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Chemistry and History

Lecture Demonstrations, Past and Present[1]

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Good demonstrations not only spice up a class session, but they also help teach principles…

When former students visit me, the parts of my lectures that they invariably recall most vividly are the lecture demonstrations, usually the more spectacular ones, even though in some cases more than four decades have elapsed. Indeed, the "live" scientific lecture demonstration is a most effective means of communication, even in this era of film, television, and other varieties of "canned" media. According to Charles Taylor, Professor of Experimental Physics at London's Royal Institution and Professor Emeritus of Physics at the University College, Cardiff, Wales [1a], "It seems to work with all age groups and is a great way of inculcating a sense of excitement about science, especially in children." To quote Taylor again, whose book, *The Art and Science of Lecture Demonstration,* is likely

[1] This article is an expanded version of a paper presented at the symposium, "Lecturing to Chemistry Students: The Lecturer as Performer," 207th National Meeting, American Chemical Society, San Diego, CA, March 16, 1994. An abbreviated version of this article titled "Lecture Demonstrations: Science's Live Theater" originally appeared and is reprinted with permission from the *Yearbook of Science and the Future, 1995* © Encyclopædia Britannica, Inc. Chicago, 1994; pp 220–240.

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to be definitive for some time to come, a demonstration is any "illustration of a point in a lecture or lesson by means of something other than conventional visual-aid apparatus [1b]" such as a blackboard, overhead projector, slides, or films. In this article I shall discuss the origins and history of the lecture demonstration; give a glimpse of some past and present masters of the art; summarize some purposes, principles, strategies, techniques, and values of demonstrations, including considerations of safety; and call attention to resources available in museums, books, and journals. I shall confine most of my illustrations primarily to chemistry and, to a lesser extent, physics, but most of the principles discussed should be valid, *mutatis mutandis*, for other sciences as well.

Origins and History of the Lecture Demonstration

Depending upon the particular definition of the term, we can assign various dates for the earliest lecture demonstrations. In ancient times eclipses, particularly of the Sun, were regarded as portents of disaster, and not only astronomical writings but also history and literature are replete with descriptions of these striking occurrences. The Babylonians, Assyrians, Chinese, Greeks, Romans, and Aztecs were able to predict eclipses, and their priests and rulers undoubtedly conducted demonstrations of these phenomena to awe their superstitious subjects.

Archimedes (287 B.C.–212 B.C.), the founder of theoretical mechanics, may have performed at least two demonstrations before King Hieron II of Syracuse. His observation of the overflowing water caused by stepping into his bath enabled him to answer Hieron's question of whether a crown made for him was pure gold or was adulterated with silver and led to his derivation of Archimedes' principle of buoyancy. Archimedes is said to have been so overjoyed by his accidental discovery that he ran home naked shouting "Eureka!," now the motto of the state of California ("I have found it!"). Another story relates how, when Hieron asked Archimedes to prove his contention that an extremely great weight could be moved by a very small force ("Give me a place to stand on, and I will move the Earth"), Archimedes provided him with a mechanical device (Sources vary as to its exact nature) to enable him to move a fully laden ship.

Although the well known legend that the Italian mathematician, astronomer, and physicist Galileo Galilei (1564–1642) dropped weights from the leaning tower of Pisa to show that bodies fall with uniform acceleration is apocryphal, in 1611 he did demonstrate his telescope to the most eminent members of the pontifical court in Rome.

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A contemporary fresco by Giuseppe Bezuolli depicts Galileo demonstrating his scientific apparatus for studying bodies in motion to an audience that included Giovanni de' Medici, half brother of Grand Duke Ferdinand I of Tuscany [2].

From ancient times alchemists performed fraudulent, so-called "transmutations" of base metals into gold that have been well documented [3]. During medieval times European kings and princes supported court alchemists and astrologers. These rulers were usually motivated by avarice and credulity rather than an interest in science, and their alchemists and astrologers lived a precarious existence, sometimes suffering untimely deaths when their demonstrations before the court proved unsuccessful or were discovered to be fraudulent.

One of the most famous scientific demonstrations performed before royalty was that of Otto von Guericke (1602–1686); the German physicist, engineer, natural philosopher, and Bürgermeister (mayor) (1646–1681) and magistrate of Magdeburg in Prussian Saxony, who invented the first air pump in 1650 and used it to study vacuum and the role of air in combustion and respiration. In a famous series of experiments carried out in 1654 at Regensburg before Holy Roman Emperor Ferdinand III, von Guericke formed a hollow sphere about 14 inches (35.5 cm.) in diameter from two copper bowls (Magdeburg hemispheres). In this first demonstration of the tremendous force that air pressure exerts (14.7 psi), he exhausted the air from the sphere with his air pump. Even though the bowls were held together only by the air around them, horses were unable to pull them apart.

It is in the field of medicine, however, that demonstrations most closely approaching Taylor's definition have been used since earliest times. Hippocrates of Cos (460 B.C.–ca. 370 B.C.), the father of medicine, in the course of teaching his pupils in the medical school at Cos may have had recourse to demonstrations. Galen (ca. 129–ca. 199), the most important physician in the ancient world after Hippocrates, performed public lectures and dissections that were well attended by the most famous persons of the day and that greatly enhanced his prestige. One of his most significant demonstrations proved that the arteries carry blood rather than air, as had been erroneously taught for four centuries.

During the Renaissance the Flemish physician Andreas Vesalius (1514–1564), on December 6, 1537, the day after receiving his M.D. degree *magna cum laude* from the

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University of Padua medical school, then the most famous in Europe, was appointed *explicator chirurgiae* with the responsibility of lecturing on surgery and anatomy. His required anatomical lectures and demonstrations were unusual because he dissected cadavers himself rather than consigning the task to an assistant, the customary practice. By the following century the annual anatomy lesson by the presiding professor of anatomy in the Amsterdam Surgeon's Guild was considered the high point of the social season and the subject for oil paintings such as Rembrandt's "Anatomy Lesson of Dr. Nicolaes Tulp" (1632)[4].

The lecture demonstration, in the modern sense of the term, became popular during the seventeenth century [1c]. Inasmuch as chemistry is an experimental science, it is not surprising that lecture demonstrations were an integral part of its teaching from the very beginnings of academic chemistry itself [5]. Academic chemistry arose largely as a side-effect of the activities of the Swiss iatrochemist (from the Greek, ιατρος, physician) Philippus Aureolus Theophrastus Bombastus von Hohenheim (1493–1541), who dubbed himself Paracelsus, a nickname that may denote "equal to or surpassing Celsus" (Aulus Cornelius Celsus (fl. ca. A.D. 25) was generally considered the greatest Roman medical writer). A transitional figure in the history of chemistry between the age of alchemy and the phlogiston theory, Paracelsus taught that the goal of chemists should not be the philosopher's stone, the transmutation of base metals into gold, or the elixir of life, but rather the preparation of chemical medicines and drugs.

Thus, during the early seventeenth century, chemistry entered the traditional university curriculum as an introductory "service course" for students of medicine and pharmacy. In Paris the first real chemistry courses were private courses given in the chemists' own homes or laboratories [6]. In about 1604 Jean Beguin (1550–1620) and Jean Ribit opened a school of chemistry and pharmacy, and Beguin's lectures were the first public expositions of chemistry in the French capital. Also in Paris, outside of the universities public lectures with demonstrations by chemists such as the Dane Ole Borch and the Frenchman Nicolas Lemery (1645–1715), author of the influential book *Cours de chymie*, which was translated into five languages and was popular for more than a century, attracted not only medical and pharmacy students but many ordinary citizens (including women) as well as foreigners.

Later, as a youth in Darmstadt, one of chemistry's most famous lecturers Justus von Liebig (1803–1873) watched a traveling pedlar demonstrate explosive silver fulminate in

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the marketplace. Liebig reproduced the preparation in his home laboratory and later, in 1824, as a young chemist, his analysis of the fulminates and cyanates of silver, which showed that they had the same chemical composition but different properties, provided the first example of what Jöns Jacob Berzelius (1779–1848) was to call isomerism in 1831. The tradition of nonacademic itinerant lecturer-demonstrators was to become popular in late-eighteenth- and early nineteenth-century Great Britain and in the United States [5]. These private lecturers, some of whom were university professors, traveled from town to town, where university education was often unavailable, and presented short courses on chemistry to groups of laymen, usually sponsored by local ministers, educators, or natural history societies.

The development of the art of chemical demonstration is inseparably linked with the history of a famous institution whose name and purpose apparently would seem to have nothing to do with chemistry [7a]. Because medicines had to be prepared from plants, pharmaceutical laboratories were built in a garden in Paris, which was established in 1626 by Jean Héroard and Guy de la Brosse, Louis XIII's physicians, as the Jardin Royal des Plantes Médicinales, known as the Jardin du Roi or Jardin des Plantes. The Royal Garden soon assumed the organizational form of a university [5, 7a, 8a]. Since 1793 it has officially been called the Muséum National d'Histoire Naturelle.

The first professor of chemistry at the Jardin du Roi was the Scottish physician William (known as Guillaume in French) Davisson (Davison or Davidson) (1593–ca. 1663), appointed in 1648, an example of the close relationship between the teaching of chemistry and medical-pharmaceutical schools mentioned above. This professorship was held by some of the most famous French chemists of the seventeenth and eighteenth centuries. The general practice was for the *Professeur* to present his lecture, followed by illustrative experiments carried out by the *Demonstrateur*, who held a lower rank. Frequently the demonstrator was promoted to the rank of professor. By the late eighteenth century in France the professor performed his own demonstrations or was aided by a lecture assistant, the usual custom in the famous medical schools of Scotland [5].

Guillaume-François Rouelle (1703–1770), who was the teacher of Antoine-Laurent Lavoisier (1743–1794), the father of modern chemistry, was reputed to be the best lecturer in France, and during his tenure the Jardin du Roi attained a worldwide

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reputation. Although well liked by his contemporaries, he was eccentric in habits and blunt in speech. According to one eye-witness report [9, 10]:

> He [Rouelle] would come to the lecture room elegantly attired with a velvet coat, powdered wig and a little hat under his arm. Collected enough at the beginning of his demonstrations, he gradually became more animated. If his train of thought became obscure, he would lose patience and would gradually divest himself of his clothing, first putting his hat on a retort, then taking off his wig, then untying his cravat. Then, talking all the while, he would unbutton his coat and waistcoat and take them off one after the other. He was helped in his experiments by one of his nephews, but as help was not always to be found close at hand, he would shout at the top of his lungs, "Nephew! O' the eternal nephew" and the eternal nephew not appearing, he would himself depart into the back regions of his laboratory to find the object he needed. Meanwhile he would continue his lecture as though he were still in the presence of his audience. When he returned, he had generally finished the demonstration he had begun and would come in saying, "There, gentlemen, this is what I had to tell you." Then he was begged to begin again, which he always did with the best grace in the world, in the conviction he had merely been badly understood.

Another high point in the history of chemical demonstrations at the Jardin du Roi was reached with the 1771 appointment of the celebrated pair of Macquer as professor and Antoine Baumé (1728–1804) as his demonstrator. Macquer, who had managed a private pharmaceutical laboratory with Baumé but had also given public lectures, was a spellbinding lecturer, and Baumé was a brilliant demonstrator. During his twenty-five years as Macquer's demonstrator Baumé claimed that the two had given sixteen courses, each with more than two thousand demonstrations, and that he himself had personally performed more than ten thousand demonstrations.

In England in 1662, the Royal Society of London (founded in 1660) appointed Robert Hooke (1635–1702) as curator and demonstrator "to provide new experiments for almost every occasion when the Royal Society met" [1d]. According to John Theophilus Desaguliers (1683–1744), a later curator of experiments at the Royal Society generally regarded as the real popularizer of demonstration lectures, however, John Keill (1671–1721), who began a series of experimental lectures on Newtonian philosophy in 1694,

> was the first who publicly taught Natural Philosophy [as science was then called] by Experiments in a mathematical Manner; for he laid down very simple Propositions, which he prov'd by Experiments....He began these courses in Oxford about the year 1704 or 1705....[1e].

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Desaguliers succeeded Keill at Oxford, and his book, *Course of Experimental Philosophy* (1763), describes numerous demonstrations still used today. In Scotland the first chemistry courses were given at the University of Glasgow by William Cullen (1710–1790), who taught there from 1746 to 1755 [6]. When he became lecturer in chemistry at the University of Edinburgh in 1755, where he made chemistry a popular study, he was succeeded at Glasgow by his former student Joseph Black (1728–1799), the discoverer of latent and specific heat and the first to understand the relationship between limestone (calcium carbonate) and quicklime (calcium oxide), which is formed from the former by loss of "fixed air" (carbon dioxide). Black also showed that carbon dioxide is acidic and is formed by respiration, fermentation, and burning charcoal. After 1766 Cullen devoted himself primarily to medicine and *materia medica*, and he was succeeded as professor of chemistry at Edinburgh by Black.

Both men were brilliant lecturer-demonstrators. In his *The History of Chemistry* (1830), the first book in English on the subject, Thomas Thomson wrote [6, 11]:

> Dr. Black [endeavoured] every year to make his courses more plain and familiar, and illustrat[ed] them by a greater variety of examples in the way of experiment. No man could perform these [lecture demonstrations] more neatly or successfully; they were always ingeniously and judiciously contrived, clearly establishing the point in view, and were never more complicated than was sufficient for the purpose....No quackery, no trickery, no love of mere dazzle and glitter, ever had the least influence upon his conduct. He constituted the most complete model of a perfect chemical lecturer that I have ever had an opportunity of witnessing.

One of Black's pupils was Philadelphia-born Benjamin Rush (1745–1813), who became the first professor of chemistry in America (1769), a popular lecturer-demonstrator in his own right, and a signer of the Declaration of Independence.

During the second half of the eighteenth century grand lectures primarily for show were accompanied by bombastic experiments, and natural scientists appeared as magicians and entertainers at court banquets and functions [7b]. By the century's end chemistry demonstrations had developed into theatrical events, and many private scholars organized them for their own amusement. An invitation to a grand dinner at Lavoisier's house often included an experimental lecture lasting an hour or frequently longer.

In Germany, at Munich's Bavarian Academy of Sciences (founded in 1764) Maximus von Imhof (1758–1817), following the French practice, demonstrated the classical

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experiments of the new "pneumatic chemistry;" he determined the composition of air and exploded various gas mixtures. At Bavaria's University of Ingolstadt (founded in 1472), which combined a medical-chemical research facility with a botanical garden patterned after the French model, Louis François Emmanuel Rousseau (1788–1868) held experimental lectures for students of all the faculties as a required part of his professorial duties. In addition to its significance in the German Humanist movement and in the Counter-Reformation, Ingolstadt was an important science center; Mary Wollstonecraft Shelley, in her classic Gothic romance *Frankenstein* (1818), chose it as the university to which Victor Frankenstein's father sent his son, who learned there all that his masters could teach him of natural science. And in Goethe's Weimar, Alexander Nicolaus von Scherer (1771–1824) offered experimental lectures, sponsored by Grand Duke Karl August, to the public with great success. In 1799 the author Joseph Rückert wrote [7b]:

> In Weimar nothing is spoken of now except gas, oxygen, combustible materials, easily—and difficultly fusible things. All the citizens of Weimar, male and female, seem to want to become chemists and want Weimar to become a big smelting furnace.

At Göttingen in 1781 Georg Christoph Lichtenberg (1742-–1799) began to lecture in the first university chair of experimental physics in Germany, which was established specifically for him. His best known demonstration—that of the figures formed when an electrical discharge is created near or in contact with a plate of insulating material dusted with powdered insulator (The so-called "Lichtenberg figures")—on which the modern photocopier is based, is still used today. An advocate of large apparatus, Lichtenberg said, "Repeating an experiment with larger apparatus is tantamount to looking at the phenomenon through a microscope" [1f].

Masters of the "Golden Age" of Demonstrations

The nineteenth century was the "heyday" of popular scientific lecture demonstrations carried out in large lecture halls for the benefit of a diverse public, many of whom were of the working class. First among the organizations fostering such lectures was London's Royal Institution of Great Britain on London's Albemarle Street, where it still stands today [12]. Founded in 1799 as a center for the popularization of the "mechanical arts" by the American Tory Benjamin Thompson (1753–1814), who had fled from the United States after being accused of spying for the British during the Revolutionary War and who is better known as Count Rumford, the title bestowed on him by the Duke of

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Bavaria, the RI is described by Sir John Meurig Thomas, its former director, as England's "oldest repertory theatre of science" and "the foremost repertory theatre for the popularization of science in the world." When the balcony is full, its lecture hall of unsurpassed design, half a hemisphere of only about twenty feet radius, can accomodate more than four hundred persons, who can hear the lecturer even when he whispers.

On August 3, 1801, physicist Thomas Young (1773–1829), best known today for his advocacy of the wave theory of light, was appointed the RI's first "Professor of Natural Philosophy, Editor of the Journals, and Superintendent of the House" [13]. His primary duty was to give popular lectures on "natural philosophy and the mechanical arts," which he presented in 1802 and 1803 with indifferent success because they were too erudite, technical, obscure, and detailed for his audience. Young resigned on July 4, 1803. Two of his experiments—"Young's fringes" (double-slit interference) and "Young's color patch" of primary colors—are still the basis for some of today's most popular optical demonstrations [1g].

Although the RI's first professor of chemistry, Thomas Garnett (1766–1802)[8b], appointed in 1799, had been a successful lecturer at Anderson's College in Glasgow, Scotland, he was broken in spirit by his wife's death in childbirth, and he soon died of typhus. His assistant lecturer, the largely self-taught, Cornish youth, Humphry Davy (1778–1829), appointed on February 16, 1801, succeeded him in May of 1802 as professor and in June of 1802 as lecturer (Figure 1)[14]. A true Romantic (he was a poet and a friend of Wordsworth, Byron, and Coleridge; Coleridge even attended Davy's lectures "to increase his stock of metaphors"), Davy quickly rose from the son of an often unemployed woodcarver to "the most brilliant chemist of his age" and "one of the most respected and most disliked men of science ever." (Many perceived his social unease as haughtiness or snobbery.) Considered the Newton of his day, he was the first scientist to be knighted (at age 33) since Newton, and when he received a baronetcy, the highest honor ever conferred on a British scientist, he surpassed even Sir Isaac.

Davy's showmanship and zeal in popularizing his discoveries made him "the first preacher of applied science." He invented the carbon arc light, the miner's safety lamp, and "cathodic protection" for vessels of the British navy. At a time when a career in science was most unusual, he became a professional scientist when only the Astronomer Royal could be so described. Davy's introductory RI lecture brought him tremendous social success and was followed by constant dinner invitations. His lectures were

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FIGURE 1. SIR HUMPHRY DAVY (1778-1829).

attended by large and fashionable audiences, whose support made the RI Britain's premier research institute [14a]. He was a special favorite among the fair sex, and the ladies said, "Those eyes were made for something besides poring over crucibles." His lectures were so popular that on RI discourse nights traffic on Albemarle Street was made one-way, and when he lectured in Ireland, a black market in tickets developed [14b].

The presentation of Davy's current research results in his lectures, together with his strong sense of theater, made them particularly exciting. Yet, unlike chemical lecturers at medical schools, his audiences were not students, and any hopes that he might have cherished that gentlemen in his audiences might take up scientific research were not fulfilled [14c]. In regency England chemistry was largely confined to the training of physicians and was not considered a suitable subject for a liberal education. Davy's lectures remained primarily entertainment, as underscored by James Gillray's famous contemporary caricature of a public lecture at the RI depicting Thomas Garnett

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FIGURE 2. JAMES GILLRAY'S CONTEMPORANEOUS CARICATURE OF A LECTURE AT THE ROYAL INSTITUTION IN 1802 (REPRODUCED WITH PERMISSION OF THE BRITISH MUSEUM).

administering nitrous oxide ("laughing gas"), whose physiological effects had been investigated by Davy, to volunteer Sir John Coxe Hippisley, one of the RI's managers, while a gleeful Davy operates the bellows (Figure 2).

In 1813, at the pinnacle of his meteoric career, Davy resigned his professorship and devoted the remainder of his life to travel and research. The previous year he had hired Michael Faraday (1791–1867)[15] as his assistant on the basis of the notes and drawings that he had made of some of Davy's lectures. Faraday, regarded as Davy's "greatest discovery," was poor like his mentor (his father was a blacksmith) and self-taught. While apprenticed to a bookbinder, Faraday, a youth with a profound desire for self-improvement, worked his way through the electrical articles in the *Encyclopædia Britannica* and later enunciated Faraday's laws of electrolysis, which established the intimate connection between electricity and chemistry and placed electrochemistry on a

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modern basis. In 1991 numerous meetings and symposia were held, a number of books were published to commemorate the 200th anniversary of the birth of one of Britain's greatest chemists and physicists [16–21], and the first two sections of Faraday's *Experimental Researches in Electricity* (1839–1855) were reprinted as "A science classic" [22]. That same year the British Royal Mint honored Faraday by replacing Shakespeare on the verso side of its new £20 note with a portrait of Faraday and a picture of him giving one of the annual Christmas lectures that he inaugurated at the RI. Also, the British Post Office issued a postage stamp to honor Faraday's birth.

After returning to London from a 18-month tour of the continent with Lady Davy and Sir Humphry; for whom he served as scientific assistant, secretary, and valet; Faraday, with Davy's backing, was reappointed laboratory assistant at the RI, where he carried out a number of revolutionary chemical and physical researches. In 1825 he was promoted, again with Davy's backing, to Director of the Laboratory and in 1833 Fullerian professor of chemistry, an endowed chair created especially for him, without lecture obligations, although he continued to make occasional public appearances.

Davy had made showmanship the essence of the RI, and his protégé Faraday continued the tradition, becoming the darling of society like his mentor and even more popular as a lecturer and demonstrator *par excellence*. According to Bryan Oakes, although it has been said that Davy's genius was overshadowed by Faraday's perfection, "a better metaphor would be to describe Davy as the dawn and Faraday as the light of day....Faraday could not have achieved what he did without Davy's early encouragement" [23].

In 1826 Faraday established the series of weekly lectures called Friday Evening Discourses, which are still held today, being timed to begin exactly at 9 p.m. and end exactly at 9:59:50 p.m. These so-called "penny lectures" for everybody, named after their entrance price, brought in considerable sums to the RI, for they were well attended. After 1835 Faraday's health began to deteriorate, and he successively began to abandon his various activities; the last that he gave up were his Friday Evening Discourses. He said that his need to perfect experiments for these lectures, such as the production of artificial rubies, the reproduction of worms, and the silvering of mirrors, stimulated his research. Disliking the separation of physics and chemistry, he called himself an "experimental philosopher." He retired from scientific work in 1858 after almost a half century's tenure at the RI, where his apparatus and lecture notes are still preserved.

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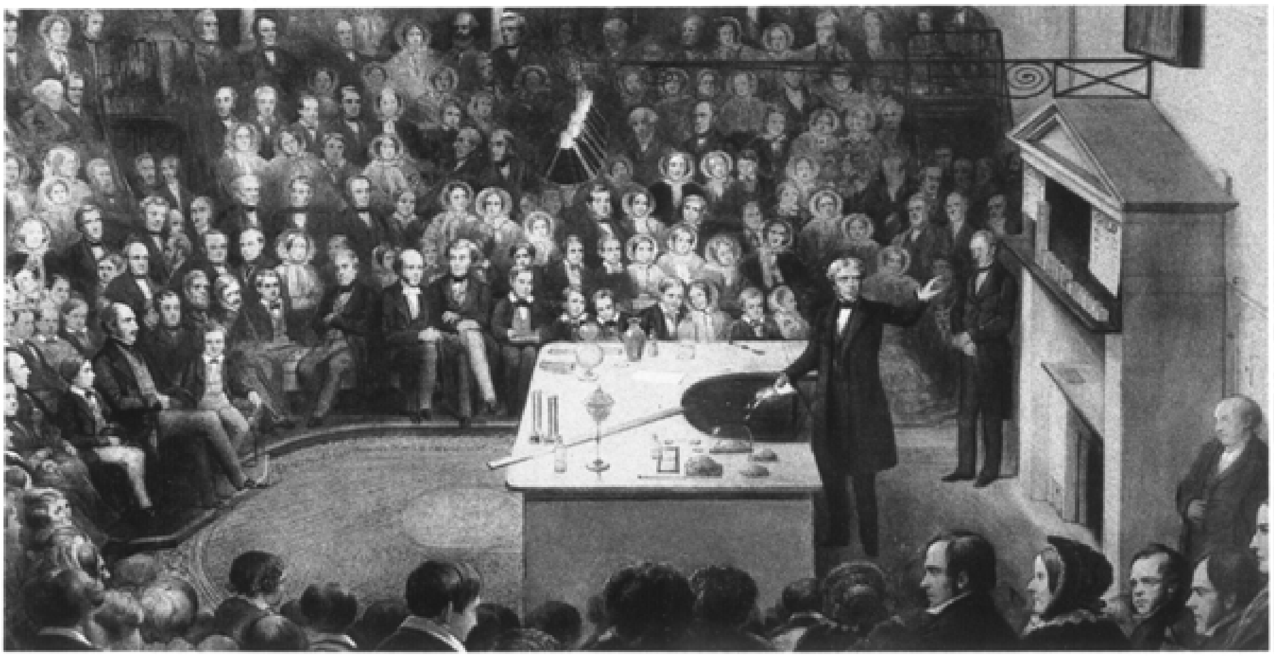

FIGURE 3. MICHAEL FARADAY'S 1855 CHRISTMAS LECTURE, ATTENDED BY THE PRINCE CONSORT ALBERT (SEATED DIRECTLY FACING THE LECTURE TABLE) AND ON HIS LEFT THE YOUNG PRINCE OF WALES (THE FUTURE EDWARD VII)(REFERENCE 23) (BY COURTESY OF THE ROYAL INSTITUTION).

In 1826 Faraday also initiated the famous series of annual Christmas Lectures for young people (known formally as "Christmas Courses of Lectures Adapted to a Junior Auditory"), long before such efforts became fashionable (Figure 3). Except for a short hiatus during World War I, these lectures have continued to the present day. The first series was given by an astronomer, John Wallis, but the next year (1827) Faraday presented a "Course of Six Elementary Lectures on Chemistry," the first of 19 series that he was to give.

The most famous series of Faraday's Christmas Lectures is "The Chemical History of a Candle," six lectures presented in 1848–1849 and repeated in 1860–1861 (Figure 4). The latter version, edited by Sir William Crookes, another ardent popularizer of science, is a true classic of science and has been reprinted in many anthologies such as *The Harvard Classics* and *Gateway to the Great Books* (Japanese translations alone have amounted to more than seventy editions!)

A number of prominent contemporary lecture demonstrators have recently updated the Faraday tradition to present Christmas lectures using a modern technological medium

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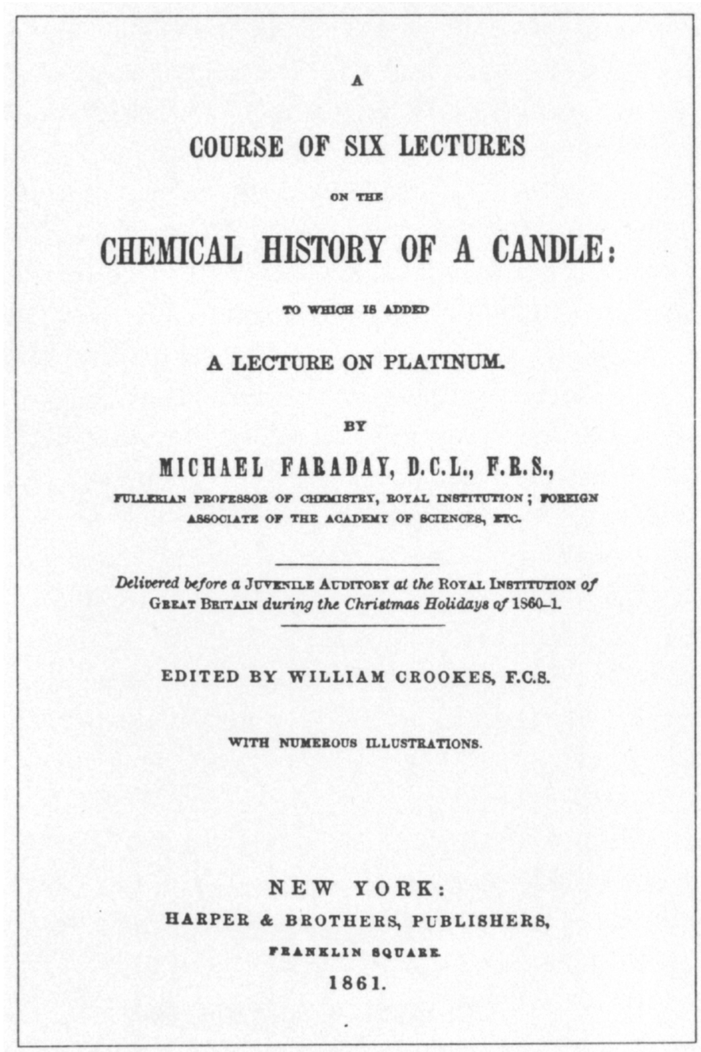

A

COURSE OF SIX LECTURES

ON THE

CHEMICAL HISTORY OF A CANDLE:

TO WHICH IS ADDED

A LECTURE ON PLATINUM.

BY

MICHAEL FARADAY, D.C.L., F.R.S.,

FULLERIAN PROFESSOR OF CHEMISTRY, ROYAL INSTITUTION; FOREIGN ASSOCIATE OF THE ACADEMY OF SCIENCES, ETC.

Delivered before a JUVENILE AUDITORY *at the* ROYAL INSTITUTION *of* GREAT BRITAIN *during the Christmas Holidays of* 1860–1.

EDITED BY WILLIAM CROOKES, F.C.S.

WITH NUMEROUS ILLUSTRATIONS.

NEW YORK:
HARPER & BROTHERS, PUBLISHERS,
FRANKLIN SQUARE.
1861.

FIGURE 4. TITLE PAGE OF MICHAEL FARADAY'S *CHEMICAL HISTORY OF A CANDLE* (1861) (REPRODUCED WITH PERMISSION OF THE *BULLETIN FOR THE HISTORY OF CHEMISTRY*).

unavailable to Faraday to reach an audience much wider than he could ever dream of—the videocassette. For example, Bassam Z. Shakhashiri has produced "Once Upon a Christmas Cheery/In the Lab of Shakhashiri" [24], and "The Michael Faraday Christmas Lecture" features Ron Ragsdale and Jerry Driscoll of the University of Utah clad in nineteenth-century garb [25]. In his book *Atoms, Electrons and Change* (W. H. Freeman: New York, 1991) Peter W. Atkins, using almost a century and a half of scientific knowledge unavailable to Faraday, again takes up the task that Faraday set for himself—to see the complexity, but underlying simplicity, of chemical change through the light of a candle, one of humanity's simplest but most symbolic artifacts.

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Furthermore, John J. Fortman presented "Updated Versions of Some of Faraday's Demonstrations" as part of the American Chemical Society's Spring 1992 lecture tours, while the laboratory program of the 1992 Dreyfus/Woodrow Wilson/NSF Institute for High School Chemistry Teachers held at Princeton University was devoted to Faraday's "The Chemical History of a Candle."

In the introduction to the first lecture of his famous classic (1860-1861) Faraday told his young audience [26a]:

> I have taken this subject on a former occasion, and, were it left to my own will, I should prefer to repeat it almost every year, so abundant is the interest that attaches itself to the subject, so wonderful are the varieties of outlet which it offers into the various departments of philosophy. There is not a law under which any part of this universe is governed which does not come into play and is touched upon in these phenomena. There is no better, there is no more open door by which you can enter into the study of natural philosophy than by considering the physical phenomena of a candle. I trust, therefore, I shall not disappoint you in choosing this for my subject rather than any newer topic, which could not be better, were it even so good. And, before proceeding, let me say this also: that, though our subject be so great, and our intention that of treating it honestly, seriously, and philosophically, yet I mean to pass away from all those who are seniors amongst us. I claim the privilege of speaking to juveniles as a juvenile myself. I have done so on former occasions, and, if you please, I shall do so again. And, though I stand here with the knowledge of having the words I utter given to the world, yet that shall not deter me from speaking in the same familiar way to those whom I esteem nearest to me on this occasion.

In concluding the sixth and last lecture Faraday, an extremely pious and high-principled man (he was a member of the Sandemanian sect), urged his listeners [26b]:

> all I can say to you at the end of these lectures...is to express a wish that you may, in your generation, be fit to compare to a candle; that you may, like it, shine as lights to those about you; that, in all your actions, you may justify the beauty of the taper by making your deeds honourable and effectual in the discharge of your duty to your fellow-men.

The Faraday lecture demonstration tradition was continued in masterly fashion by his successors at the RI such as John Tyndall (1820–1893), Sir James Dewar (1842–1923), and Sir William Lawrence Bragg (1890–1971). Also other scientists, both domestic and foreign, demonstrated their latest discoveries at the RI.

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On the Continent a number of 19th-century chemists found fame for their lectures and demonstrations in addition to their research. In Sweden, during the 1820s, Jöns Jacob Berzelius (1779–1848), the great systematizer of chemistry, who had been knighted in 1818, lectured in his Academy of Sciences uniform bedecked with medals before the Swedish royal family—women in elaborate, decolleté gowns and men in full dress uniforms adorned with swords [7c]. The young German Friedrich Wöhler (1800–1882), who assisted him with demonstrations, was soon to become a famous chemist in his own right. Justus von Liebig (1803–1873), whose name is often paired with that of his friend and collaborator Wöhler, as one of the founders of organic chemistry, had completed his studies in Paris where he absorbed the lecture tradition of the Jardin des Plantes, which he brought to Germany upon his return. Liebig was particularly influenced by Louis-Nicolas Vauquelin (1783–1829), whose lovable character was memorialized by Honoré de Balzac in his novel *Histoire de la grandeur et de la décadence de César Birotteau* (1834–1837) as well as by Joseph Louis Gay-Lussac (1778–1850) and Louis Jacques Thenard (1777–1857)[7c].

In 1824 Liebig, who, incidentally, was said to be a clear but boring lecturer, was called to the University of Giessen, where he founded his famous school of chemistry, said to be the first to include student laboratory work as an integral part of the instruction. Previously, chemistry was taught solely by demonstration [5]. Paradoxically, Liebig was bored by laboratory teaching, and one of his conditions for accepting the chemistry chair at Munich in 1853 was that he be exempted from this duty. He simultaneously served at the Bavarian Academy of Sciences, where, despite the fact that he was said to be a sloppy demonstrator [27], he continued the tradition of presenting “Abendvorlesungen für Hörern aller Stände” (Evening Lectures for Hearers of All Social Classes), which became a great social event that attracted many of the women of Munich. In fact, it was to a woman, Josephine, the wife of Ludwig I’s court painter Joseph Karl Stieler, that we are indebted for a transcript of Liebig’s lecture notes [7c]. In 1983 Otto Paul Krätz and Claus Priesner published Liebig’s lecture notes with detailed descriptions of his demonstrations [28]. Because chemical lecture demonstrations have been a prominent tradition at German universities, numerous manuals on the subject were published, the most famous of which were *Anleitung zum Experimentieren bei Vorlesungen über anorganische Chemie* (Braunschweig: Vieweg, 1876, 1893) by Karl Heumann (1850–1893) and *Technik der anorganischen Experimentalchemie* (Leipzig: Voss, 1881, 1891–92, 1900, 1910) by Rudolf Arendt (1828–1902).

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In the United States the previously mentioned appointment in 1769 of Benjamin Rush (1745–1813) as professor of chemistry at the College of Philadelphia (now the University of Pennsylvania Medical College) marked the formal beginning of chemistry in America. Prominent nineteenth-century American chemical demonstrators included Amos Eaton (1776–1842), an itinerant lecturer who wrote a handbook for such lectures; Robert Hare (1781–1858) of the University of Pennsylvania, inventor of the oxyhydrogen blowpipe; Thomas Duché Mitchell (1791–1865) of Miami, Transylvania, and other universities, one of the Midwest's earliest chemistry teachers; John Webster (1793–1850) of Harvard University, famous—or infamous—for being hung for his murder of a fellow faculty member; and Samuel P. Sadtler (1847–1923) of the University of Pennsylvania, author of the first American book on chemical demonstrations, *Chemical Experimentation, Being a Handbook of Lecture Experiments in Inorganic Chemistry* (Louisville, KY: Morton, 1877).

Twentieth-Century Demonstration Virtuosos

In Britain, the Davy-Faraday tradition is alive and well at the Royal Institution. The two former directors—the 1967 Nobel chemistry laureate Lord Porter (formerly Sir George Porter) and Sir John Meurig Thomas [29] are well known for their superb lecture demonstrations as are Charles Taylor, Professor of Experimental Physics at the RI [1]; David Phillips, Professor of Chemistry at Imperial College, London and former Wolfson Professor of Natural Philosophy at the RI; and Brian Iddon, reader in chemistry at the University of Salford. Brian Bowers of London's Science Museum has also established a similar reputation.

In the United States for many years the grand old master of chemistry lecture demonstrations has been, without a doubt, the nonagenarian Hubert Newcombe Alyea (1903–1996), Professor Emeritus at Princeton University and the prototype for "The Absent-Minded Professor" (played by Fred MacMurray) in Walt Disney's 1961 motion picture of the same name (Figure 5). A living legend, he has inspired generations of students and teachers. As one prominent chemical demonstator remarked, "To hear him talk about his life is to live chemistry."

In 1928 Alyea proposed the domino theory to explain how chemical inhibitors break chains in chemical reactions, and it became the first of the hundreds of demonstrations that he devised (His classic domino board used in this demonstration is on exhibit at the

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Beckman Center for the History of Chemistry in Philadelphia). More than two decades later U. S. President Dwight D. Eisenhower applied Alyea's domino theory to political conditions in the Far East (the "domino effect"). Alyea's "Old Nassau Reaction," a clock (delayed time) reaction so-called because the solution first turns orange and then black (the colors of the House of Nassau and of Princeton, whose Old Nassau Hall was the world's first undergraduate chemistry laboratory) is probably the most imitated chemical demonstration. Variations of it by other demonstrators are perennial items in journals and books. Alyea has delighted and enlightened countless audiences with his thousands of lectures through the years. He has presented his popular demonstration lecture, "Lucky Accidents, Great Discoveries, and the Prepared Mind" alone on more than three thousand occasions. His demonstration books [30–33] have gone through numerous editions. During 1954–56 and 1957–64 his features "Tested Demonstrations in Chemistry" and "Demonstration Abstracts," respectively, appeared monthly in the *Journal of Chemical Education.* Beginning with 1957 the journal initiated the monthly series "Chem-Ed Tested Demonstrations," edited first by Frederic B. Dutton of Michigan State University, East Lansing (1957–64), later by Dale Dreisbach (1964–74), and now by George L. Gilbert of Denison University, Granville, Ohio (1974–). Other journals and magazines such as *Chem 13 News*, the *Journal of College Science Teaching*, *Scientific American*, and *The Science Teacher* are also good sources for demonstrations.

With National Science Foundation (NSF) support (1960–62) Alyea developed a series of overhead projections of chemical experiments (TOPS, Tested Overhead Projection Series) and conducted workshops on this new technique for NSF; Atomic Energy Commission (AEC); Asia Foundation; Fulbright Foundation; United States Department of State Agency for International Development (AID); United Nations Educational, Scientific, and Cultural Organization (UNESCO); and the U.S. Department of Commerce in more than 75 countries. Using only 28 devices that he himself designed, he was able to carry out all 1000 experiments from his "Tested Demonstrations" series. These experiments appeared in his "TOPS in General Chemistry" series (1962–71) in the *Journal of Chemical Education.* Doris Kolb of Bradley University, Peoria, IL is currently editing the series "Overhead Projection Demonstrations" for the journal.

When carried out on the stage of an overhead projector, demonstrations can be performed simply, quickly, and easily. Ideal for a time of decreasing budgets and increasing workloads, they are inexpensive because the quantities of chemicals as well

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FIGURE 5. HUBERT NEWCOMBE ALYEA (1903–1996)(COURTESY, PROF. H.N. ALYEA).

as the preparation and clean-up time required are minimal. Furthermore, in today's safety-conscious and litigation-prone society, small-scale reactions involve very little danger. Most important of all, projected reactions are readily visible—even by students in the last row of the lecture theater. Although the lecturer may use only drops of solution, the audience as far as a hundred feet away sees them on the screen live, in color, as big as baseballs in test tubes six feet tall and two feet wide.

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One problem with the technique is that all reactions are viewed from the top, looking down rather than from the side, a disadvantage when bubbles of gas are being viewed. Alyea's TOPS technique, which permits vertical projection of reactions, allows the audience to see bubbles rise when a gas is generated, although the apparatus is somewhat cumbersome. For this reason in 1989 Alyea introduced an inclined-stage projection adaptor that was less awkward and cheaper than the vertical-stage adaptor. The latest edition of his *Micro-Chemistry Projected* [31] features this "tilted-TOPS" technique. To commemorate Alyea's numerous contributions to the art of chemical demonstrations a "Symposium in Honor of Hubert Alyea: Prepared Accidents and Planned Discoveries" was sponsored by the Division of Chemical Education at the 197th National Meeting of the American Chemical Society, Dallas, Texas, April 11, 1989. Hubert Alyea died on October 19, 1996 at the age of 93.

The currently reigning dean of American chemistry lecture demonstrators is Bassam Zekin Shakhashiri, Professor of Chemistry at the University of Wisconsin, Madison. Born in Lebanon in 1939, he is probably best known to the public at large for his previously mentioned annual entertainment, "Once Upon a Christmas Cheery/In the Lab of Shakhashiri" [24], which he has been performing since 1969. His December 16, 1991 performance at the National Academy of Sciences in Washington, DC was taped by the Public Broadcasting Service (PBS) for showing nationwide just before Christmas. As an articulate advocate for science, Shakhashiri seeks to impart the joy of discovery that has aroused young minds throughout history (For the show he wears a "Science Is Fun" T-shirt) (Figure 6). He believes that this excitement will lure future generations to careers as researchers, entrepreneurs, and teachers on whom the nation's continuing economic health and national security will depend. He is famed for his development and use of demonstrations in teaching chemistry in lecture halls and laboratories as well as in less formal settings such as convention centers, shopping malls, and retirement homes. His interactive chemistry exhibit has been on permanent display at Chicago's Museum of Science and Industry since 1983, the year in which he founded and became first Director of the Institute for Chemical Education (ICE). In 1984 he became the National Science Foundation's Assistant Director for Science and Engineering Education. He returned to Madison in 1990. Some selected science lecture demonstrators are listed in Appendix I.

Demonstrators and popularizers of science outside of academe have exerted a profound influence on a wide audience of young and old alike by use of the mass media. No less an authority than Shakhashiri dedicated the latest volume (No. 4, 1992) of his critically

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FIGURE 6. BASSAM ZEKIN SHAKHASHIRI (B. 1939)(COURTESY, PROF. B.Z. SHAKHASHIRI).

acclaimed series, *Chemical Demonstrations* [34], the definitive sourcebook on the subject, "to Don Herbert, Television's Mr. Wizard, who has perfected the art of communicating science to kids of all ages." More recently (May, 1993), K. C. Cole, a senior editor of the magazine *Discover*, said "I grew up watching not only Mr. Wizard but Rod Serling." In 1994 Herbert (born in 1917), the film and television producer-performer whose TV show was broadcast by the NBC Network from 1951 to 1965, received the American Chemical Society's James T. Grady-James H. Stack Award for Interpreting Science for the Public. Another popular TV science program making extensive use of demonstrations is the weekly PBS series, "Newton's Apple," originally hosted by Ira Flatow, who was succeeded in 1987 by David Heil, Associate Director of Portland's Oregon Museum of Science and Industry.

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Demonstrations, performed either by professional demonstrators or by the visitors themselves, are also an integral part of the program of many museums. After the passage of half a century, I still vividly remember myself as an adolescent repeatedly pushing buttons in Philadelphia's Franklin Institute—first to electrolyze water into its constituent gaseous elements hydrogen and oxygen and then to combine them explosively with a loud report to re-form water. Doubtless other youngsters have likewise been encouraged to pursue science as a career by similar experiences. In addition to the "interactive" museums mentioned earlier, New York's Museum of Natural History, Jersey City's Liberty Science Center, London's South Kensington Science Museum, Paris' Palais de la Découverte, Eindhoven's Evoluon, Munich's Deutsches Museum, San Francisco's Exploratorium, and Chicago's Museum of Science and Industry should be singled out for special attention.

Accidents, Safety, and ''Failed'' Demonstrations

Jearl Walker, Professor of Physics at Cleveland State University, editor of the "Amateur Scientist" feature of *Scientific American*, and a flamboyant master demonstrator, has been quoted as saying, perhaps with some exaggeration, "The way to capture a student's attention is with a demonstration where there is a possibility the teacher may die" [34a]. In the "old days," when safety precautions that we take for granted today were routinely neglected, demonstration accidents were not uncommon. Three historic accidents are typical [35]:

> During a lecture by Justus Liebig before a selected audience in Munich he exhibited the strikingly beautiful combustion of carbon bisulfide [disulfide] 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.

In 1894 Julius Lothar Meyer (1830–1895), an independent discoverer of the periodic law of the elements, was demonstrating one of his favorite reactions—the explosive combustion of acetylene—when the apparatus shattered [35]:

> 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

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> could see me talking but could hear nothing because the report had deafened him temporarily.

Another historic demonstration accident, described by Benjamin Silliman in his 1830 textbook, *Elements of Chemistry*, is recounted by Bodner [35]:

> [Jean-François] Pilatre de Rozier [1754–1785] 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.”

To prevent such occurences, in 1988 the American Chemical Society adopted “Minimum Safety Guidelines for Chemical Demonstrators” [36], according to which they 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.

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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.

It has been aptly said that students and the demonstrator can learn more from a demonstration that does not proceed as expected (No demonstration can be said to have failed if it is instructive, and if the demonstrator attempts to learn the reason for the "failure") than from one that does. In the words of master chemistry demonstrator Henry A. Bent [34b, 37],

> Nature's an ideal lecture assistant. *She* never fails....What may fail, however, is the lecturer's imagination. There are no failed experiments, only unimaginative responses to unexpected occurrences....Doing experiments in lecture frequently yields unexpected, interesting, and memorable observations; and something about [Alfred] Whitehead's First Law of Higher Education: "The chief aim of a university professor [should be] to exhibit himself in his own true character—that is, as an ignorant man thinking." It's the unexpected occurrences in life that we remember.

The classic example of an incredibly productive demonstration that "failed" is the one performed during the autumn of 1882 by the German chemist Victor Meyer (1848–1897), whose histrionic ability and theatrical perfection of his lecture demonstrations (As a youth he had intended to become an actor) had attracted many students from both Europe and America [38–40]. In his course of lectures on benzene derivatives at Zürich's world–famed Polytechnikum (now the Eidgenössische Technische Hochschule or ETH), where he had been appointed full professor at the early age of 24, Meyer applied Adolf von Baeyer's indophenine test to a sample of benzene (C_6H_6) prepared by decarboxylating (removing carbon dioxide) from benzoic acid. To his amazement, the test, which results in a deep blue color and which was then supposedly a test for benzene, proved negative. Meyer's lecture assistant, Traugott Sandmeyer (1854–1922), later a famous chemist in his own right, reminded him that the benzene sample used that morning in the pre-lecture rehearsal of the test was commercial benzene prepared from coal tar. (In contrast to the practice in the United States, demonstration assistants were and still are frequently Ph.D. scientists rather than technicians.)

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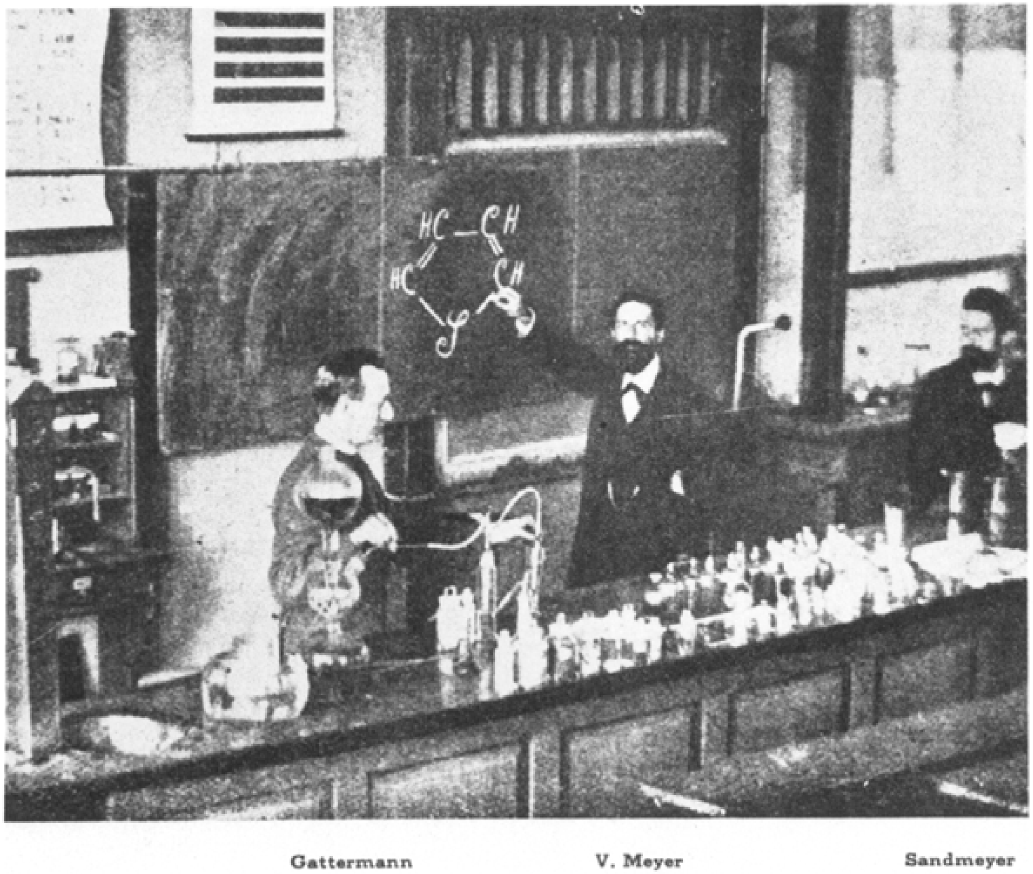

FIGURE 7. VICTOR MEYER (1848-1897) LECTURING ON THIOPHENE (STRUCTURAL FORMULA ON BLACKBOARD) WITH STUDENT LUDWIG GATTERMANN (1860-1920)(LEFT) AND TRAUGOTT SANDMEYER (1854-1922) (RIGHT) (REPRODUCED WITH PERMISSION OF EIDGENÖSSISCHE TECHNISCHE HOCHSCHULE).

That very same day Meyer began to investigate the indophenine reaction that had failed. By November 28 he had found that the purest benzene samples from coal tar always gave a positive reaction, while the same samples, after extraction with sulfuric acid, did not, nor did benzene prepared from benzene derivatives. He concluded that coal-tar benzene was a mixture of two substances with similar chemical and physical properties, only one of which gave a positive indophenine test. On June 1, 1883 he reported the isolation of the unknown compound (C_4H_4S), which he called thiophene because it contains sulfur (Greek, θειον) and because of its similarity to benzene and the similarity of its derivatives to benzene derivatives (Figure 7):

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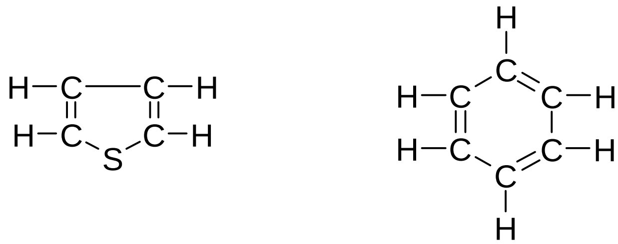

Thiophene C_4H_4S (b.p. 84°C)

Benzene C_6H_6 (b.p. 80°C)

It was the thiophene present in coal-tar benzene, rather than benzene itself, which undergoes the indophenine reaction. This, his most brilliant discovery, opened an entirely new area of research, and within five years he had published his 300-page monograph, *Die Thiophengruppe* (1888), which contained a list of 106 articles on the topic by him and his students.

Goals, Principles, and Techniques of Lecture Demonstrations

Almost every book of demonstrations features an introduction discussing the general philosophy of demonstrations. The best of these are probably Shakhashiri's and Taylor's volumes. According to Shakhashiri [34c],

> Lecture demonstrations help to focus students' attention on chemical behavior and chemical properties, and to increase students' knowledge and awareness of chemistry….The lecture demonstration should be a process, not a single event.

He feels that [34d],

> the single most important purpose that lectures serve is to give teachers the opportunity to convey an attitude toward chemistry—to communicate to students an appreciation of chemistry's diversity and usefulness, its cohesiveness and value as a central science, its intellectual excitement and challenge.

Thus demonstrations can enhance scientific literacy and help combat our society's prevalent anti-scientific attitude, fostered by the news media's frequently sensationalistic, one-sided stories that have given the public a poor perception of science and scientists. Chemistry, in particular, has been singled out for abuse; the phenomenon

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of "chemophobia"—an irrational fear of chemicals—is widespread. Scientists are blamed for technological disasters such as Three Mile Island, Bhopal, and Chernobyl and current environmental problems such as pollution, the greenhouse effect, acid rain, the erosion of the ozone layer, oil spills, and the proliferation of pesticides and of nuclear weapons and wastes. Education of the public, in which demonstrations can play a vital part, is the solution to the problem of misinformation and distortion.

Paul Saltman of the University of California, San Diego has arranged the intellectual activities in which teachers and students engage in learning chemistry in a hierarchy of increasing complexity that can provide a framework of goals for the practice of lecture demonstrations [34c, 41]: (1) observing phenomena and learning facts; (2) understanding models and theories; (3) developing reasoning skills; and (4) examining chemical epistemology (the limits and validity of fundamental chemical knowledge). Because of the first goal—to increase the students' ability to make observations—it is well not to announce what should happen before performing the demonstration. The technique of "show and tell" rather than "tell and show" can also increase suspense and interest, treat the demonstration as an experiment, and avoid embarrassment to the lecturer if the demonstration does not proceed as expected.

Wesley Smith of Ricks College, Rexburg, ID has outlined six desiderata for performing an effective demonstration [34e]. It must be [42]:

1. timely and appropriate, i.e., related to the lesson material; well prepared and rehearsed [As Frederick H. Juergens, lecture demonstrator at the University of Wisconsin, aptly and alliteratively put it, "Prior practice prevents poor presentation."];

2. visible and largescale [This characteristic can also be accomplished by use of Alyea's TOPS techniques];

3. simple and uncluttered [For those enamoured of elaborate Rube Goldberg-type setups, the acronym KISS—Keep it simple, stupid!—is excellent advice.];

4. direct and lively [Quick results act as attention grabbers and provide maximum educational value. A prominent feature of the Biennial Conferences on Chemical Education is the presentation of a series of "quickie demos" requiring only a minute or two each.];

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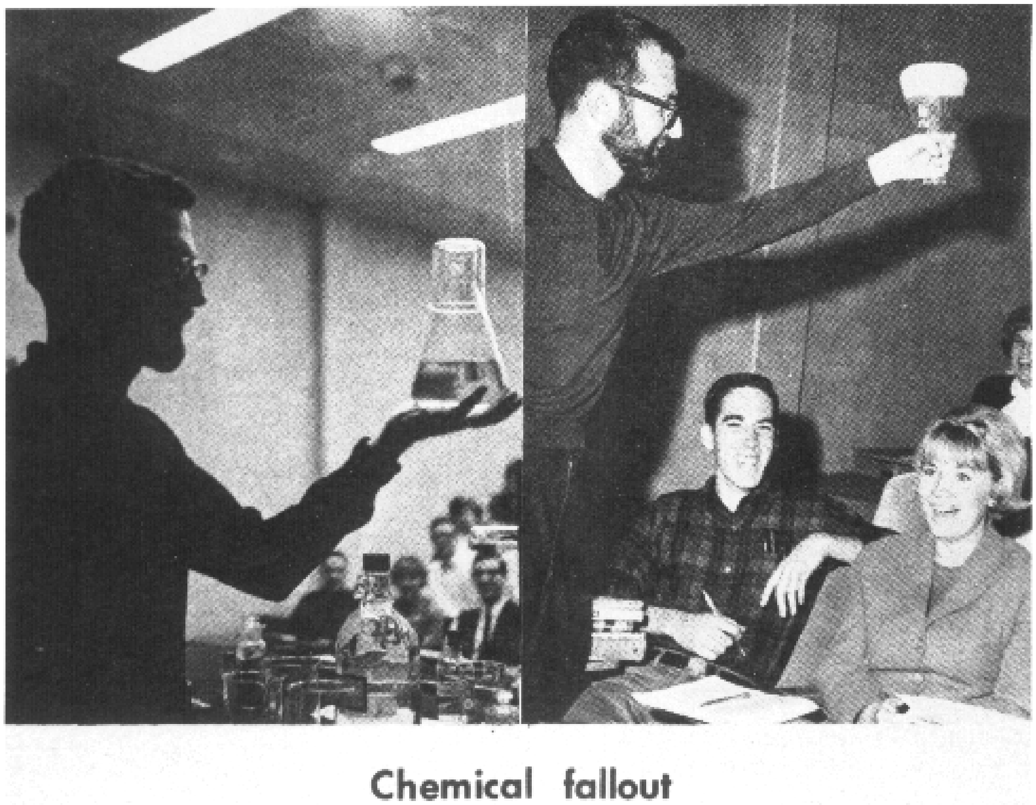

FIGURE 8. CHEMICAL FALLOUT: SEEDING A SUPERSATURATED SOLUTION OF SODIUM ACETATE; GEORGE B. KAUFFMAN AND STUDENTS, BEFORE THE ERA OF SAFETY CONSCIOUSNESS (CSUF *DAILY COLLEGIAN* PHOTOGRAPH, DEC. 2, 1966).

5. dramatic and striking (Figure 8) [Because a demonstration has much in common with a stage play, theatrical considerations, e.g., mental as well as physical preparation, presentation, audibility, audience participation, audience psychology, appropriateness for the audience's age group, contrasts, and climaxes, are important.]

To this list we might add an obvious function of demonstrations: As Alyea maintained, they provide welcome "breaks" that help students recover from the plethora of information with which they are inundated in a typical lecture [35].

Because Faraday insightfully analyzed the art of lecture demonstrating in a series of letters to Benjamin Abbott, a friend of his youth, excellent advice for lecturers is available in the words of a true master of the art (Appendix II)[43]. But perhaps the most succinct tribute to the lecture demonstration was stated by master demonstrator Richard W. Ramette, Professor of Chemistry at Carleton College, Northfield, MN [34f, 44]:

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> Chemistry is relatively boring to read and work problems about, unless the student has some vivid mental images of the experimental side of the science. Good demonstrations not only spice up a class session, but they also help teach principles, and they help build up general experimental knowledge of a sort that makes chemistry seem less abstract. ...the teacher who does not take advantage of demonstrations is doing his students a disservice.

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