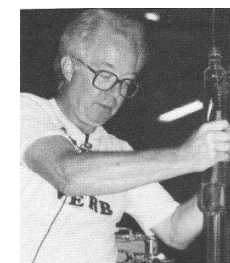
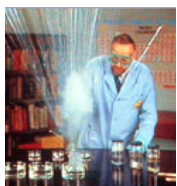
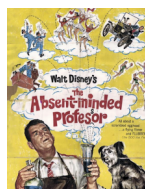
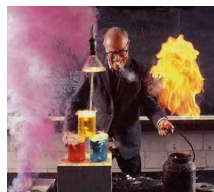


Chemical Demonstrations: The good, the bad, and the ugly

David A Katz

**Chemist, Educator and Consultant
Tucson, AZ, USA**

<http://www.chymist.com>



Chemical demonstrations are a part of the history of chemistry – this is how chemistry was taught 200 years ago.



Some demonstrations are safer than others



Unfortunately, when a chemist or chemical educator brings demonstration materials into a classroom or lecture hall, the immediate reaction of the audience is “What are we going to blow up today?”



Everyone wants their 5 seconds of fame

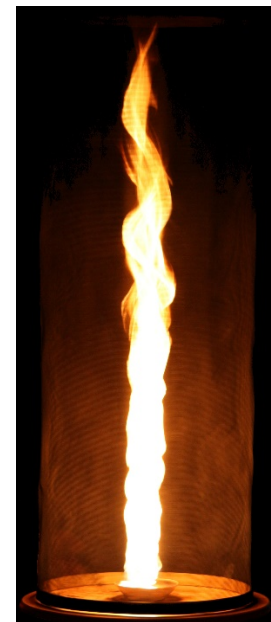
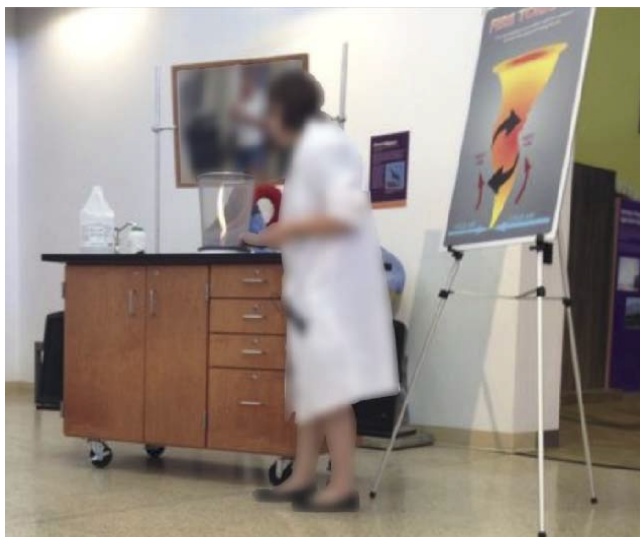
Diet Coke and Mentos



In April 2015, a teacher in the UK demonstrated the burning of liquid methane by pouring it onto the floor of the classroom



On Sept. 3, 2014, a demonstrator at a museum in Reno, Nev., was attempting to create a colored “fire tornado” when she poured methanol from a 4-L container onto a smoldering cotton ball.



On Oct. 30, 2015, a teacher and 5 students, at a Fairfax, VA high school, were burned, some seriously, when she poured methanol onto a still burning “rainbow flame” demonstration.

On Sept. 15, 2014, a teacher at a high school in Denver was demonstrating flammable properties when he poured methanol from a 4-L container onto an open flame.

On Oct. 20, 2014, a Cub Scout group trying to produce a green flame poured methanol-containing antifreeze from a 355-mL bottle onto a fire in Raymond, Ill.

On Oct. 31, 2014, high school students in Chicago were also using methanol to create a green flame



Calais Weber was 15 years old when her chemistry teacher poured methanol from a 4-L bottle onto an open flame during a flame test demonstration in 2006. Weber suffered burns over 40% of her body.



Almost a proper rainbow flame demonstration.

“I came very close to dying from my injuries,” Weber said at an Oct. 30 press briefing about CSB’s new safety bulletin. “My greatest fear is that eventually there will be a child [who] won’t be as lucky as I was to have survived.”

On chemical demonstrations, she takes a harder line than CSB. She said:

“It is my belief that until there exists a standard mandatory protocol for training all science teachers, there is no reason for methanol to be used in classrooms. My education and love for chemistry were not fostered by seeing a demonstration in person, and it would not have been hindered by simply watching a video of it being performed in a controlled setting by trained chemists”

The problem in these demonstrations is blamed on methanol.

Why methanol?



Methanol burns with a pale blue flame.

In normal room light, that flame may not be very visible, but that is not a reason to ban methanol from the classroom or from chemical demonstrations.

Chemistry uses chemicals

- Every chemical has some degree of hazard, although some are essentially negligible.
- Don't ban chemicals because they are flammable or corrosive – each chemical must be evaluated for the demonstration, any vapors produced, and disposal hazards.
- Don't ban a demo due to inexperienced demonstrators.
- Demand that presenters are properly trained in demonstration techniques.



Even water can be dangerous

Active learning

A report by Scott Freeman and colleagues in the Proceedings of the National Academy of Sciences (*Proc. Natl. Acad. Sci. USA* 2014, DOI: 10.1073/pnas.1319030111) reported that students get better grades and fail less when professors use active-learning methods in the classroom.

Active learning in the classroom can utilize a number of methods including demonstrations, mini-experiments, active hands-on activities, clickers, small group discussions, and more depending on an instructor's methodology.

Minimum Safety Guidelines for Chemical Demonstrations

American Chemical Society Division of Chemical Education

Chemical Demonstrators Must:

- 1. Know the properties of the chemicals and the chemical reactions involved in all demonstrations presented.**
- 2. Comply with all local rules and regulations.**
- 3. Wear appropriate eye protection for all chemical demonstrations.**
- 4. Warn the members of the audience to cover their ears whenever a loud noise is anticipated.**
- 5. Plan the demonstrations so that harmful quantities of noxious gases (e.g. NO₂, SO₂, H₂S) do not enter the local air supply.**
- 6. Provide safety shield protection wherever there is the slightest possibility that a container, its fragments, or its contents could be propelled with sufficient force to cause personal injury.**
- 7. Arrange to have a fire extinguisher at hand whenever the slightest possibility for fire exists.**
- 8. Not taste or encourage spectators to taste any non-food substance.**
- 9. Not use demonstrations in which parts of the human body are placed in danger (such as placing dry ice in the mouth or dipping hands into liquid nitrogen).**
- 10. Not use "open" containers of volatile, toxic substances (e.g. benzene, CCl₄, CS₂, formaldehyde) without adequate ventilation as provided by fume hoods.**
- 11. Provide written procedure, hazard, and disposal information for each demonstration whenever the audience is encouraged to repeat the demonstration.**
- 12. Arrange for appropriate waste containers for and subsequent disposal of materials harmful to the environment.**

Additional safety guidelines from Flinn Scientific Inc.

http://www.flinnsci.com/media/396174/l678_ms_scisafetyart.pdf

- 1. Always practice all demonstrations before performing them in front of students. A demonstration should only be attempted after all the potential pitfalls and hazards have been identified.**
- 2. Never attempt a demonstration that will place you or your students at risk.**
- 3. Have students wear safety goggles or use a safety shield if there is the slightest possibility that a container, its fragments or its contents could be propelled with sufficient force to cause personal injury. A good rule of thumb is if heat or pressure are involved, audience protection is required.**
- 4. If heat is involved in the demonstration, make sure all glassware is borosilicate (e.g., Pyrex®) glass and check for chips and cracks before using.**
- 5. If a flammable liquid is used in a demonstration, make sure to cap all reagent bottles after dispensing the appropriate quantities and be aware of heat sources and flammable vapors. Never repeat a demonstration using flammable liquids until all containers and surfaces are cool to the touch.**
- 6. Use fresh chemicals and clean glassware to prevent possible contamination.**
- 7. All demonstrations should have an educational objective. If the demonstration uses toxic chemicals or a potentially hazardous procedure, review the demonstration again and be sure it has educational benefits.**
- 8. Always ensure that electrical devices are properly grounded and inspect every electrical circuit before turning the current on.**

Safety Guidelines from CCCS

Chemical Demonstrators must:

1. Be familiar with the chemical properties and reactions involved in all demonstrations. Always wear appropriate personal protective equipment.
2. Perform a risk assessment and practice the demonstration before presenting it in front of students or the public.
3. Demonstrators and observers should always wear safety goggles and/or use a safety shield if there is any possibility of splashes or a violent reaction that could propel chemical or debris with sufficient force to cause personal injury.
4. If heat and/or pressure are involved in the demonstration, use temperature resistant glass and check for scratches, cracks, or chips before beginning.
5. When using flammable liquids, keep all containers closed and isolated from potential ignition sources, and make sure a fire extinguisher is immediately available if there is any possibility of a fire.
6. Do not use “open” containers of any volatile or toxic substance without appropriate ventilation (such as a laboratory hood).
7. If transporting chemicals, follow all US DOT regulations for packaging and labeling of chemicals (consult the Hazardous Materials Table, 49CFR172.101). Always provide secondary containment for transported liquids.
8. Do not perform demonstrations in which parts of the human body are placed in danger (such as placing dry ice in the mouth or dipping hands in liquid nitrogen). Never taste or have observers taste any non-food substance.
9. Provide detailed written information on the complete procedure whenever the audience is encouraged to repeat the demonstration, including how to dispose of any residues.
10. Plan for and dispose of any chemical by-products of the demonstration properly in compliance with all regulations.
11. All electrical devices and circuits must contain an easily accessible on-off switch.

CSB Recommendations

Implement strict safety controls—written procedures, training, and personal protective equipment—when lab demonstrators are handling hazardous materials.

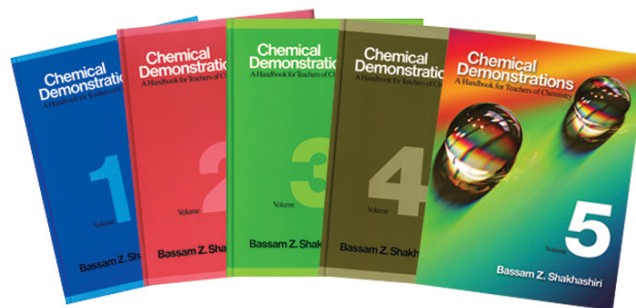
Conduct a thorough hazard review before performing any activity with flammable chemicals.

Avoid using bulk containers of flammable liquids in education demonstrations—separately dispense only the amount needed.

Provide a safety barrier between any activity involving flammable chemicals and the audience.

Sources of chemical Demonstrations

- Books
- YouTube demos
- TV shows such as America's Funniest Home Videos encourage stupidity
- TV news shows often show home-made or YouTube videos



Reference: Katz, David A., *Science Demonstrations, Experiments, and Resources*, *Journal of Chemical Education*, **68**, 235, March 1991.

Why some demonstration books, YouTube, or TV videos are dangerous

Little or no instructions

No safety guidelines (or limited or outdated safety information)

Non-informed viewers try to duplicate “cool” demos

Accidents don’t happen to me

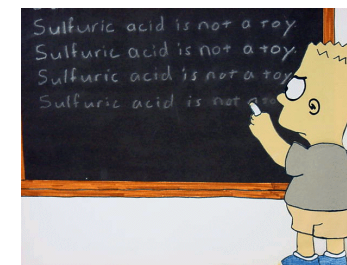
Chemicals not always measured

Bigger is not better

No disposal information



Sulfuric acid and sugar



What the safety guidelines, many books, and most videos don't tell you

- Safety shields may be required
- Never pour from bulk containers
- Use small quantities of chemicals and flammable liquids
- Pre-measure chemicals. Have just enough chemicals for the demo or activity in appropriate sized containers
- Close containers after measuring materials
- Move containers away from the demo
- Keep a back-up supply if needed
- Repeat any demo from the start – do not try to replenish a reaction in progress
- Small may be better – just project it onto a large screen



Each demonstration or activity must have some educational value

While there can be a great deal of entertainment value to a demonstration, or a series of demonstrations, each demonstration or activity should have some educational value.

Explain the principles to the audience or guide them to discovery.

Where does one learn chemical demonstrations?

Chemical demonstrations are usually observed and shared at conferences such as ChemEd, BCCE, ICCE, NSTA, and regional conferences.

Most presenters are responsible and observe proper safety precautions.

Some presenters are not.

In the 1980's there were programs that taught chemical demonstrations

ICE (Institute for Chemical Education)

Hope College

Dreyfus

Some journals (J. Chem. Educ., Education in Chemistry, and NSTA) include chemical demonstrations.

Some schools do teach demonstrations to prospective teachers.

Flinn Scientific has produced both safety and demonstration videos.

There is no current national program that teaches chemical demonstrations and proper demonstration techniques.

Guidelines for successful demonstrations

- **Know what you are working with. (Read and understand the SDS.)**
- **Use proper laboratory glassware (*e.g.*, borosilicate glass).**
- **Inspect all equipment and apparatus, especially glassware for cracks or chips.**
- **When doing demonstrations, materials must be organized.**
- **Provide for proper ventilation.**
- **Practice your demo.**
- **Repeat, if necessary, to illustrate principles being taught, not just for “fun” (*e.g.*, multiple hydrogen balloon explosions)**

Guidelines for successful demonstrations

- **When using a volatile and flammable liquid, keep it covered. Do not allow it to stand in the open air for any period of time, especially if it is to be ignited (or if flames will be used nearby).**
- **If a demo does not work, make sure there is no possibility of any fire or reaction. Move everything to a safe location. Start fresh.**
- **Reactions work different when quantities are changed or increased. (Understand the kinetics involved.)**
- **Things can go wrong, no matter how well you prepared – make sure that all necessary safety materials are available.**

Gloves

Not necessary for every demonstration.

Must have a good fit.

Must have good dexterity for handling all materials.

Appropriate for materials being used.

Latex or nitrile gloves should be adequate for most materials in demonstrations.

(Check glove compatibility data or charts)

Must be changed when contaminated.



Eye Protection

**Essential for the demonstrator
AND for any assistants.**

Splash goggles preferred.

**Proper fit required.
(There are small sized goggles available)**

**Note: Eye protection is best cleaned
with soap or detergent and water.**

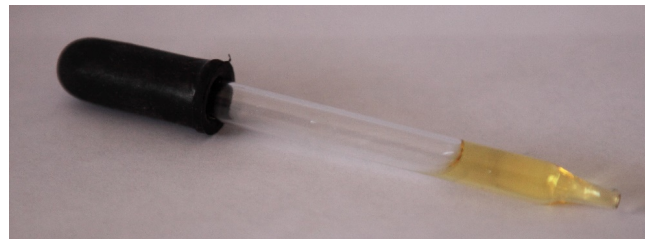


Spills

Contain apparatus to prevent, or minimize, spills.

Not every spill is a large one.

Clean up spills promptly.



Colored flames



Wood splint soaked in solution of chemical salt.



Wire or wood splint with small amount of solid chemical.



Anhydrous salt aspirated into air jet of Bunsen burner.



Color flame candles



Chemistry crayon labels

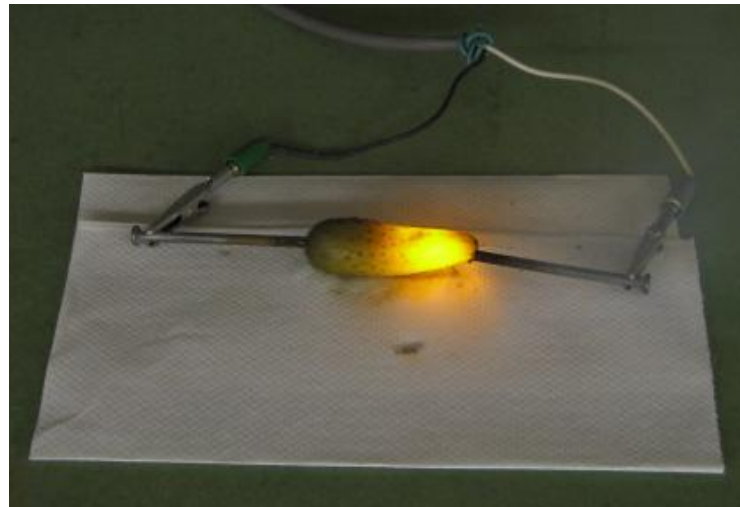
Conductivity Testing

- Fit the apparatus with a momentary switch.
- Use a battery powered conductivity tester.



Electric pickle

Electrical circuits must have an on-off switch or a momentary switch.



Perform this demo on an elevated support or on a non-flammable surface.

Methanol Cannon

- **DO NOT USE A SCREW CAP** on the bottle.
- Only after the bottle is corked, should the igniter be attached. This prevents any sparks when adding the methanol.
- **DO NOT HOLD THE BOTTLE** when igniting the methanol-air mixture.
 - Stand the bottle up on a table **BEHIND A SAFETY SHIELD**.
 - If the bottle is laid on its side, the bottle itself can become a projectile.
- If the reaction does not work, there was not sufficient methanol, or too much methanol in the bottle. There is no safe way to determine that.
 - Methanol burns with a blue flame that is not obvious to the experimenter. There is a strong possibility that there could be a flame in the bottle.
 - DO NOT, UNDER ANY CIRCUMSTANCES, ATTEMPT TO ADD ADDITIONAL METHANOL TO THE BOTTLE** unless you are absolutely positive that there is no flame in the bottle.
 - The better procedure would be to have a second bottle available.



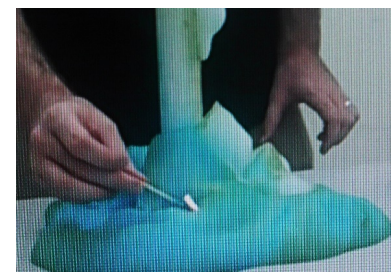
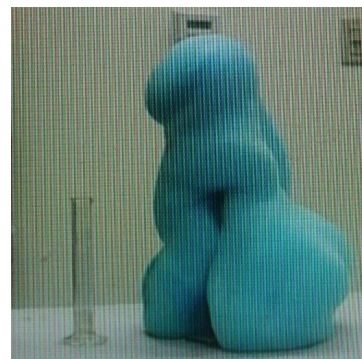
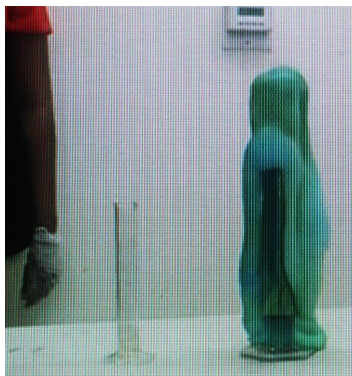
Dry ice in a 2-Liter bottle

Why you do not want a screw top on a 2-Liter bottle.



Elephant's Toothpaste Demo

Depending on recipe, 6% to 30% hydrogen peroxide is used.



Demonstrator wore gloves for everything else

The foam is not flammable, but the oxygen gas produced supports combustion.

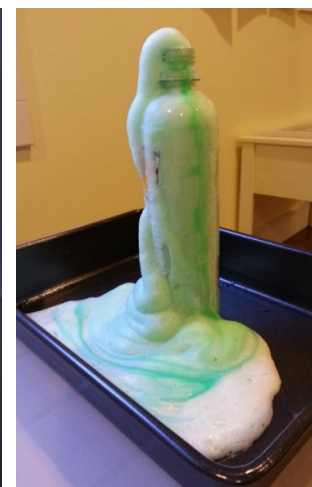
The foam contains oxygen gas within its bubbles. Note, in video, that the flame of the match does increase in size in contact with the pockets of oxygen gas in the foam.

Elephant's Toothpaste Demo

Contain the foam.

The foam may contain some unreacted hydrogen peroxide. Take care in handling it.

What is the principle being demonstrated?



This is toothpaste?

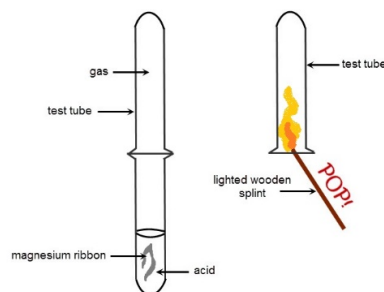
Hydrogen

Hydrogen balloons

Was audience warned about loud noise?

How many do you need for the audience to get the idea that hydrogen burns?

Best teaching moment is using a test tube.



Hold the match with tongs

Oxygen

Burning in oxygen

Make sure that container is resistant to heat.

Safety shield is recommended



Burning magnesium in dry ice

Protect your hands with insulated gloves.

Use a non-flammable cover for table top.

Sparks may be emitted from space between dry ice slabs.

Use a safety shield.



Thermite

Best done outside on a concrete surface.

Never attempt to capture the molten metal in water or in wet sand.

Keep all observers at a minimum distance of 10 meters.

Have a piece of pig iron from a previous reaction to show your audience.

Thermite will work with other metal oxides. **CAUTION:** Test first, in small quantity.

Some mixtures, although safe in small quantity, are explosive when scaled up.



Welding railroad track with Thermite



Gummi Bear Experiment

Can be explosive.

Use an ignition tube which can withstand high temperatures.

Safety shield is essential.



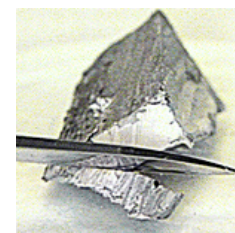
The test/ignition tube can melt or break

Alkali Metals: Li, Na, and K

Use small pieces of metals in a 600 or 800-mL beaker.

Cover with a fine wire gauze.

Project the reaction on a large screen.



Nitrocellulose: Flash paper/Flash cotton

Commercial materials from magic shop are preferred.

Nitration reaction must be carefully monitored.

Home made flash paper can be explosive on impact or may be under-nitrated producing smoldering ashes.



Must be kept damp in storage

Storage

- You do not have sufficient space and materials to store complete demonstrations.
- Store only the essential items that are unique to that demonstration. You have a list of materials needed and should be able to gather them from your regular classroom or laboratory supplies.
- Have containers or bottles for chemicals and solutions clearly labeled with the labels protected by clear, waterproof tape, such as shipping tape.
- **CAUTION:** Never use containers that were once used for food materials such as baby bottles or soft or fruit drink bottles. If anyone ingests any materials from a former food contain and becomes ill, or worse, there is no lawyer who can save you from the liabilities incurred.
- All storage containers should be of manageable size. Do not bring 4-Liter size bottles of liquid or solution if you only need 100 mL (or less) of the liquid or solution.

Moving demonstrations to your presentation site

- **Set the demonstration materials on a rolling cart and roll it around your room or laboratory or to another classroom.**
- **Get some plastic wash basins (rectangular shape preferred) or similar containers, to hold materials for each separate demonstration or activity (secondary containment). This keeps everything together and provides some safety in case of a spill during transport.**
- **Use plastic (unbreakable) and/or safety coated bottles for chemicals whenever possible.**



Summing up: Safety with demonstrations and activities

- **Safety doesn't mean that things don't go wrong.**
- **Safety means that all necessary precautions are taken to minimize any risks.**
- **Safety means that all necessary demonstrations are tested and materials are measured and prepared in advance.**
- **Safety means that all materials are properly transported to the site of the demonstration or activity.**
- **Safety means that any potential problems (i.e., vapors, sparks, projectiles, etc.) are contained.**
- **Safety means that no one, including the demonstrator, is injured.**
- **Safety means that the facilities (i.e., the classroom, lab, furnishings, etc.) are not damaged.**
- **Safety means that all waste materials are properly handled and disposed of.**

Some references

- Katz, David A., Science Demonstrations, Experiments, and Resources, **Journal of Chemical Education**, **68**, 235, March 1991 and at <http://www.chymist.com/Booklist.pdf>
- Katz, David A., Safer Alternatives to Fire and Explosions in Classroom Demonstrations, **Journal of --Hazardous Materials**, **36**, No. 2, 149, February 1994.
- Also see <http://www.chymist.com>
 Demonstrations: Compleat Chymical Demonstrator
 Experiments: Laboratory Experiments