)/LiCl (fuchsia).

The "Burners"

Two types of burners were used and each has advantages. The compact re-fillable (butane) micro burner makes the demonstration very portable. The trade-off is a smaller flame. The ultralight camping stove canister on the other hand cannot be re-filled, but it provides a larger and more brilliant flame. Although the ultralight camping stove is larger, it is approximately half the cost of the micro burners. An even larger propane camping stove was tested, but the resulting colored flame was of not as brilliant as with the other two burners used.

HAZARDS

Before the commencement of any chemical demonstration, it is advisable to review the *American Chemical Society (ACS) Safety Guidelines for Chemical Demonstrations*.[18] Standard safety procedures should be followed, but the most significant hazard of this demonstration was eliminated by removing flammable solvents as the matrix for introducing salts into the flame. When handling the salts and preparing the saturated salt solutions, chemical splash goggles, nitrile gloves, and proper lab attire should be worn. Cutting the soft insulating firebrick generates dust and wearing a dust mask is recommended. Dust can be minimized by having the brick slightly damp.

The demonstration should be performed a minimum of 3 m from the audience. A safety shield is recommended. The demonstrator should wear a flame retardant/resistant lab coat, safety goggles, and possibly heat resistant gloves. The demonstration should be performed only with adequate ventilation (laboratory air changes recommended) as fumes from some of the salts can cause respiratory irritation.[19-24] The demonstration set up should be kept away from flammable and/or combustible materials and an appropriate fire extinguisher available. Allow the burner, firebrick, and tweezers to cool before handling and storing.

Care should be taken when refilling the micro burners with butane. The burners should never be refilled when hot, in the presence of an audience or from a large butane container. Additionally, burners should always be refilled away from any heat or ignition sources as jetting of the butane can occur. An appropriate fire extinguisher should be available and proper safety glasses and gloves worn.[25-27]

DISCUSSION

The published procedures have their advantages, but none offer improvement in all aspects of the demonstration as outlined by our experimental criteria – controlled burning, low risk, brilliant color, convenient setup/clean up, portable, long lasting and green.[4,9]

Low Risk/Controlled Burning: Our method has a strong safety advantage as we only employ a controlled flame. This differs from many of the other methods, where the flame is only extinguished through the consumption of the flammable material or through the employment of fire suppression methods. This method can also be stopped and restarted in seconds.

Brilliance of color: The improved safety features did not come at the expense of the visual experience of the demonstration. Rather this method retains the brilliance of color found in many of the published demonstrations. This includes the method of burning methanol in a ceramic dish containing a salt.

Convenience setup/cleanup and Green: After an initial time investment to assemble the supplies for this procedure, such as to cut the firebrick and make the saturated solutions, very little time is required to run this demonstration. As the ultralight camping stove or micro burner, firebrick strips, pipettes, tweezers and solution bottle are all repeatedly used, this method has only two consumables: the fuel for the burners and the saturated solutions. Both consumables are easily and quickly replaced.

Long lasting: Since the matrix for the salt in not consumed, this allows for longer demonstrations. This provides a degree of flexibility in performing this demonstration, as one can easily alter its length to ensure all audience members have time to view it.

Portable: Given its compact set-up, this demonstration is very portable and allows the flame demonstration to be easily and safely performed outside of the chemistry department setting to engage the general public and all students.

Pedagogical Application

The preliminary results from a separate, unpublished study by one of the authors (JPC) shows that student understanding of energy transfer and atomic emission phenomena was improved by viewing this demonstration. The students that took part in the study (n = 91) attended class on a campus without a laboratory set up and so the inclusion of this demonstration in the study was only possible due to the improved safety of the method and portability presented here. The students in this study were all non-science university students in their final year of courses. The improvements were ascertained by (1) the results of a student survey (see Figure 7) and (2) improved scores on standardized short-answer exam questions, which related color and energy transfer.

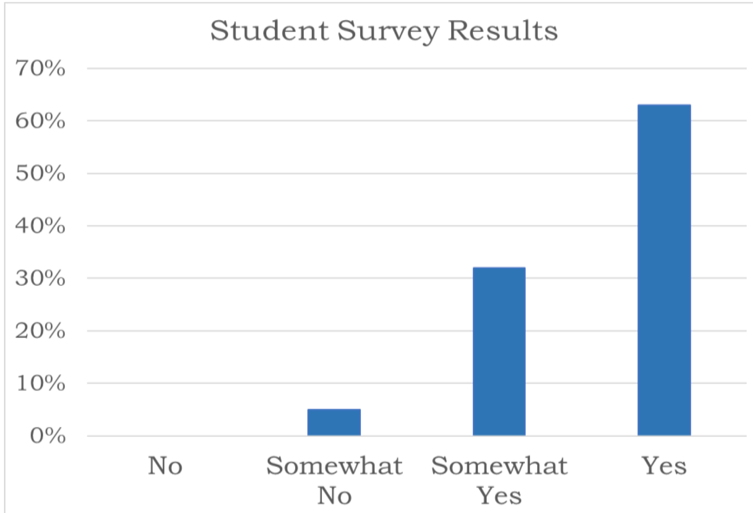


Figure 7. Results of the student survey: “Did this demo help in your understanding of energy transfer?”.

CONCLUSION

Historically, the rainbow flame test has been used for both pedagogical purposes and to impress an audience, but incidents with injury made it too risky for classroom demonstrations. By using an insulting firebrick as the salt matrix and a portable burner as the flame source, we have introduced a new approach that is low risk, convenient, portable, and greener. This method generates a visually appealing flame and allows for mixed colored emissions. With the safety concerns addressed, the rainbow flame test can now be used as an effective teaching tool in our repertoire of demonstrations. With our new method, which eliminates the flammable solvent matrix, this demonstration can continue to inspire learners.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX.

The Supporting Information consist of two compressed files. One file (Images_Flame.zip) contains images of the single colored and mixed colored flames. The second file (Video_Flame.zip) consists of videos of the single colored and mixed colored flames.

AUTHOR INFORMATION

Corresponding Author

*E-mail: jcanal@sfu.ca

ACKNOWLEDGMENTS

The authors would like to thank the Department of Chemistry at Simon Fraser University (SFU) for financial support.

REFERENCES

1. Wilson, E. K. What's that Stuff? Fireworks. *C&EN* **2017**¸ 95(27), 24-25. DOI: 10.1021/cen-09527-scitech3
2. O'Hara, P. B.; Engelson C.; St. Peter, W. Turning on the Lights: Lessons from Luminescence. *J. Chem. Ed.* **2005**, 82, 49-52. DOI: 10.1021/ed082p49
3. Gouge, E. M. A Flame Test Demonstration Device. *J. Chem. Educ.* **1988,** 65, 544-545. DOI: 10.1021/ed065p544
4. Bretz, S.T.; Mayo, A. V. M. Development of the Flame Test Concept Inventory: Measuring Student Thinking about Atomic Emission. *J. Chem. Educ.* **2018,** 95, 17-27. DOI: 10.1021/acs.jchemed.7b00594
5. Ragsdale, R. O.; Driscoll, J. A. Rediscovering the Wheel. The Flame Test Revisited *J. Chem. Educ.* **1992**, 69 (10), 828−829. DOI: 10.1021/ed069p828
6. Hill, R. H. Jr. Safety Alert: The Rainbow Demonstration. *Chem. Eng. News.* **2014**, 92(11), 43.
7. Sigmann, S. B. Playing with Fire: Chemical Safety Expertise Required. *J. Chem. Educ.* **2018**, 95 (10), 1736-1746. DOI: 10.1021/acs.jchemed.8b00152.
8. A Safer "Rainbow Flame" Demo for the Classroom. https://www.youtube.com/watch?v=kkBFG1mTSBk (accessed June 18, 2019).
9. Emerson, J. M. New and Improved -- Flame Test Demonstrations ("Rainbow Demonstration") https://www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/safetypractices/flame-tests-demonstration.pdf (accessed June 18, 2019).
10. Fleming, D. The Rainbow Flame Demonstration. *Educ. Chem.* [Online access] https://eic.rsc.org/exhibition-chemistry/the-rainbow-flame-demonstration/3009399.article (accessed June 18, 2018).
11. 12 Design Principles of Green Chemistry https://www.acs.org/content/acs/en/greenchemistry/principles/12-principles-of-green-chemistry.html (accessed June 18, 2019).
12. Micro Burner (Global Market) https://www.amazon.ca/Global-Market-MF-2001-DS-Portable-Burner/dp/B07D21FQ6K/ref=sr_1_9?keywords=micro+burner&qid=1551818049&s=gateway&sr=8-9 (accessed June 18, 2019).
13. Butane (Ronson) https://www.amazon.ca/Ronson-Multi-Fill-Ultra-Butane-Fuel/dp/B078H

638YL/ref=sr_1_4?keywords=butane&qid=1551818126&s=gateway&sr=8-4 (accessed June18, 2019).

14. Ultralight Camp Stove (Reehut) https://www.amazon.ca/Ultralight-Portable-Camping-Outdoor-Backpacking/dp/B01MG66UV5/ref=sr_1_6?keywords=ultralight+camping+stove&qid=1557343224&s=gateway&sr=8-6 (accessed June 18, 2019)
15. Insulating Firebrick (Amaco 28035N) https://www.amazon.ca/Amaco-28035N-Insulating-Firebrick-Size/dp/B007VEOIVA/ref=sr_1_5?keywords=firebrick&qid=1551817623&s=gateway&sr=8-5-spell (accessed June 18, 2019)
16. Stanley 24T Bi-Metal Hacksaw Blades 10 ct. Pack https://www.walmart.com/ip/Stanley-24T-Bi-Metal-Hacksaw-Blades-10-ct-Pack/19284317 (accessed June 18, 2019)
17. Optimus https://www.optimusstoves.com (accessed June 18, 2019)
18. ACS Safety Guidelines for Chemical Demonstrations https://www.acs.org/content/dam/acsorg/education/policies/safety/divched_2018_safetyflyer2pager_proof1.pdf (accessed June 18, 2019).
19. LiCl MSDS https://www.fishersci.co.uk/store/msds?partNumber=10578430&productDescription=250GR+Lithium+chloride+anhydrous%2C+Certified+AR+for+analysis&countryCode=GB&language=en (accessed June 18, 2019).
20. NaCl MSDS https://fscimage.fishersci.com/msds/21105.htm (accessed June 18, 2019).
21. KCl MSDS https://www.fishersci.com/shop/msdsproxy?productName=P21710 (accessed June 18, 2019).
22. $CaCl_2$ MSDS https://fscimage.fishersci.com/msds/03901.htm (accessed June 18, 2019).
23. $CuCl_2$ MSDS https://fscimage.fishersci.com/msds/05625.htm (accessed June 18, 2019).
24. $SrCl_2$ MSDS https://fscimage.fishersci.com/msds/21980.htm (accessed June 18, 2019).
25. Butane Refill MSDS http://eurotool.com/ftp_files/MSDS_Sheets/Micro_Therm_Torch_Butane_Refill.pdf (accessed June 18, 2019).
26. How to use your portable butane micro burner video https://www.carolina.com/teacher-resources/Interactive/how-to-use-your-portable-butane-micro-burner-video/tr39543.tr (accessed June 18, 2019).
27. RK4203-Micro Burner & Stove https://www.youtube.com/watch?v=fX_n7lPWfB0 (accessed June 18, 2019).