NOTE: A MODERN SCIENTIFIC INTERPRETATION OF JOSEPH PRIESTLEY'S DISCOVERY OF CO

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This effort to understand at a distance of more than two hundred years how Joseph Priestley (Figure 1) discovered and characterized the gas carbon monoxide (CO) may interest today's chemists and students of chemistry. By using modern techniques we came to appreciate what Priestley was talking about and verify that he indeed got the results he claimed.

Priestley's accounts of his experiments are often difficult for even a modern chemist to understand, much less a casual reader. He used arcane language and reported on nearly every experiment he tried. Unlike a present-day scientist, who would describe relevant results as a coherent whole, Priestley threw everything in, results that made sense to him and others that left him puzzled. In the eighteenth century chemists were still struggling to understand which materials were what we call elements, which were compounds and what happened in the course of chemical changes. Famously Priestley employed the phlogiston theory in his explanations and interpreted his experimental results in those terms.

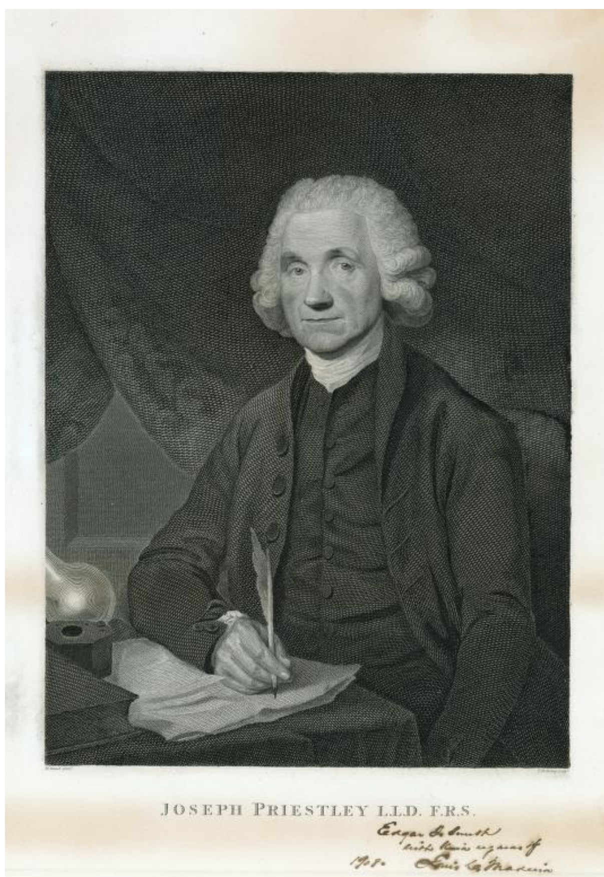

Figure 1*. Joseph Priestley, shown with two of his principal tools, a pen and a flask. Image Courtesy of the Edgar Fahs Smith Collection, University of Pennsylvania.*

The larger project of reenacting several of Priestley's gas discoveries was originally inspired by a desire to enliven the experience of visitors to the Joseph Priestley House Museum in Northumberland, Pennsylvania (Figure 2). Most visitors to the museum are not trained chemists, and so we sought a way to explain to non-specialists what Priestley did as a chemist and what it meant. This also gave us the opportunity to show how modern chemistry can and does connect with these eighteenth-century discoveries. In the rest of the Priestley House, the visitor is encouraged to recognize that Priestley's ideas and deeds resonate today on such varied subjects as separation of church and state, assimilation of immigrants into the United States, and free inquiry into virtually all realms of knowledge. Similarly, Priestley's chemistry should be seen as more than a matter of flickering candles, archaic apparatus, and strange concepts like phlogiston.

Visitors to the house can enter the room that Priestley designed as his laboratory, recently furnished with faux furnaces, fume hood, and reproduction apparatus. But this static context cannot ignite visitors' imaginations about the genius of Priestley's experimentation nor the excitement of chemistry in general. The docents, virtually all non-chemists, mention the gases Priestley discovered before he ever got to Northumberland dwelling on oxygen. They mention with local pride carbon monoxide, the gas he made famous while in residence. Our video series including actual experiments help to provide the needed context for his scientific work.

Priestley is well known as one of the co-discoverers, along with Carl Scheele and Antoine Lavoisier, of oxygen, a substance which Priestley called "dephlogisticated air." The phlogiston theory was a central paradigm of chemistry prior to the work of Lavoisier, who established a new theory that the transfer of oxygen from one substance to another explained chemical change. Phlogiston provided a unifying explanation for seemingly disparate processes (Table 1). Priestley, and even Lavoisier early on, were among the many researchers who saw unity in metallurgical processes, the combustion of plant and animal materials, and even respiration. In one group of these processes, *something* was lost or given off. In another, *something* was gained. According to the phlogiston theory, that something was a single substance, phlogiston, which imparted various properties such as inflammability, luster, and vitality. To recognize that phlogiston had been lost or gained, Priestley and other investigators relied on observed changes in color, luster, smell, combustibility, volume, and occasionally weight. In the course of applying phlogistic reasoning to more reactions, often involving newly discovered gases, the phlogiston chemists modified their theory, just as oxygen chemists would adjust theirs (1).

In spite of his advocacy for the phlogiston theory for too long in the face of the far superior "French" chemistry, Priestley remains an admirable figure in the-history of chemistry. He is credited with the discovery and characterization of nine gases in total (2). He was acknowledged in his own time and ever since as a master at following up observations that had been overlooked by other chemists (3).

Table 1. Some phlogistic explanations. Notation style below is modern.

Phlogiston Lost
Metal – Phlogiston → Calx (e.g., iron rust)
Plant or Animal – Phlogiston → Ash
Animal + Phlogiston + Air → Animal + Phlogisticated Air
Phlogisticated Air→Respirable Air (due to some unknown action of plants)
Phlogiston Gained
Calx + Phlogiston → Metal
Phlogiston Balanced Out
Phlogisticated Water + Dephlogisticated Water → Water

Figure 2. *Joseph Priestley House Museum, Northumberland, Pennsylvania. The laboratory protrudes from the main building on the right. Photo by Wikipedia user Ruhrfisch from Wikimedia Commons under a Creative Commons Attribution-Share Alike 3.0 Unported license.*

Priestley's original path to the discovery of carbon monoxide is something of a case in point. Like other chemists before and after, he had inadvertently produced carbon monoxide—as early as 1772—but had not thoroughly explored it (4). In 1785 he made "scales of iron" also known as "finery cinder," a byproduct of smelting iron ores, in the laboratory. He described two methods to produce this material: he passed steam over iron or he heated iron in "dephlogisticated air." Upon heating the "finery cinder" in the presence of "inflammable air" (hydrogen), he was able to "revive" the iron and condense water evolved during the reaction. He predicted that he would get a similar result if he heated finery cinder mixed with charcoal, a supposed source of phlogiston, which he and other proponents of the phlogiston theory thought imparted metallicity to materials. Instead, he got no water but just gases, which he eagerly investigated, one of which proved to be CO (5).

As was the case with oxygen, priority disputes arose about the discovery of carbon monoxide. In 1776 Joseph Marie François de Lassone submitted a paper to the Académie Royale des Sciences recording the production of a flammable gas from heating flowers of zinc (ZnO) with charcoal. The gas burned with a blue flame and did not explode (6). Like Priestley, de Lassone did not succeed in determining the composition of the new gas. It was not completely characterized until 1801 by William Cruickshank in England (7) and, working independently in France, by the duo, Charles-Bernard Desormes and Nicolas Clément (8).

Priestley's experiments leading to his discovery of oxygen have often been repeated or mimicked in some fashion, as in live chemistry shows performed on special occasions at Priestley House in Northumberland by retired chemistry teacher Ron Blatchley and in the recent PBS series, "The Mystery of Matter" (9). Such is not the case with carbon monoxide or any other of Priestley's discoveries in gas chemistry.

Convinced by a proposal submitted by the Susquehanna Valley Local Section of the American Chemical Society, the ACS, through its program of Local Section Innovative Projects, agreed to underwrite the creation of a ten-minute video about Priestley's discovery of carbon monoxide to be available at the house and online (10). This video was envisaged as the first of several on his chemical discoveries, and two additional videos have been completed—on ammonia gas and on nitrous oxide (11).

No one needs reminding that carbon monoxide is, in itself, an important subject. We are daily urged to install carbon monoxide detectors in our homes and workplaces lest we succumb to the toxic effects of its binding to blood hemoglobin. Less recognized are carbon monoxide's many industrial uses. With significant safety precautions, it is used to make detergents, liquid fuels, and other common products. But these recognitions came after Priestley's time, in some cases, long afterwards.

Priestley repeated the experiments he had performed in 1785 generating carbon monoxide and characterizing it several times over the years with some variations, but he sometimes just referenced earlier experiments (12). To drive off any gases that might already be contained in his reagents, he first heated the charcoal and the "finery cinder" separately. Then he heated them, mixed together, in a ceramic retort, and produced iron metal, "fixed air" (CO_2), and "heavy inflammable air" (CO).

Priestley concluded from various tests that he had found a different gas from other gases he had already catalogued. He estimated its specific gravity and early noted it was "quite as heavy as common air" (13). Measuring specific gravities of gases was difficult experimentally. Priestley often resorted to pigs' bladders as containers to avoid problems presented by the extra weight of water or mercury clinging to glassware used in a pneumatic trough to store a gas. A bladder could be connected directly to the experiment's delivery tube. But weighing a bladder filled with air and then the same bladder filled with the gas being tested presented problems as well. For example, it would not be certain that all ambient air had been squeezed out of such a bladder before it was used to receive a test sample, although Priestley flushed the bladder out with the gas being tested before filling it for the final time (14).

Priestley also tested the solubility in water of the new gas, finding it far more soluble than the "purest kind" [hydrogen] made from the solution of metals in acid or from steam passed over red hot iron (15). And he found that the new air burned with a low blue flame but did not explode when ignited as did some others of the "inflammable airs" (16).

What was most important for Priestley about his discovery of carbon monoxide was the use he could make of it in his never-ending disputes with Lavoisier and his followers about how to explain the familiar processes of transforming metallic ores into metals (17). While in America, Priestley recalled James Watt's role in pointing out the importance of this experiment. "It was one that the Antiphlogistians could never reconcile to their hypothesis; and the more I consider it, and the objections that have been made to it, the more reason I see to be of his opinion" (18).

Priestley's explanation of the experiment generating CO evolved during the course of more than a decade. By the time he was in America he was theorizing that finery cinder actually contains tightly bound water, which he considered a component of many substances, an element so-to-speak. This water could not be released by heat alone but required phlogiston to set it free. Moreover, he had concluded that all gases contain this elemental water, "water entering into the constitution of all kinds of air, and being, as it were, their proper *basis* that without which no aëriform substance can subsist" (19). In 1796 he wrote (20)

> The finery cinder containing water, as one of its component parts, gives it out to any substance from which it can receive phlogiston in return. The water, therefore, from the finery cinder uniting with the charcoal makes the inflammable air, at the same time that part of the phlogiston from the charcoal contributes to revive the iron. Inflammable air of the very same kind is procured when steam is made to pass over red-hot charcoal.

A few lines later he claims that fixed air, which he often observed as a product of the finery cinder experiment, consists of inflammable air [CO] and dephlogisticated air [O].

From America in 1796 and again in 1800, Priestley challenged the chemical world to give other explanations (22). American, French, and English chemists responded vigorously (23). They repeated Priestley's experiments and interpreted them mainly in ways a modern chemist would approve, and certainly without phlogiston. According to Cruickshank, Desormes, and Clément, heat released oxygen from the iron compound, and the combination of oxygen with charcoal, an "element" in their estimation, formed "fixed air" and "oxide of carbon" as expressed in English (7); "gaz carbonique" and "gaz oxide de carbone" in French (8).

The focus of the video is carrying out, in some fashion, key experiments that Priestley performed in the process of discovering carbon monoxide. Accomplishing this feat turned out to be easier said than done. Dee Casteel, Associate Professor of Chemistry at Bucknell University in Lewisburg, PA, rose to the challenge. She and others argued against a re-enactment entailing reproduction eighteenth-century apparatus, such as a pneumatic trough filled with mercury, reagents of unknown

finery cinder (including water)	+	charcoal (including phlogiston)	→	iron (including phlogiston) Fe	+	heavy inflammable air (charcoal + water) CO	+	fixed air (1) (heavy inflammable air + dephlogisticated air) CO_2

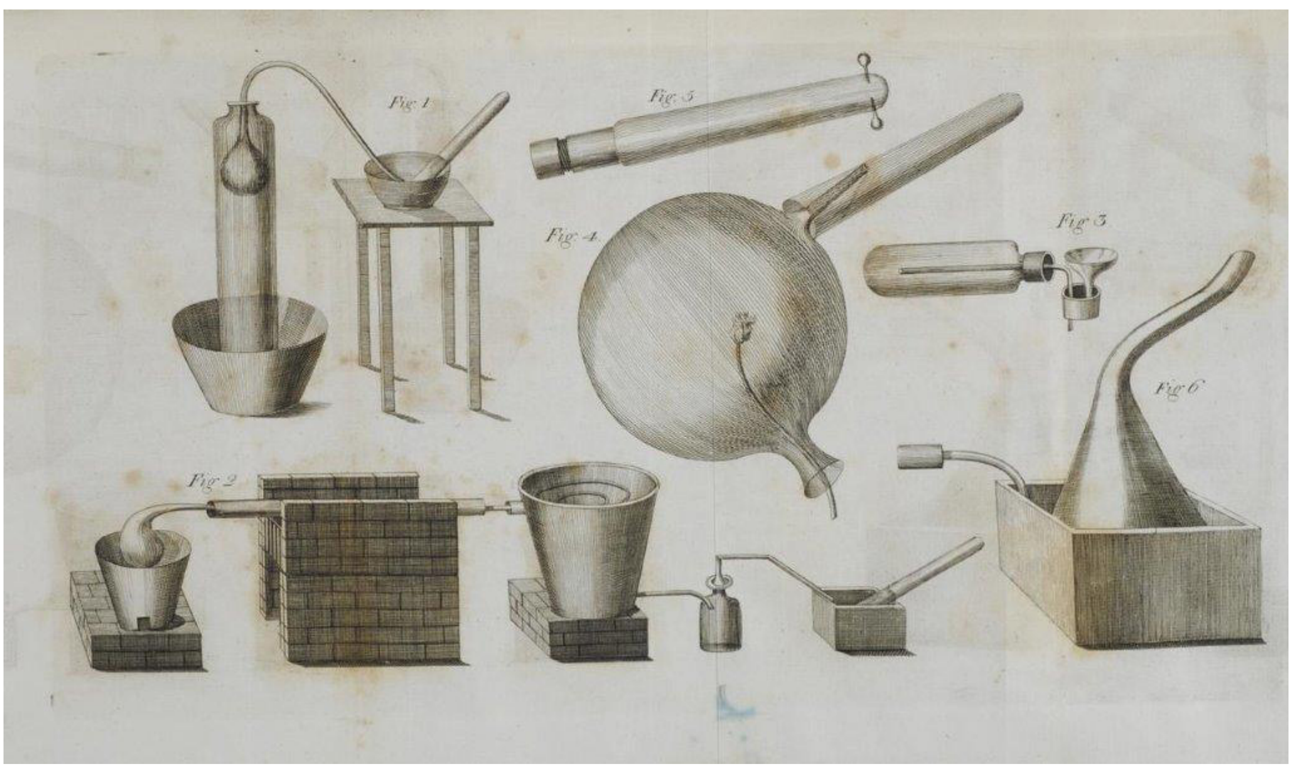

Figure 3*. Various gas-handling apparatus used by Priestley, from Ref. 12 (Priestley 1790, Vol. 1, endpapers). The train at lower left, including a furnace and bottle for a scrubbing solution would be similar to what Priestley used to generate carbon monoxide. Image courtesy of Science History Institute.*

purity, and little or no concern for safety. Priestley and his peers were mostly unaware of the effects of chronic exposure to mercury vapor or the speedy lethal effects of carbon monoxide. In general, though, they did understand that chemical laboratories should be well ventilated (24), and that perhaps explains Priestley's good luck in not being overcome by the new gas. Desormes and Clément were unusual in conducting experiments in 1801 that demonstrated the poisonous effect of carbon monoxide (25). Casteel would use instead modern apparatus, pure reagents, and safety precautions.

In choosing to modernize Priestley's 1785 experiments, Casteel was left with a number of questions. What is "finery cinder" in modern terms? Priestley's contemporaries all seemed to understand what substance he meant. Chemists commonly gathered this substance from iron-making furnaces, hence its name. Priestley sometimes made it from scratch as described in his 1785 account (26). In the *Incompleat Chymist* (1975), Smithsonian curator Jon Eklund identified the substance as Fe_3O_4 (27). Fe_3O_4 occurs in the natural world as the iron ore magnetite, which is a combination of FeO and Fe_2O_3. What other valence states of iron in what proportions Priestley's cinder might have contained is unknown. Rather than making "finery cinder," Casteel chose to order magnetite from chemical supplier Sigma-Aldrich.

Priestley and his contemporaries used charcoal-fired furnaces into which they could put an entire retort with the spout poking outside the furnace wall or they placed in their furnaces iron or ceramic tubes packed with reagents. They could, therefore, use large amounts of reactants, like 70 ounces of finery cinder, which "dissolved" the retort; no weight of charcoal was noted in this particular experiment (28).

Eighteenth-century chemists spoke of heating vessels and contents "red hot," which according to the "Draper point" would be a minimum of 525°C. A simple charcoal-fired furnace constructed recently to mimic Isaac Newton's way of making sulfuric acid reached temperatures close to 1000°C (29).

In modern terms the relevant equations for the main reactions describing Priestley's experiment are:

$$Fe(II)O + C \rightarrow Fe(0) + CO$$

$$Fe(III)_2O_3 + C \rightarrow 2\ Fe(0) + CO_2 + CO$$

It is possible that Priestley did not in all cases drive the reactions to completion. In a couple of places Priestley reported the solid product as "pretty firmly concreted together" (30). In other places he mentioned the presence of iron characteristically attracted by a magnet (31). Indeed, he opined that the finery cinder, previously considered a waste product, might be used to manufacture iron, but he left that decision to iron-making experts (32).

Casteel chose to work with a 2:1 molar ratio of charcoal to magnetite and on a smaller scale than Priestley did, She used 1.51 g and 15 g respectively (33). The two solids were placed in a bottle with mixing beads and rolled mechanically together for several minutes so that they were well combined.

Casteel first used a Bunsen burner and Pyrex flask to heat the combined solids. Only droplets of condensed water vapor were produced, probably from water that had been adsorbed on the unreacted reagents. No other gas was generated. The experiment required a more serious source of heat. Casteel then turned to an electric tube furnace from MTI Corporation. The furnace allowed her to heat the sample to 1000°C. A portion of the combined solids was placed in a crucible in the furnace and the temperature was set to ramp up to 1000°C at the rate of 10 °C/min. On a trial, with video crew present, a fuse on the electric furnace blew at 938°C. A week later a replacement fuse put the experiment back on track.

One expected complication was that both water vapor and oxygen might be present at the beginning of the experiment, adhering to the solids, the crucible, and/or the interior of the furnace. As the temperature in the furnace was increased, water vapor and adventitious oxygen could be swept away using a stream of dry nitrogen. Excess oxygen would be especially problematic since over oxidation of the charcoal might produce carbon dioxide at the expense of the desired carbon monoxide.

Before Casteel ever tried Priestley's tests to characterize these gases she turned to IR spectrometry to determine what gases were in fact exiting from the furnace. First she took an infrared spectrum of the mixture of gases emerging raw from the furnace—finding a mixture of gases consistent with both CO_2 and CO being present. Then, similarly to Priestley's removal of CO_2 from the gas stream with "lime water" [$Ca(OH)_2$], she used a NaOH solution to scrub the gas produced. With some of the CO_2 removed, the IR spectrum clearly showed, via twin absorbances near 2140 cm^{-1}, that CO had indeed been produced. She checked Priestley's specific gravity for carbon monoxide against a modern specific gravity table. She found his figures to be in the right ballpark (34). He had given his specific gravities as fractions of the weight of common air, but he mentioned no concern for air temperature or pressure.

Casteel then went on to set fire to a stream of CO emerging from a commercial cylinder of CO: the flame was indeed blue as Priestley had noted.

The videos for carbon monoxide, ammonia and nitrous oxide as well as audience surveys are available on the Priestley House website, www.josephpriestleyhouse.org (10, 11). Seventeen college chemistry students invited to Priestley House for the premiere of the video responded to a questionnaire. They gave the video high marks for increasing their appreciation of Priestley House, the place, and their understanding of Priestley's role in the discovery of CO and of the science involved. A number of respondents to the same questionnaire published online responded similarly, but several expressed a desire to learn more about Priestley's experimental difficulties.

Modern audiences were not, to be sure, treated to the behind-the-scenes story of the problems overcome by the modern chemist, Dee Casteel, even with her instrumental and conceptual advantages. The challenges of making the CO video illustrate the difficulties of presenting almost any historic chemical experiments to provide students and others an appreciation for the work of pioneering chemists.

References and Notes

1. For a detailed discussion of the cogency of phlogistic theory see H. Chang. *Is Water H_2O: Evidence, Realism and Pluralism,* Springer, Dordrecht, 2012.
2. In order of discovery with Priestley's own names for these gases in parentheses: nitric oxide, NO (nitrous air); nitrogen dioxide, NO_2 (phlogisticated nitrous air); anhydrous hydrochloric acid, HCl (marine acid air); ammonia, NH_3 (alkaline air); nitrous oxide, N_2O (dephlogisticated nitrous air); sulfur dioxide, SO_2 (vitriolic acid air); oxygen, O_2 (dephlogisticated air); silicon tetrafluoride, SiF_4+H_2O (fluor acid air); carbon monoxide, CO (heavy inflammable air).
3. J. Davy, Ed., *The Collected Works of Sir Humphry Davy,* London, Smith Elder, 1840, Vol. 7, pp 115ff. Perhaps most famous of these appreciations are Humphry Davy's remarks in a lecture before the Royal Institution in 1810, "As a discoverer, Dr. Priestley stands in the highest rank." Then Davy went on to mention Priestley's weaknesses, especially as a theoretician.
4. R. Schofield, *The Enlightened Joseph Priestley,* Pennsylvania State University Press, University Park, PA, 2004, pp 102-103.
5. J. Priestley, "Experiments and Observations Relating to Air and Water," *Phil. Trans. R. Soc. Lond.*, **1785**, *75*, 279-309 (at 299-302).
6. J. M. F. de Lassone, "Notices d'une Suite d'Expériences Nouvelles ...," *Mémoires de Mathématique et de Physique*, **1776**, 686-696. [Often bound with *Histoire de L'Académie Royale des Sciences* and thus retrievable under that title. Available online at https://books.google.com/books?id=47CS_2dUeosC&&pg=RA1-PA686 (accessed Feb. 8, 2019).]
7. W. Cruickshank, "Some Observations on different Hydrocarbonates and Combinations of Carbone with Oxygen," *Journal of Natural Philosophy, Chemistry and the Arts,* **1801**, *5*, 1-9.
8. C.-B. Desormes and N. Clément, "Sur la réduction de l'oxide blanc de zinc par le charbon, et sur le gaz oxide de carbone qui s'en dégage," *Ann. Chim.,* **1801,** *39,* 26-64.
9. *The Mystery of Matter: Search for the Elements*, Episode 1 "Out of Thin Air," aired Aug. 19, 2015.
10. Priestley House, Discoveries of Joseph Priestley: Carbon Monoxide, http://www.josephpriestleyhouse.org/learn/discoveries-of-joseph-priestley-carbon-monoxide/ (accessed Nov. 1 2018).
11. Priestley House, Discoveries of Joseph Priestley: Ammonia http://www.josephpriestleyhouse.org/learn/discoveries-of-joseph-priestley-ammonia/.

    Priestley House, Discoveries of Joseph Priestley House: Nitrous Oxide, http://www.josephpriestleyhouse.org/learn/discoveries-of-joseph-priestley-nitrous-oxide/. (Both accessed Nov. 1, 2018).
12. Ref. 5, pp 300ff. J. Priestley, *Experiments and Observations Relating to Various Branches of Natural Philosophy with a Continuation of the Observations on Air*, J. Johnson, London, 1779-1786, Vol. III (1786), pp 151, 375 (hereafter referenced as Priestley, 1786). *Experiments and Observations on Different Kinds of Air, and Other Branches of Natural Philosophy*, J. Johnson, London, 1790, Vol. I, Part I, pp 204ff, Part III, pp 297ff. (Schofield (Ref. 4, p 185) characterizes this 1790 edition as largely a reorganization of materials already presented in the 1776 edition of *Experiments and Observations on Different Kinds of Air*, volume II.) J. Priestley, *Considerations on the Doctrine of Phlogiston and the Decomposition of Water*, Thomas Dobson, Philadelphia, 1796, reprinted in W. Foster, *Lectures on Combustion*, Princeton University Press, Princeton, NJ, 1929, pp 37-38. (Here Priestley does not give any experimental detail whatsoever. He may just have been referring to earlier experimentation. Or experiments producing CO may have been among those Priestley demonstrated to James Woodhouse but did not publish. See E. F. Smith, *James Woodhouse*, John C. Winston, Philadelphia, 1918, p 118.) J. Priestley, *Doctrine of Phlogiston Established*, A. Kennedy, Nor-

thumberland, PA, 1800, pp 18ff. (Here Priestley relied on James Woodhouse's experimental account, "as Dr. Woodhouse repeated this experiment with peculiar exactness." Woodhouse, however, interpreted his own results very differently.)

In the complicated debates that ensued in the pages of the *New York Medical Repository* and the *Journal of Natural Philosophy, Chemistry, and the Arts* (*Nicholson's Journal)*, Priestley only records fresh experimentation on the topic of "finery cinder" and "heavy inflammable air" in trying to disprove Cruickshank's theory that heat causes finery cinder to release oxygen which unites with carbon to form fixed air and subsequently changes fixed air into flammable air. For hours at a time Priestley focused a burning glass on fixed air confined above mercury or water and reported no change. "A Reply to Mr. Cruikshank," *New York Medical Repository,* **1802**, *5*, 390-392 (at 391). (But Priestley reported just such a change in a related experiment performed in the 1780s involving passing fixed air back and forth through a red hot ceramic tube by squeezing bladders attached to the ends of the tube. In that case he did produce "a slightly inflammable" gas: J. Priestley, "Experiments on the Transmission of Acids, and other Liquors, in the Form of Vapour, over several Substances in a hot earthen Tube," *Transactions of the American Philosophical Society*, **1802**, *5*, 1-13 (at 13).) James Woodhouse reported watching Priestley perform experiments in his Northumberland laboratory, possibly the classical finery cinder experiment. J. Woodhouse, "An Answer to Dr. Joseph Priestley's Considerations on the Doctrine of Phlogiston," *Transactions of the American Philosophical Society*, **1799,** *4*, 452-475.

13. J. Priestley, Ref. 12: 1785, pp 10, 301; 1790, p 298. In other places he reported the specific gravity of CO as "two grains more than an equal quantity [volume] of common air." (Ref. 12: 1786, p 151; 1790, p 204.)
14. J. Priestley, *Experiments and Observations on Different Kinds of Air,* J. Johnson, London, 1775-1777, Vol. 2 (1776), pp 92-94, for an early discussion of this technique.
15. J. Priestley, Ref. 12: 1786, pp 151-153; 1790, Vol. 1, 205.
16. J. Priestley, Ref. 12: 1786, pp 162ff and 1790, pp 308ff for his most systematic investigation of the various inflammable gases.
17. J. Priestley, Ref. 12: 1790, pp 299 n.
18. J. Priestley, Ref. 12: 1800, p 22.
19. J. Priestley, "Experiments and Observations Relating to the Principle of Acidity, the Composition of Water, and Phlogiston," *Phil. Trans. R. Soc. London*, **1788**, 147-157 (at 154). For an extensive discussion of Priestley's position on the elemental nature of water, see Chang, Ref. 1.
20. J. Priestley, Ref. 12: 1796, pp 37-38; 1800, pp 10-22.
21. Notation of reaction ours.
22. J. Priestley, Ref. 12: 1796, pp 17-18; 1800, pp x-xiii.
23. Some participants in the debate with their contemporary affiliations: P.-A. Adet, coauthor of the symbol system appended to *Méthode de Nomenclature chimique* (1787) and in 1796 France's ambassador to the United States; J. Maclean, Princeton College; S. Mitchill, Columbia College and editor of the *Medical Repository*; J. Woodhouse, University of Pennsylvania; W. Cruickshank, Royal Military Academy, Woolwich; L.-B. Guyton de Morveau (known at this time as Guyton or Guyton-Morveau) and C.-L. Berthollet, Académie des sciences and Ecole polytechnique; C.-B. Desormes and N. Clément, Ecole polytechnique.

    For secondary accounts of these disputes, see S. M. Edelstein, "The Chemical Revolution in America from the Pages of the 'Medical Repository,'" *Chymia,* **1959,** *5,* 155-179, and M. F. Conlin, "Joseph Priestley's American Defense of Phlogiston Reconsidered," *Ambix* **1996***, 43,* 129-145. With the exception of the response to Priestley by Adet, these authors do not treat French debaters in these controversies.
24. Joseph Priestley House, Renewed Laboratory Exhibit, http://www.josephpriestleyhouse.org/learn/renewed-laboratory-exhibit/ (accessed Nov. 1, 2018). Mention of the architectural remains of a fume hood located between the brick chimneys for the two furnaces in the laboratory at Priestley House and of its modern representation.
25. Ref. 8, p 56.
26. Ref. 5, p 300.
27. J. Eklund, *The Incompleat Chymist: Being an Essay on the Eighteenth-Century Chemist in his Laboratory, with a Dictionary of Obsolete Chemical Terms of the Period*, Smithsonian Institution Press, Washington, DC, 1975, p 27.
28. J. Priestley, Ref. 12: 1786, p 374.
29. Wikipedia, Draper Point, https://en.wikipedia.org/wiki/Draper_point (accessed Nov. 1, 2018). The Chymistry of Isaac Newton, Experiments in Mineral Acids, http://webapp1.dlib.indiana.edu/newton/reference/mineral.do (accessed Nov. 1, 2018).
30. J. Priestley, Ref. 12: 1786, p 151; 1790, p 204.
31. J. Priestley, Ref. 12: 1786, p 376; 1790, p 298.
32. J. Priestley, Ref. 12: 1786, p 376. Priestley's brother-in-law was famed iron maker John Wilkinson.
33. Subsequent to Casteel's experiment Bowden discovered that Priestley had in one or two places mentioned weights for both reagents: one ounce of charcoal to two ounces of finery cinder, in our terms, a molar ratio of 3:1. J. Priestley, Ref. 12: 1786, p 151; 1790, p 204.

34. Specific gravities additional to CO shown in the video—CO_2 and H_2—were probably drawn by Priestley from Henry Cavendish's work. Among other references to this sourcing, see J. Priestley, "Three Papers Containing Experiments on Factitious Air," *Phil. Trans. R. Soc. Lond.*, **1766**, *56,* 41-184; J. Priestley, *Philosophical Empiricism,* J. Johnson, London, 1775, p 42.

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2019 HIST Award to O. Theodor Benfey

The recipient of the 2019 HIST Award of the Division of the History of Chemistry of the American Chemical Society is Dr. Otto Theodor (Ted) Benfey. This award is the successor to the Dexter Award (1956-2001) and the Sydney M. Edelstein Award (2002-2009), also administered by the Division of the History of Chemistry. The HIST Award will be presented to Dr. Benfey at the fall national meeting of the American Chemical Society in San Diego, CA, on Tuesday, August 27, 2019.

Ted Benfey was born on October 31, 1925, in Berlin, Germany. He was sent to England in 1936 and was educated at the Watford Grammar School. His parents immigrated to the United States in 1938, but Ted stayed on in England. He entered University College London in 1942 and eventually graduated with a Ph.D. in 1947 under the direction of Christopher Ingold. During his English period, Benfey became a Quaker, an affiliation he maintains to the present.

Benfey came to the United States as a post-doctoral fellow with Louis P. Hammett at Columbia University in 1947. In 1948, he was appointed to the chemistry department at Haverford College, a Quaker institution, and served there until 1955, when he spent a year on sabbatical leave with Frank Westheimer at Harvard University. Rather than pursue a career in research at a major university, Ted chose to teach at Earlham College, a small Quaker school in Richmond, Indiana. This allowed him to pursue what would become his real passions: teaching and the history of science, especially chemistry. He stayed at Earlham from 1956-1972. In 1973 he was appointed the Dana Professor of Chemistry and History of Science at Guilford College in Greensboro, North Carolina, another school with Quaker roots. He retired from Guilford in 1988 and joined Arnold Thackray at the Beckman Center for the History of Chemistry in Philadelphia, then part of the University of Pennsylvania. At what was soon to be

called the Chemical Heritage Foundation, now known as the Science History Institute, Ted edited the institution's newsmagazine, *Chemical Heritage*, for six years.

Benfey was immersed in the history of science in 1949 during a Harvard Summer school on "Case Histories in Experimental Science" run by Harvard President James B. Conant; there he also met Leonard Nash and Thomas Kuhn. Benfey's first published paper on history of chemistry and chemical education was titled "Prout's Hypothesis" in the Journal of Chemical Education in 1952. He has written seven books on chemistry and the history of chemistry. He also served as Chair of the Division of the History of Chemistry of the ACS in 1966, now over 50 years ago.