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Safer alternatives to fire and explosions in classroom demonstrations*

David A. Katz[1]

Department of Chemistry, Community College of Philadelphia, 1700 Spring Garden Street, Philadelphia, PA 19130 (USA)

Abstract

Chemical demonstrations are an effective means of promoting student interest, as well as a means of presenting abstract concepts on a concrete basis. Student excitement, however, is particularly aroused by fire and explosions. Such demonstrations are often attempted by inexperienced individuals and occasionally result in accidents and injury even to experienced demonstrators. Many demonstrations involving fire and explosions have safer alternatives or hazards that can be greatly reduced by using commercially available materials or utilizing microscale quantities. This paper provides a number of safer alternatives to fire and explosion demonstrations along with recommended safety precautions.

1. Introduction

Several years ago, attending a conference, a high school teacher presented a paper on using pyrotechnics demonstrations to enliven his classes. He demonstrated a series of reactions which included how to make gun-powder; flame tests with mixtures of potassium chlorate, sugar, and metallic nitrates; alkali metal reactions with water; an alcohol explosion; a dust explosion; methane explosions; hydrogen and hydrogen–oxygen explosions; a reaction of red phosphorus and potassium chlorate; a potassium permanganate explosion using sulfuric acid; and the preparation and explosion of nitrogen triiodide.

At the conclusion of the presentation, a booklet of directions was handed out to the attendees so that they could repeat these demonstrations. The booklet contained a disclaimer that there are inherent dangers in these types of reactions, that there is no guarantee of the correctness or completeness

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[1] Present address: Department of Chemistry, Cabrini College, 610 King of Prussia Road, Radnor, PA 19087-3699, USA.

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of the information provided, that it cannot be assumed that all necessary warnings and procedures were given, that safety shields should be used, and that the person performing these demonstrations should use proper techniques.

Where does one get these proper techniques for handling and disposing of pyrotechnic materials? Several books were consulted for additional information. Davis [1] reviews the history, development, and uses of powder and explosives and gives a number of formulations, but does not give explicit directions for handling and safety. McLain [2] reviews pyrotechnics from the viewpoint of solid state chemistry to provide a coherent basis for the science of pyrotechnics. McLain's information is more complete regarding reactivity of pyrotechnic materials, but he does not give directions for handling these materials. Conkling [3] looks at the chemistry of pyrotechnics with an emphasis on ignition and propagation. Again, no detailed directions are given.

2. Discussion

Pyrotechnics provide a spectacular show, but they also send the wrong signal to the audience. This gives the impression that chemistry is a series of fires, smoke, and explosions and can lead to accidents when students or untrained individuals, with incomplete directions, attempt to emulate the presenter. In addition, these presentations do not illustrate the true fascination of chemistry. There are thousands of exciting demonstrations and activities that can be used to teach concepts and reactions without having to resort to pyrotechnics.

An alternative to gunpowder is the cap gun, available in toy stores. Caps are a mixture of potassium chlorate, red phosphorus, manganese dioxide, sand, and either magnesium oxide or calcium carbonate as a preservative. They can be used most effectively with transparent plastic cap guns so that the burning can be observed along with the controlled explosion. Accompanied by an explanation of the chemistry occurring, along with the student recognition factor in using a familiar product adds excitement to this demonstration.

Flame tests for elements provide a quick, qualitative method of identification. The use of platinum or nichrome wire test loops does not provide for an exciting demonstration as produced by a flare made from potassium chlorate and sugar with metal salts added. The flames tests can be effectively viewed in class or studied by students by using small bottles containing finely powdered anhydrous salts of the elements to be studied. In use, the bottle is shaken while sealed, then opened and held next to the air intake vents of a Bunsen burner (see Fig. 1). This technique produces brilliantly colored flames with minimal fumes.

The alkali metal reaction with water usually calls for a piece of metal ill-defined as the size of a pea. If the piece is too large, an explosion may result. Alexander [4] provides a safer reaction of alkali metals with water. A 500 mL glass cylinder is filled with 200 mL water, a few drops of phenolphthalein, and

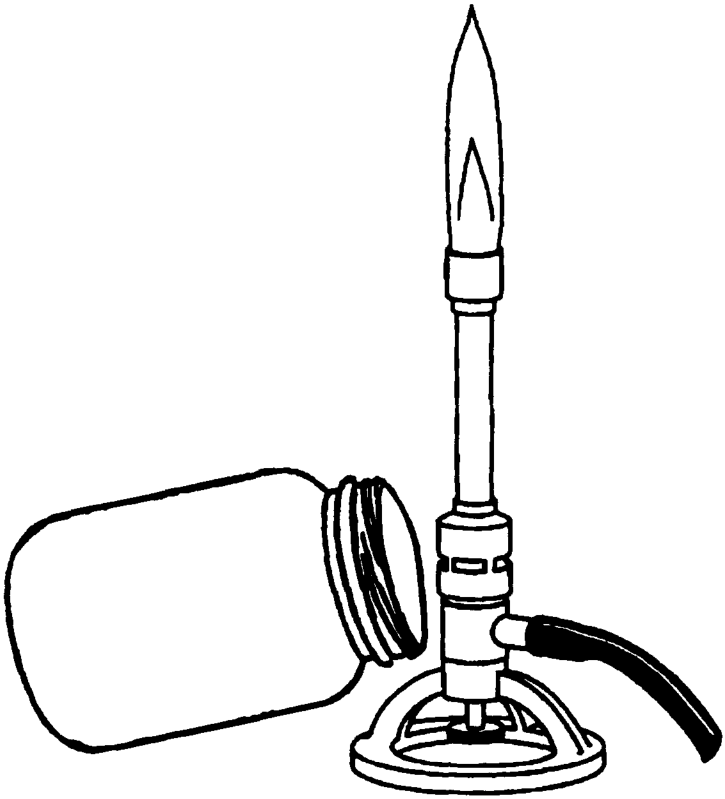

Fig. 1. Producing colored flames from containers of anhydrous salts.

200 mL paint thinner (hydrocarbon mixture), then a piece of sodium or lithium metal is added. When the metal reaches the water layer, the hydrogen produced by the reaction causes the metal to rise into the hydrocarbon layer temporarily stopping the reaction. The reaction allows the students to view the metal cleaned of surface oxidation and the slow rate and reduced danger of explosion allows easy collection of hydrogen by air displacement.

The alcohol cannon, consisting of a plastic bottle with two nails placed in opposite sides, is normally ignited using a Tesla coil to produce a spark between the nails. There have been reports, but no documentation, that occasionally, the nails can be propelled from the bottle on detonation. A new variation of this demonstration uses a 20-L narrow mouth plastic bottle, the type used for bottled water, which is rinsed with alcohol, drained and then ignited by placing a flame near the mouth. It has been reported, but not documented, that these bottles will harden, crack, and eventually rupture. This latter reaction is the reason a flame arrestor screen is placed in the mouth of any flammable solvent container. A safer alternative is an alcohol cannon

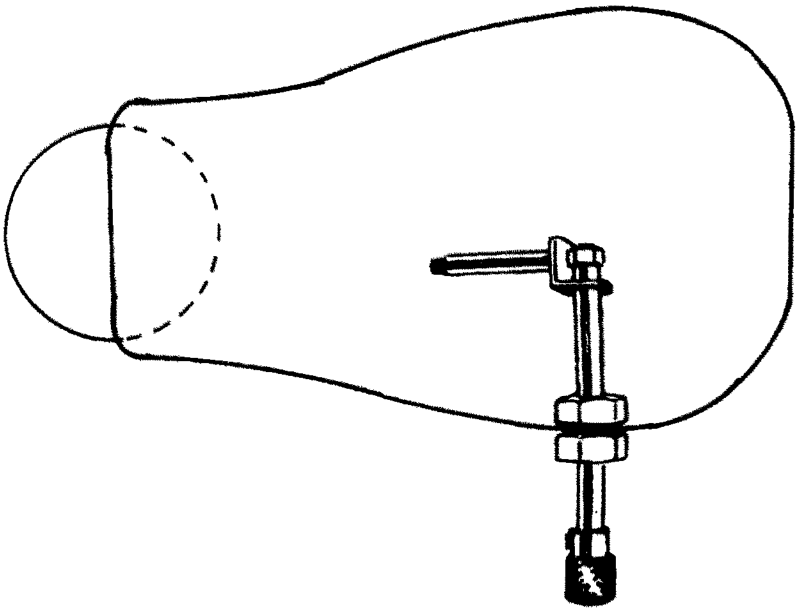

Fig. 2. A hand-held alcohol cannon showing location of sparking device and ping pong ball.

made from the rubber bulb from an automobile battery filler with a lantern lighter (a flint and steel device) obtained from a camping supply store[1] (see Fig. 2). A few drops of methanol or ethanol are added to the bulb, the excess is drained, the opening is closed with a ping pong ball, and the lighter is used to ignite the alcohol–air mixture propelling the ball across the room or vertically up into the air.

Hydrogen explosions, particularly when using a series of mixtures with varying quantities of oxygen in large balloons, can be quite loud. The demonstrator should wear hearing protectors and the audience should cup their hands over their ears. A more effective method of demonstrating the combustion of hydrogen can be performed using a large test tube in a darkened room. When the tube is filled with hydrogen gas, the audience can observe the flame moving through the tube and when the lights are restored, the condensed water vapor in the tube. Even when balloons of the gas are used, this smaller version better illustrates the combustion of hydrogen.

Another variation of the hydrogen–oxygen explosion can be performed in microscale using the cut-off bulb from a one-piece plastic pipette [5] (see Fig. 3). Microgenerators or hydrogen and oxygen are used to fill the pipette bulb by

[1] Lantern lighters are marketed by Coghlan's Ltd., Winnipeg, Canada.

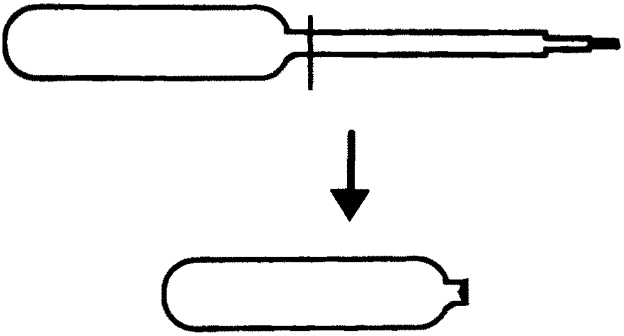

Fig. 3. Cutting off the bulb from a one-piece plastic pipette.

water displacement. The gas mixtures are ignited by placing the pipette near a burner or candle flame. This method allows one to easily investigate the combustion of different hydrogen to oxygen ratios.

The microscale hydrogen–oxygen apparatus can also be used for a hydrogen–chlorine reaction. The gases are generated using minigenerators of gases so only a small amount of gas is produced and collected by water displacement. The mixture is initiated using a flash bulb or electronic flash. This variation requires the use of a hood.

Minigenerators of gases are made by using a 13 × 100 mm test tube fitted with a two-hole stopper with a 3 mm diameter glass delivery tube and a plastic one-piece pipette (see Fig. 4). To produce hydrogen gas, 3 *M* hydrochloric acid is added dropwise, as needed, to mossy zinc pieces in the tube. The oxygen generator uses a 3% hydrogen peroxide solution added to manganese chips (there will be sufficient manganese dioxide on the surface of the chips to catalyze the decomposition). Chlorine is produced from the reaction of 3 *M* hydrochloric acid added dropwise to a small amount of solid potassium permanganate.

Mixtures of red phosphorus and potassium chlorate are explosive and should not be used [6]. A safer alternative is a toy called Blaster™ Balls[2] or Hand Blasters. These consist of two ceramic balls covered with a thin coating of red phosphorus, sulfur, and powdered silica. The balls are nonflammable, but will produce a reaction with a loud bang, about the same sound level of a cap gun, at the point of impact when hit together. The balls will only detonate when they hit each other or a surface with a high silica content such as some types of concrete.

The reaction of sulfuric acid with damp potassium permanganate results in an explosion [7]. This reaction should *never* be attempted for demonstration purposes.

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[2] Blaster™ Balls are a registered trademark of Placo Products Co., Los Angeles, California.

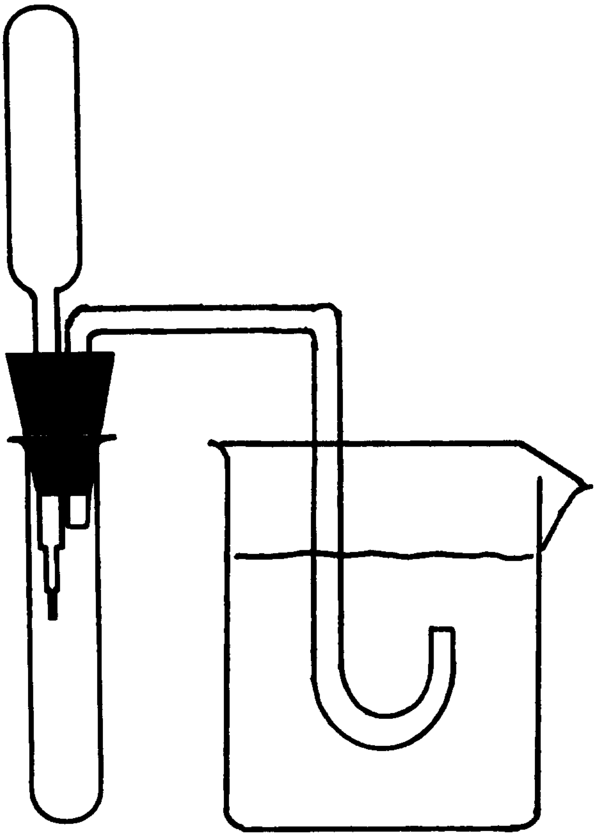

Fig. 4. A mini gas generator.

Nitrogen triiodide is a contact explosive when dry, it can be detonated by minimal amounts of energy such as light, heat, sound or mechanical vibrations. Even when wet, nitrogen triiodide can still be detonated by heavy friction [8]. It detonates with the release of iodine vapor and, when used in quantity, may splatter material for a meter or more in all directions. This material is too unstable for classroom demonstration purposes. An alternative to nitrogen triiodide is silver fulminate, available commercially under the names of Snap n' Pops, Rio Snappers, and Bomber Snaps. These devices typically contain less than 0.001 g of a silver fulminate coating on about 0.18 g of small gravel, wrapped in a piece of cigarette paper. Snap n' Pops will detonate when thrown against a hard surface. They are nonflammable, except for the paper, and generate little flame and almost no gas. Even when detonated in the hand, they produce no burn, tingle, or damage.

The reaction of 30% hydrogen peroxide with manganese dioxide has been used to produce a chemical "genie" [9]. In this reaction, the heat produced by the catalyzed decomposition of the peroxide causes the water–peroxide mixture to boil resulting in a cloud of condensing water vapor and a small amount of hydrogen peroxide escaping from the flask or bottle. This reaction cannot be used to demonstrate the evolution of oxygen as the high water vapor content in the flask will cool a glowing wood splint sufficiently to prevent it from igniting. Repeating the reaction with a 3% solution of hydrogen peroxide and testing for oxygen will demonstrate the chemistry of this reaction.

The non-burning towel demonstration [10] can produce a large flame which may be difficult to control. A safer, more manageable alternative utilizes pieces of paper the same size as local paper currency. It can be demonstrated that the paper burns in air and that it does not burn when wet with water. Wetting the paper with alcohol (ethanol or 2-propanol) will result in both the alcohol and paper burning. At this point the alcohol is diluted with an equal volume of water and paper currency is substituted for the plain paper. There will be sufficient water present to allow the alcohol to burn, but not the paper. As a safety factor, the alcohol should be covered and kept away from open flames and a flame-proof board should cover the table top. Also, it is a safer practice to pour water into the alcohol so that one is not left with a container of alcohol vapors.

The demonstration of nitrocellulose is another popular demonstration. This compound can be made in the laboratory by the reaction of cotton with a nitric acid–sulfuric acid mixture. The acid mixture is a strong nitrating mixture and the nitrocellulose can be extremely flammable and may ignite or detonate in storage [11]. A safer alternative is commercially available flash paper from a magician's supply store. The commercial nitrocellulose is stabilized and can be stored safely in a moisture-free container such as a plastic bag.

Flash powders are often used for special effects with fire and smoke. There are many formulations for flash powders and they all require special handling and storage. These mixtures are unstable and can ignite in storage and will detonate if confined. A safer alternative is a commercial photographic flash powder available from a magician's supply store or theatric supply. A common photographic flash powder[3] consists of a mixture of powdered aluminum and zinc which is mixed with potassium chlorate before use. The author has found that this type of flash powder is mixed in a ratio of three parts powdered metal with one part potassium chlorate, by mass. The flash powder cannot be safely stored if mixed. It is safer to mix small quantities of 1–2 g of material immediately before use. Safety shielding and a remote detonator are recommended.

Sparklers are another area where commercial products are preferred over those prepared in the laboratory. A typical sparkler is composed of gunpowder, powdered metals such as magnesium, aluminum, or iron, and a metallic nitrate salt to produce colors. In a commercial sparkler, the metal powders are

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[3] Manufactured by Newco Products, Inc., Loveland, Ohio.

coated with paraffin wax to prevent oxidation during storage. The advantage to commercial sparklers is a relatively slow and constant rate of combustion. Laboratory made sparklers may be less controlled. The same effect as a sparkler can be obtained by sprinkling a small amount of powdered metal into a burner flame. The metal may be placed on a spatula or in a small plastic wash bottle. A particularly effective demonstration is to start with a large piece of metal, such as a small iron frying pan, and showing the effect of placing it in a flame. The metal is then reduced in particle size to an iron nail, steel wool, and finally powdered iron to demonstrate surface area effects on combustion.

Pharaoh's serpents, mercury(II) thiocyanate, produce long columns of ash as it burns resembling a "snake". These produce vapors containing carbon disulfide, nitrogen, and mercury [12]. For this reason, these are particularly dangerous due to the inhalation toxicity of mercury as well as the possible skin contact with the solid. A safer alternative are the commercial non-mercury snakes. These are made from a naphthol pitch that has been mixed with linseed oil, treated with nitric acid, washed, dried, and further treated with picric acid. They are mixed with gum-arabic, pelleted, and aged for several months. Due to their odor and smoke produced, these snakes should be used with good ventilation. No information has been found indicating any toxicity of the vapors produced.

The combustion of magnesium in solid carbon dioxide, dry ice, produces a spectacular visual reaction [13]. This reaction may eject pieces of magnesium, white powder, and produces a large amount of white smoke. It is recommended that only magnesium turnings be used and that the demonstrator uses safety shields and keeps a dry chemical fire extinguisher nearby. A smaller, safer version of this reaction utilizes a piece of burning magnesium ribbon which is slowly lowered into a 2-L or larger beaker filled with carbon dioxide gas which is generated from dry ice or the reaction of sodium carbonate or bicarbonate with 1 *M* hydrochloric acid. The magnesium ribbon will spark and pop, producing small particles of carbon inside the beaker.

There are numerous reactions that can be utilized for producing explosions in chemistry demonstrations. The combustion of acetylene–air mixtures produced by the reaction of calcium carbide with water, using a carbide cannon[4], can provide an effective and safe method for an explosion. These explosions are particularly effective when discussed in the context of the carbide miners' lamps and the development of the Davy safety lamp.

There are many safer alternatives to and variations on common pyrotechnic demonstrations that can be used to more effectively teach chemistry. In addition when performing any demonstrations, it is recommended that demonstrators follow the Minimum Safety Guidelines for Chemical Demonstrations as developed by the ACS Division of Chemical Education (see Table 1). Safety and understanding should be the demonstrator's primary goals.

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[4] Carbide cannons are manufactured by The Conestoga Company, Bethlehem, Pennsylvania.

TABLE 1

ACS Division of Chemical Education Minimum Safety Guidelines for Chemical Demonstrations[a]

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 demonstration so that harmful quantities of noxious gases (e.g. NO_2, SO_2, H_2S) 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, CCl_4, CS_2, 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.

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