Lecture Demonstration Accidents from Which We Can Learn

George M. Bodner
Purdue University, West Lafayette, IN 47907

There are many reasons for the recent resurgence of interest in lecture demonstrations. Lecture demonstrations are fun. They grab the students' attention. Students like them. They provide breaks that help students recover from the deluge of information in the typical lecture. They can provide concrete examples of abstract concepts. As Ramette has noted, they can be exocharmic (*1*). Most importantly they teach chemistry.

Unfortunately, demonstrations are routinely done under conditions where neither the students nor the instructor are adequately protected against injury. We have therefore collected examples of accidents and near accidents that might remind chemistry teachers of the need to pay more attention to safety when doing demonstrations, without frightening them away from doing demonstrations.

Historic Lecture Demonstration Accidents

Winderlich (*2*) described an accident which occurred during the demonstration of the explosive reaction between NO and CS_2 (*3*).

> During a lecture by Justus Liebig before a selected audience in Munich he exhibited the strikingly beautiful combustion of carbon bisulfide in nitric oxide. The delight of the onlookers led him to repeat the demonstration. This time, to the great horror of all present, there was a terrific explosion, the flask was shattered into bits. Queen Therese, Prince-regent Luitpold, and Liebig himself were seriously wounded by the flying glass. The accident would have been fatal for Liebig if his snuff box had not prevented a large splinter of glass from penetrating his femoral artery.

He also noted that Lothar Meyer was inordinately fond of demonstrating the explosion of acetylene, in spite of warnings of the potential danger, until 1894 when an explosion shattered the apparatus. Although Meyer somehow escaped serious injury,

> The explosion was a quite powerful one, and one of the students, who sat rather far from the lecture table, reported to me later that after the bang he could see me talking but could hear nothing because the report had deafened him temporarily.

Davenport (*4*) reminded us of another historic accident described in Silliman's "Elements of Chemistry" (*5*).

> Pilatre de Rozier was accustomed, not only to fill his lungs with hydrogen gas, but to set fire to it as it issued from his mouth, where it formed a very curious jet of flame. He also mixed pure hydrogen gas with one ninth of common air, and respired the mixture as usual; "but when he attempted to set it on fire, the consequence was an explosion so dreadful, that he imagined his teeth were all blown out."

Demonstrations That Have Led to Serious Injury and Should Not be Repeated

Permanganate Volcano

The permanganate volcano is based on the reaction between $KMnO_4$ and concentrated sulfuric acid which gives a dark green oil that undergoes rapid decomposition in the presence of moist air to form MnO_2 and oxygen.

$$2\,MnO_4^-(aq) + 2\,H^+(aq) \rightarrow Mn_2O_7(l)$$

$$2\,Mn_2O_7(l) \rightarrow 4\,MnO_2(s) + 3\,O_2(g)$$

There have been several serious accidents with this demonstration. In one case, during a practice session prior to class, enough acid was added to cover the permanganate completely. When the demonstrator walked to the blackboard, the mixture detonated, shattering two panels of the chalkboard and spraying reagents over a distance of 40 feet. The demonstrator was not injured (*6,7*). In a second case, however, 15 sixth-grade students were injured, two seriously, when this demonstration exploded (*8*).

Peroxyacetone

A mixture of peroxides known as "peroxyacetone" can be prepared by reacting 30% H_2O_2 with acetone (*9*). When a small sample of peroxyacetone is placed on a piece of paper and touched with a match, the solid bursts instantly into flame without igniting the paper (*10*).

In light of the fact that these peroxides have been implicated in explosions which occur when 30% H_2O_2 in acetone is used as an oxidizing agent in organic synthesis (*11–13*), it is not surprising that there have been a number of accidents with peroxyacetone which have ranged from minor to potentially crippling. In one case, a sample detonated when ignited in the palm of the demonstrator's hand, producing a partial loss of feeling in his hand. In a second case, peroxyacetone detonated while being ground, and pieces of the mortar and pestle had to be removed from the demonstrator's chest.

In a third case, peroxyacetone was used as the last demonstration in an hour-long program for elementary students. A small sample was removed from a storage bottle, placed on a demonstration tray, and ignited with a match. For unknown reasons, the peroxyacetone in the storage bottle exploded, and glass was scattered throughout the room. Several children suffered minor cuts, and one child had a small piece of glass that was removed from her eye without permanent damage. (The demonstrator believes that more serious injuries were avoided because the glassware from each demonstration was removed from the table as soon as the demonstration was done.) The medial nerve in the demonstrator's hand was severed and considerable damage was done to the base of his thumb. Many small pieces of glass were embedded in his arms, hands, legs, neck, and face. There were also full-thickness burns to the left side of his face and ear which required extensive hospitalization and eventual skin grafts.

In a fourth case, 2 or 3 grams of peroxyacetone left over from a demonstration were being disposed of by ignition. When the bottle was gently tapped with the finger, "detonation occurred resulting in serious damage to the hand holding the jar, and severe eye cuts due to flying particles of pulverized glass" (*14*).

Powdered Aluminum/Oxygen

Demonstrations with liquid nitrogen and liquid oxygen have been popular for over 50 years (*15*). If care is taken to avoid touching metal objects in contact with cryogenic liquids, the danger of most liquid nitrogen demonstrations is minimal.

Serious accidents have occurred, however, with a demonstration in which powdered aluminum is covered with liquid oxygen, the liquid oxygen is allowed to evaporate, and the moist aluminum is ignited with a candle to produce a blinding flash of light as the temperature rises from −183°C to more than 3400°C (*15*).

In 1957, this demonstration was done at Indiana University for a group of high school students (*16*). Instead of producing a bright, harmless flare, the mixture detonated, hurling fragments of the container and the stone tabletop throughout the auditorium. Injuries ranged from the loss of an eye to crushed bones and severe face and body lacerations.

Subsequent analysis showed that similar explosions had occurred at least six times before the accident at Indiana was reported.

Demonstrations that are Questionable because of the Potential for Injury

Burning Methane

At least one lecture demonstrator used to collect liquid methane by passing natural gas through a test tube immersed in liquid nitrogen. A gas jet threaded through a one-hole rubber stopper was then inserted in this tube, and the methane was ignited as it boiled off.

On several occasions, the reaction got out of control, and injury to the demonstrator and/or audience was avoided only because of the small quantity of methane that had been collected. On one occasion, the methane was kept in the liquid nitrogen bath for about an hour. Liquid oxygen apparently condensed in the tube, and the mixture of methane and oxygen exploded when ignited, sending stopper and glass tubing to the ceiling. No trace of the glass was later found. Fortunately, the tube had been held vertically, and no one was injured.

Hydrogen/Acetylene Generators

The gas given off by hydrogen or acetylene generators is often ignited to demonstrate the ease with which these gases burn. As might be expected, several accidents have occurred when this demonstration was done in an apparatus that contained residual air. In at least one case, the instructor received what he described as "a chest full of glass."

The ease of combustion of hydrogen is best demonstrated by filling a balloon with the gas, and igniting the balloon with the flame of a candle attached to a meter stick.

"Setting Exams on Fire"

Several demonstrations of "cold flames" have been developed. Alyea and Dutton suggested igniting cheesecloth soaked in a 1:2 mixture by volume of CCl_4 and CS_2 (*17*). Shakhashiri recommended a 1:1 mixture of isopropyl alcohol and water and advised against using CCl_4 and CS_2 (*18*).

Several years ago, it was suggested that a bottle labeled "gasoline" should be filled with one of these liquids, and the liquid poured onto exams and ignited before returning the exams to the students (*19*). Although no accidents have come to our attention, there is a potential for serious injury if students try to repeat this demonstration with "gasoline."

Worthwhile Demonstrations that Should be Done, but Done with Care

Ammonia Fountain

There have been several accidents when flat-bottomed flasks such as Erlenmeyer or Florence flasks were used instead of round-bottomed flasks to set up the popular ammonia fountain demonstration (*20, 21*). Flat-bottomed flasks cannot stand the vacuum produced in this demonstration, and often implode with the potential for serious injury to the lecture demonstrator.

Combustion of Hydrogen and/or Mixtures of Hydrogen and Oxygen

Many demonstrators fill a "pop" bottle with mixtures of hydrogen and oxygen and then ignite the gas with a match. Although no accidents have been reported, this demonstration is potentially dangerous, and it should not be done unless the bottle is wrapped with tape.

As noted above, the combustion of hydrogen or mixtures of hydrogen and oxygen is best demonstrated by igniting a balloon filled with the gas with the flame of a candle attached to a meter stick. It should be noted, however, that at least one demonstrator has left his signature on the lecture hall when the hydrogen balloon came too close to the ceiling before it was ignited.

Alkali Metal (Group Ia) Explosions

One of the most common demonstrations of chemical reactivity involves dropping small pieces of Li, Na, and K into water. Explosions can happen, however, when these alkali metals are added to water (*22*). In one case, a 1-L beaker roughly half full of water was shattered by the explosion which occurred when a thumbnail-sized piece of sodium was dropped into the beaker.

The most serious hazard, however, results from attempts to repeat this demonstration with potassium (*23, 24*). In one instance, there were face and hand injuries due to cuts from glass fragments as well as burns from burning oil and potassium when the instructor cut into a piece of potassium metal with a knife.

In virtually all explosions of this nature, the potassium being used was an old sample whose surface was described as having the appearance of cheese. It is likely that a layer of potassium superoxide formed on the surface of the potassium over the years, and that the force of the knife pushing down on this surface layer induced a reaction in which fresh potassium metal reduced the superoxide to the peroxide or oxide. The heat of reaction between K and KO_2 is sufficient to spray potassium metal into the surrounding air, where it reacts explosively (*25*).

Common sources of injury from this demonstration can be avoided by: (1) cutting the alkali metal before lecture to avoid using too large a sample, (2) carefully drying the metal to remove any hydrocarbon adhering to the surface before it is dropped into the water, and (3) partially covering the crystallizing dish or beaker with a glass plate or watch glass to prevent the metal or solution from splattering.

Reaction of Zinc with Ammonium Nitrate/Ammonium Chloride

In 1981, a mixture of powdered zinc, ammonium nitrate, and ammonium chloride used in the "Green Spontaneous Flame" demonstration (*26, 27*) ignited prematurely, seriously burning the hands of the demonstrator (*28*). Note that any reaction which is initiated by the addition of water can become self-initiated if the hygroscopic crystals become moist.

Liquid Oxygen

The potential for serious injury to demonstrators working with liquid oxygen has not received enough attention. Clothing that comes in contact with liquid oxygen can remain saturated with oxygen for as much as 24 hours (*29*). Numerous industrial accidents, often with fatal results, have occurred when an individual whose clothing was saturated with oxygen lit a cigarette. If liquid oxygen is spilled on clothing during the course of a demonstration, do not under any circumstances light a match until you have an opportunity to change your clothes.

Thermite

Demonstrations of the thermite reaction,

$$Fe_2O_3(s) + 2\ Al(s) \rightarrow Al_2O_3(s) + 2\ Fe(l)$$

are used so often that we tend to forget the hazards associated with any exothermic reaction. There have been a number of accidents and near accidents with this demonstration. In one well-publicized instance, the thermite reaction was set up so that it could be videotaped. To help provide contrast for the filming, a screen was pulled down behind the lecture table. A spark from this reaction ignited the screen, which burst into flame. Fortunately, the individual behind the camera kept shooting, the accident was caught on tape, and it has been shown to thousands of students and chemical educators over the years.

This tape invariably meets with laughter when shown, particularly when viewed by other chemists. This laughter is an excellent example of the theory that the principal purpose of laughter is to release tension (*30*), and thus we tend to laugh at that which we fear the most (*31*).

Breathing Hydrogen

There are several potential hazards for those who breathe H_2 gas to raise the timbre of their voices. One hazard is the ease with which hydrogen can be ignited by a static discharge. Another, which is less commonly recognized, is the danger of arsine impurities in H_2 made by reacting zinc with acid that result from arsenic impurities in the zinc. Although breathing helium may not be completely safe (*4*), it is undoubtedly safer than breathing H_2.

Nitrogen Triiodide

The decomposition of NI_3 is a popular demonstration that can be well worth doing. It should not be done, however, if the classroom is either too small or two crowded. At Purdue, we can clear a 10′ × 10′ space in one corner of a large lecture hall where this demonstration can be safely done. Furthermore, we can lock the door in that corner of the classroom, so that students cannot accidentally set off the demonstration as they walk into the classroom.

Although there are many examples of incidents with nitrogen triiodide, we will describe just one. The instructor prepared a sample of NI_3 ahead of class which he stored on a board inside a drawer in the lecture demonstration cabinet. When the time came for lecture, he opened the drawer, and lifted out the board to place it on the table top. He would normally have detonated the NI_3 with a feather attached to a long pole. This time, the NI_3 detonated while he was lifting the board.

Burning of Magnesium or Other Metals

Several years ago, a teacher was seriously injured when sparks from a demonstration ignited an open container of magnesium metal (*26*).

Magnesium or Iron and Sulfur

Winderlich (*2*) reported demonstrating the reaction between a "tiny amount of powdered magnesium and flowers of sulfur" which produced an explosion that shattered the test tube, and a flame that ignited a window shade 6 feet away.

Chlorates

It has been argued that the largest contributor to chemical accidents is the decomposition of a chlorate, either by itself or in the presence of phosphorus or one of the active metals (*32*). In fact, it has been suggested that potassium chlorate is less stable than potassium perchlorate (*2*).

Lycopodium Powder

Although the burning of lycopodium powder is a popular demonstration, with little or no direct hazard from the flame, it is worth noting that a small fraction of the population can have a potentially dangerous allergic reaction to lycopodium powder.

Phosphorus in Carbon Disulfide

Several accidents have occurred when a bottle of phosphorus in carbon disulfide has been spilled, the CS_2 evaporated, and the phosphorus burst into flame. Painful phosphorus burns have also occurred when this solution was spilled on the demonstrator's hands. These accidents can be easily prevented by clamping the bottle containing P_4 in CS_2 to a heavy ring stand.

Conclusion

Others have noted that students often root for us to make mistakes when we do lecture demonstrations. There is even evidence to suggest that accidents attract certain people to chemistry. At the close of a note describing an explosion when sodium was added to water, Peacocke notes: (*21*) "... but whatever the cause the effect on me was that I fell in love with chemistry from that moment." We can fulfill our obligation to ourselves and our students, however, by following a few simple rules.

1) Never do a demonstration in class that you have not tested previously.
2) Never do demonstrations unless you are wearing safety goggles.
3) Never do potentially dangerous demonstrations without safety shields to protect the students.
4) Never do exothermic demonstrations unless there is a fire extinguisher nearby.
5) Apply the same rules of safe conduct to lecture demonstrations that you would use for experiments done in the laboratory.

By following these simple rules, we can take advantage of the well-known pedagogical value of lecture demonstrations without exposing either ourselves or our students to injury.

Literature Cited

(1) Ramette, R. W., J. CHEM. EDUC., **57**, 68 (1980).
(2) Winderlich, R., J. CHEM. EDUC., **27**, 670 (1950).
(3) Shakhashiri, B. S., "Chemical Demonstrations; A Handbook for Teachers of Chemistry," Volume 1, University of Wisconsin Press, Madison, WI, **1983**, p. 117, Demonstration 1.44.
(4) Davenport, D. A., Grant, M-H., and Srinivason, V., J. CHEM. EDUC., **56**, 523 (1979).
(5) Silliman, B., "Elements of Chemistry," Hezekiah Howe, New Haven, CT, **1830**, Volume I, p. 205.
(6) Haight, G. P., Jr., and Phillipson, D., J. CHEM. EDUC., **57**, 325 (1980).
(7) Haight, G. P., Jr., and Phillipson, D., *Chem. Eng. News*, March 31, 1980, p. 3.
(8) Weand, B. L., *Chem. Eng. News*, June 9, 1980, p. 4.
(9) Milas, N. A., and Golubovic, A., *J. Amer. Chem. Soc.*, **81**, 6461 (1959).
(10) Ref. (*3*), p. 46, Demonstration 1.18.
(11) Seidl, H., *Angew. Chem. Intern. Educ.*, **3**, 640 (1964).
(12) Treibs, W., *Angew. Chem. Intern. Educ.*, **3**, 802 (1964).
(13) Brewer, A. D., *Chem. Brit.*, **11**, 335 (1975).
(14) Hutton, W., and Heideman, S., *Chem. Eng. News*, September 17, 1984, p. 4.
(15) Cady, H. P., J. CHEM. EDUC., **8**, 1027 (1931).
(16) Austin, C. M., Rohrer, C. S., and R. L. Seifert, J. CHEM. EDUC., **36**, 54 (1959).
(17) Alyea, H. N., and Dutton, F. B., "Tested Demonstrations in Chemistry," 6th ed., Journal of Chemical Education, Easton, PA, **1965**.
(18) Ref. (*3*), p. 13, Demonstration 1.4.
(19) Jardin, J., Murray, P., Tyszka, J., and Czarnecki, J., J. CHEM. EDUC., **55**, 655 (1978).
(20) Weaver, E. C., J. CHEM. EDUC., **21**, 199 (1944).
(21) Kauffman, G. B., J. CHEM. EDUC., **59**, 80 (1982).
(22) Peacocke, T. A. H., *Chem. Brit.*, **15**, 233 (1979).
(23) Monk, R. G., *Chem. Brit.*, **15**, 65 (1979).
(24) Bretherick, L., *Chem. Brit.*, **11**, 376 (1975).
(25) Sloan, S. A., *Chem. Brit.*, **14**, 597 (1978).
(26) Bailey, P. S., Bailey, C. A., Anderson, J., Kashi, P. G., and Rechsteiner, C., J. CHEM. EDUC., **52**, 524 (1975).
(27) Ref. (*3*), p. 51, Demonstration 1.20.
(28) Nagel, M. C., J. CHEM. EDUC., **59**, 868 (1982).
(29) Wilk, I. J., J. CHEM. EDUC., **45**, A547 (1968).
(30) Koestler, A., "The Art of Creation," Hutchinson, London, **1964**.
(31) Bodner, G. M., *CHEM TECH*, April 1985, p. 203.
(32) Burns, C., J. CHEM. EDUC., **33**, 508 (1956).