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Priestley, the furious free thinker of the enlightenment, and Scheele, the taciturn apothecary of Uppsala

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'The more elaborate our means of communication, the less we communicate'.
Joseph Priestley

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AMERICANS are taught that the English Unitarian minister Joseph Priestley discovered oxygen in 1774. Scandinavians are taught that the Swedish apothecary Carl Wilhelm Scheele generated oxygen in Uppsala in 1771–2, several years before Priestley.

Scheele claimed that he wrote Lavoisier, describing the experiments in September, 1774. However, Lavoisier denied seeing or receiving his letter. Among Nordic historians, Lavoisier has never been forgiven for this rebuff (1). Some historians have doubted whether such a letter was ever sent or received, because Scheele first published in 1777. Priestley brought the news of his discovery to Lavoisier in October 1774. It was undoubtedly Priestley who triggered Lavoisier to realize over the next few years that air contained a new element, oxygen, which combined with combustible materials in fire. Lavoisier spent most of a decade in experiments to clarify the chemistry of oxygen and in publications overturning the conventional Phlogiston Theory, causing a revolution in chemistry.

My interest in this history began in 1996, when Julian Biebuyck invited me to present the annual Priestley lecture at Penn State University. This included a visit to Priestley's last home in Northumberland, Pennsylvania, a 2-hour drive from the Medical School. The American Chemical Society was founded following a visit to Priestley's laboratory on the centenary of Priestley's discovery of oxygen in 1874. The restored house and laboratory are now a National Monument.

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I spoke about Priestley to the British Physiologic Society when they met in Birmingham in late 1999. Priestley's statue stands in front of the main library, which he founded. He is holding a lens, or burning glass, the method he used for heating mercuric oxide in a sealed glass vial to release oxygen.

Two years ago, the 200th anniversary of Humphry Davy's discovery of the analgesic effect of nitrous oxide was celebrated by a joint meeting of the English History of Anesthesia Society and the American Anesthesia History Association in Bristol. The conferees visited the laboratory in which Priestley discovered oxygen in 1774 at Calne, Wiltshire, an hour's drive east of Bristol. Bowood, Lord Shelburne's estate, is a National Trust, open to the public, a large romantically landscaped park and garden which was designed about Priestley's time by the famous English garden designer Capability Brown. Lord Byron had been a guest there about 1810, seduced another guest's wife, a duel may have occurred, after which Byron hurriedly left England, as fictionalized in Tom Stoppard's play 'Arcadia'. The play jumps between 1810 and the present in the library of a manor, possibly Bowood, undergoing a revolution of garden design. As in the play, Bowood has both a Greek revival octagon pavilion and a hermitage. Byron married Annabella Milbanke, English mathematician, an associate of Charles Babbage. Their daughter, Lady Augusta Ada Byron, born in 1815, was the mathematician who wrote the world's first computer program for Charles Babbage's computer, and after whom the computer language ADA is named. She may be regarded as Stoppard's model for the precocious 15-year-old Tomasina Coverly who told her tutor Septimus one could write an equation for a rose. After her suicide upon rejection by Septimus, he becomes a hermit, trying to write the fractals which she invented.

Priestley

Born near Leeds in 1733, Priestley was the oldest of six children of a modestly successful cloth dresser. For several years during his childhood, Joseph was often sickly, but, perhaps as compensation, he became an avid learner on his own. Although his parents were Calvinists, they were open to other religious views and wanted him to enter the ministry of the Dissenting church, the diverse congregations of which, such as Presbyterian or Independent, did not conform to the Church of England.

To prepare himself, he studied Hebrew, Chaldee, Syriac and a little Arabic. In 1752 he became a theology student at a new Dissenting Academy at Daventry, Northamptonshire, a school of high-quality education that attracted the best teachers and students. In addition to the required curriculum, he studied history, philosophy, and science.

In 1755 he became assistant minister to the independent Presbyterian congregation in Needham Market, Suffolk.

Priestley's intellectual development passed from the Calvinism of his family, through Arianism, with its denial of Christ's divinity, to a rational Unitarianism, with its complete denial of the trinity and atonement. His unorthodox and even heretical opinions as a 'furious freethinker' gradually lost him the confidence of his orthodox congregation, and he resigned.

In 1758 he transferred to a more sympathetic congregation in Nantwich, Cheshire, where he opened a day school with 36 students. Becoming interested in science, he provided them with philosophical instruments such as an air pump and a static generator for electrical demonstrations.

One of his students at Nantwich invited Priestley to his home in Wrexham. In 1762 Priestley married the student's sister, Mary Wilkinson, aged 18, who was endowed with the qualities of common sense, courage and humor. Her father, John Wilkinson, an iron master at Bersham, Denbigh, in Wales developed the accurate way of boring true cylinders for engines and pumps and cannon. His firm still exists as the Wilkinson Sword Company. At about the time of their marriage, John Wilkinson moved to Staffordshire, just north of Birmingham. Mary's family did not come to her wedding for unknown reasons. I assume they disagreed with Priestley's antiestablished church teachings. They nevertheless provided some of the luxuries of Priestley's homes and belongings, from library to scientific instruments. The Priestleys had a daughter and three sons.

His teaching success led to his appointment in 1761 as a tutor in language and literature at Warrington Academy, near Liverpool in Cheshire. Because Oxford and Cambridge Universities and learned professions were closed to Dissenters, Priestley developed new courses and textbooks that were suitable for students preparing for careers in industry and commerce. In 1761 he published the "Rudiments of English Grammar", a work based on spoken and written contemporary English. It remained in use for 50 years. His educational activities made Warrington Academy the most distinguished school of its kind in England.

In 1765, Edinburgh University conferred an honorary doctorate on Priestley, in part for his thesis 'Eminent men of all ages'.

Priestley attended lectures and demonstrations on practical chemistry given in 1763–65 by the surgeon Matthew Turner. Beginning in 1765, Priestley spent a month of every year in London, where he met the leading men of science, including the American statesman and inventor Benjamin Franklin. On the

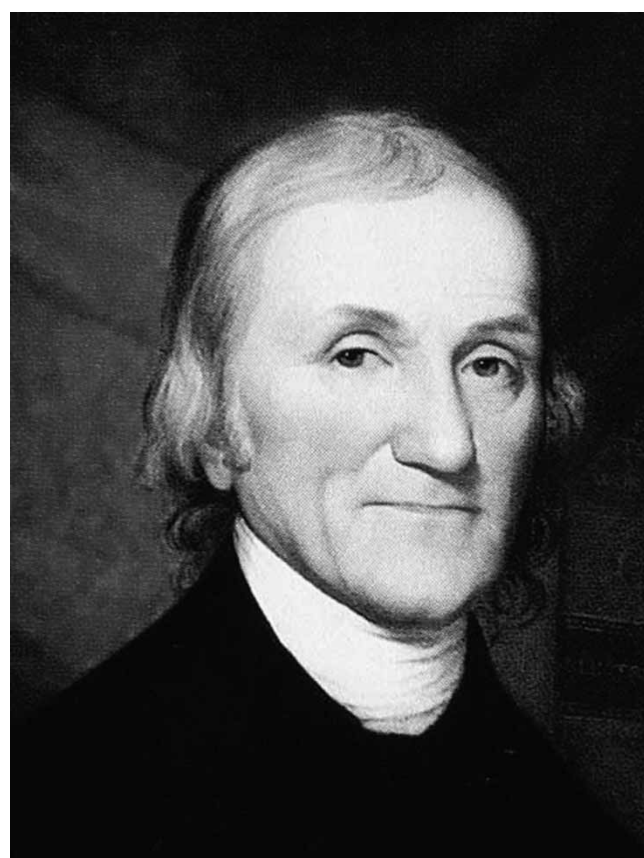

Fig. 1. Joseph Priestly (1733–1804).

basis of his electrical experiments, Priestley in 1766 was elected to membership in the Royal Society of London. The next year, with Franklin's encouragement and generous loan of the requisite books, he published "The History and Present State of Electricity", in which he also described his own experiments. He discovered that charcoal conducts electricity and noted the relationship between electricity and chemical change.

However, within the next year, 1767, he resigned from Warrington due to (presumably theologic) disagreements with the trustees. Priestley became pastor of the Mill Hill Chapel in Leeds, a free church where his home was next to a brewery. By dissolving the CO_2 produced by fermentation in water, he discovered and popularized soda water, then called windy water.

This won him the Copley Medal of the Royal Society in 1773.

While in Leeds, he began doing chemistry experiments, and discovered four gases: nitric oxide (nitrous air), nitrogen dioxide (red nitrous vapor), nitrous oxide (diminished nitrous air, later called 'laughing gas') and hydrogen chloride.

Again the furor of his antiestablishment preaching led to trouble in Leeds. In December 1772, he met a fellow liberal sympathizer of the American colonists, the powerful politician, William Fitzmaurice-Petty, 2nd Earl of Shelburne, later 1st Marquis of Lansdowne. It was he who negotiated the treaty of Paris that ended the American Revolution. Shelburne invited Priestley to come to his home, Bowood, as librarian, literary companion and tutor to his two young sons, on generous terms, with the freedom to preach and write as he wished.

At Bowood, Priestley set up a laboratory to continue his research on gases. On August 1, 1774, he discovered that by heating the mineral red mercuric oxide with a newly acquired burning glass, a new gas was liberated in which a candle burned furiously and a mouse could live longer than in a similar sealed volume of air.

He discovered photosynthesis by showing that a sprig of mint left in air in which a mouse had died, regenerated the substance needed to keep a mouse alive. He knew that the heated mercury lost weight, but then had to assume that phlogiston had negative weight. As he was unable to abandon the Phlogiston Theory, he called the new gas "dephlogisticated air" to the end of his life.

Priestley's description of his previous gas experiments in the Philosophical Transactions, titled 'On Different Kinds of Air'(1772), first drew the attention of Antoine-Laurent Lavoisier, France's most distinguished chemist. At Lavoisier's invitation, in October 1774, Priestley travelled to Paris with Lord Shelburne and described his results, particularly the new air which supported fire and life, to a large and distinguished group of French scientists at a dinner given by Lavoisier. Lavoisier realized the importance of this discovery, and began experiments with it.

During his decade at Bowood, Priestley published violently antiestablishment essays, books and pamphlets on his Unitarian theology, rational Christianity, and philosophy, some of which were seen as dangerously controversial even by supporters. He fought for Parliamentary reform, opposed the legal and civil impediments of dissenters, and lauded the American revolution.

Priestley left the employ of Shelburne in 1779, amicably but after an unrecorded disagreement, and moved from Bowood to Birmingham as minister of the dissenting New Meeting congregation. Here he found kindred liberals, among them Josiah Wedgewood, Erasmus Darwin, Coleridge, Wordsworth, and James Watts, members of the Lunar Society, meeting on Monday night near each full moon. Outsiders called it the lunatic society.

His Birmingham years were the happiest of his life.

Priestley's essays made him a major political theorist among 18th Century liberals, and a major leader of the enlightenment. He emphasized individualism; he believed that people should have a voice in their government and power over their own actions. He inspired the motto 'the greatest happiness of the greatest number'. He espoused both the American and French revolutions. An outspoken rebuttal of Edmund Burke's attack on the French revolution made him exceedingly unpopular with the predominantly royalist public.

Priestley founded the first Unitarian periodical in England, editing it until his emigration. In his "History of the Corruptions of Christianity" (1782), he rejected most of the fundamental doctrines of Christianity, the divinity of Jesus, the Trinity, predestination, and the divine verbal inspiration of the Bible and traced them to their historical sources of error. This work aroused another storm of protest. By the time of the French Revolution he had acquired a reputation as the antagonist of both establishments: church and state. He became the prime target for political cartoons, editorial denunciation and threats to his safety.

As the Unitarian minister in Birmingham, Priestley was the most outspoken and controversial member of the Lunar Society. His extreme left wing political essays, lectures and sermons supporting the French revolution generated hosts of enemies.

On July 14, 1791, the small liberal community in Birmingham planned to celebrate the 2nd anniversary of the French revolution. A royalist mob assembled at the celebration, reputed to have been encouraged by local clergy. Priestley's laboratory was ransacked, his instruments books and papers destroyed. The mob violence spread immediately, ending only after burning down the laboratory and his home, two non-conformist churches, and many of the dissenting church congregation's homes. Priestley escaped in disguise on horse back to Worcester and went by stage to London where his family joined him. For the next 3 years, Priestley resided unhappily in Hackney, near London, where he taught at New College. In 1793, when England and France went to war, Priestley knew he had to emigrate. His three sons had already emigrated to America. He preached a 'Fast Sermon' denouncing both the government and church.

Joseph and Mary sailed for New York on April 7, 1794. The Birmingham riots in 1791 lost England a brilliant articulate leader of the Enlightenment.

On arrival in New York, Priestley received but declined offers of professorships and a ministry. He settled briefly in Philadelphia, then America's capital, influenced by his friendships with Benjamin Franklin, Thomas Jefferson and John Adams.

However, he soon left Philadelphia, due to his disdain for the Quaker merchant class, and the epidemic of yellow fever.

His sons formed a land company, buying four lots and building homes far up the Susquehanna River in Northumberland, speculating that it would become the state capital. He moved there in 1794 and lived in one son's home while designing and building his own home. The house was to be his wife's delight, but she died of tuberculosis in 1796, 2 years before it was finished. The capital went to Harrisburg, and land prices fell drastically. A stage route to Northumberland failed. A college that Priestley was to have headed failed because the legislature disagreed with Priestley's Unitarianism.

Despite the difficulties in communicating with his scientific colleagues, and in getting equipment, he established what has been called the first scientifically equipped laboratory in the United States. He continued his research and deduced the composition of carbon monoxide. He published copiously even in his last years in the *Transactions of the American Philosophical Society*, the *Journal of Natural Philosophy*, the *New York Medical Review* and *Science and the Arts*.

He preached in Philadelphia during Thomas Jefferson's inauguration. After hearing him several times, Jefferson wrote him: 'Yours is one of the few lives precious to mankind for the continuance of which every thinking man is solicitous.' His correspondence with Jefferson contributed to the philosophical design of the American liberal arts college curriculum. Seven months before his death, he described himself in a letter to a friend as 'an exhausted volcano', having taken a fever in Philadelphia, possibly the yellow fever which had devastated the city in 1793. He died in Northumberland February 6, 1804.

American scientists convened a meeting at Priestley's home site in 1874 to commemorate the centenary of his discovery of oxygen. That led 2 years later to founding the American Chemical Society. The ACS met again there in 1926 to dedicate a Priestley library as part of Pennsylvania State University.

Priestley's home is now a museum and National Historic Landmark of the U.S. National Park Service. His laboratory is undergoing reconstruction. Much of the laboratory equipment and furniture of his home is now at Dickenson College in Carlisle, PA. It was purchased shortly after Priestley's death on the recommendation of his friend Thomas Cooper, a professor of chemistry and mineralogy at Dickenson.

Priestley wrote six volumes on different kinds of air. Before Priestley's work, only three gases were known: air, carbon dioxide, and hydrogen. Priestley discovered nine gases: NO, NO_2, NO_2, O_2, SO_2, HCl, SiF_4, H_2S, NH_3, four in 1767–73 while at Leeds. His success resulted in large part from his ability to design ingenious laboratory apparatus, particularly an improved pneumatic trough, and his skill in its manipulation. Moreover, by collecting gases above mercury in the trough, instead of in water, he was able to isolate, by trial and error, those that were water-soluble. He discovered the electrical conductivity of charcoal and carbon. He first described photosynthesis, invented gum erasers, first described how to use compressed gases to produce refrigeration, invented and commercialized soda water. He altered the course of higher education. His was the quintessential Enlightenment mind of a great communicator.

Carl Wilhelm Scheele

I now turn to what little is know of Scheele, whom we now realize discovered oxygen before Priestley.

Carl Scheele was born December 9, 1742, one of 11 children. He received very little formal education and no scientific training. At age 14, he was apprenticed to apothecaries in Gothenburg, Malmø and Stockholm. He read the scientific books of the day and

Fig. 2. Carl Wilhelm Scheele (1742–1786).

started experimenting. He and A. J. Retzius published the isolation of tartaric acid from cream of tartar.

In 1770, he moved to Uppsala as a laboratory assistant, where he met and was helped by Sweden's great chemist Torbern Bergman.

Scheele soon discovered 'fire air' (oxygen), probably in 1771. He produced oxygen using at least four different chemical reactions. But he delayed publication or disclosure for 4 years. His book, "On Air and Fire", ready for the press in December 1775, was then delayed because Bergman, who may have been a bit jealous, did not deliver his promised preface until July 1777.

In some reports this delay is blamed on the printer. One other written document of his work has been uncovered before the 1777 book, a paper written by Bergman in early 1775 in Latin, mentioning Scheele's discovery (2).

Some of Scheele's earlier work seems to have been described to Lavoisier because in the spring of 1774, Lavoisier sent his book to Bergman with a second copy for Scheele.

Scheele later claimed that he had written to thank Lavoisier on September 30, 1774. He said that, in his letter, he had described his ways of preparing fire air, asking Lavoisier to repeat them with his larger burning lens. He never received a reply and was unable to interpret his experiments since he believed in the faulty Phlogiston Theory.

By the time of his book's publication in 1777, Scheele had learned of Priestley's discovery, and of Lavoisier's subsequent confirmation. By then, Scheele had demonstrated that common air consists of 'fire air' (oxygen) which supports combustion, and 'foul air' (nitrogen), which does not. "On Air and Fire" also describes Scheele's experiments with hydrogen sulfide gas, which he was the first to synthesize. Scheele noted the action of light on chloride of silver and the insolubility of blackened silver chloride in ammonia – discoveries that would later prove significant for photography.

On February 4, 1775, Carl Scheele was elected to membership into the Royal Academy of Sciences. This great honor (the King of Sweden was in attendance) had never before (and has never since) been given to a student of pharmacy.

In 1775, Carl Scheele moved to Köping, Sweden, where he took a position as superintendent of the pharmacy, although he had been offered academic positions. The town of Köping did not want to lose their new famed son so they obtained for him his own pharmacy. He wrote:

'Oh, how happy I am! No care for eating or drinking or dwelling, no care for my pharmaceutical business, for this is mere play to me. But to watch new phenomena this is all my care, and how glad is the enquirer when discovery rewards his diligence; then his heart rejoices."

At Köping, Scheele prepared compounds of cyanide and arsenic. Without analytic methods, he tasted the poisons he made.

Scheele was aware of the cause of his poor health and he referred to it as 'the trouble of all apothecaries.' He died, probably from arsenic poisoning, at age 43 on May 26, 1786. He is now credited with the discovery of seven elements (N, O, Cl, Mn, Mo, Ba, W) and many compounds: hydrogen fluoride, silicon fluoride, hydrogen sulfide, hydrogen cyanide, glycerol, tartaric acid, citric acid, lactic acid, uric acid, benzoic acid, gallic acid, oxalic acid, lactose, Prussic acid, arsenic acid, molybdic acid, tungstic acid and copper arsenite (called 'Scheele's green'), which was used to decorate candy for 50 years before it was found to be a poison.

Antoine Laurent Lavoisier

After Priestley's visit and disclosure of his experiments in October 1774, Lavoisier concluded that the Phlogiston Theory was wrong. He repeated some of Priestley's experiments, and talked about others as if he had done them himself. He first called the new air 'eminently breathable air' but, after several years, he named it oxygen, incorrectly believing it was a component of all acids. For more than a decade most chemists remained sceptical that this gas was an element rather than dephlogisticated air.

Lavoisier was able to overcome the old ideas using precise quantitative measures of volume and weight of the reactants in various reactions which could only fit with his new oxygen theory. The discovery of oxygen revolutionized chemistry.

Lavoisier repeatedly denied having received Scheele's letter, although it must have arrived at the time of Priestley's visit. Scheele did nothing more about this rebuff, but completed his book. In the meantime, Priestley had published his discovery of the new gas he called dephlogisticated air. Scheele may not have appreciated the revolutionary importance of his discovery until he learned of Lavoisier's interpretation of its meaning, because he too had been taught the Phlogiston Theory and maintained his belief in it. Before his book was finally published, others of his discoveries had also been made public without his consent.

Oxygen

What then impelled me to prepare this Priestley lecture?

Last year a new play, 'Oxygen', was read first in San Francisco, then London. The authors are Professor Roald Hoffman of Cornell University, who received the chemistry Nobel prize in 1982, and Carl Djerassi, the Stanford biochemist who popularized the pill for contraception nearly 40 years ago. On April 2, 2001 I attended the play's premiere in San Diego at the American Chemical Society annual meeting.

The premise of the play is that, in 2001, a committee in Stockholm proposes awarding the first 'Retro-Nobel Prize' for the greatest discovery of all time to celebrate the centenary of the Nobel Prize. The Nobel committee's discussions are interwoven with flashbacks to 1777. The protagonists, Priestley, Scheele and Lavoisier and their wives are invited to Stockholm by Gustav III to choose whose contribution was most important.

When they each claim the major credit, the king decides not to make an award. The four members of the 2001 Nobel committee also take four different views of who really is to credit for oxygen's discovery, three choosing a different man, and the chair choosing all three. They fail to agree on who to credit, or whether to award a Retro-Nobel Prize.

Lavoisier's wife

The letter which Scheele claimed to have sent to Lavoisier in September 1774, although never acknowledged by Lavoisier, has been rediscovered. In the 1890s a French chemist and historian, E. Grimaux, wrote: 'Une lettre inédite de Scheele à Lavoisier' (in Revue générale des sciences pures et appliquées, 1890: 1: 1–2). He had found the letter in a collection of papers and artifacts of Lavoisier's wife Marie Anne. He described it and published the text, but the letter was again hidden and never made available to the public view, leading to disbelief among historians. Amazingly, the original letter came to light finally in 1993 in a donation to the Archives de l'Académie de Sciences of Lavoisier's artifacts.

Fig. 3. Antoine Laurent Lavoisier (1743–1794) and Marie-Anne Pierette Paulze Lavoisier (1749–1836).

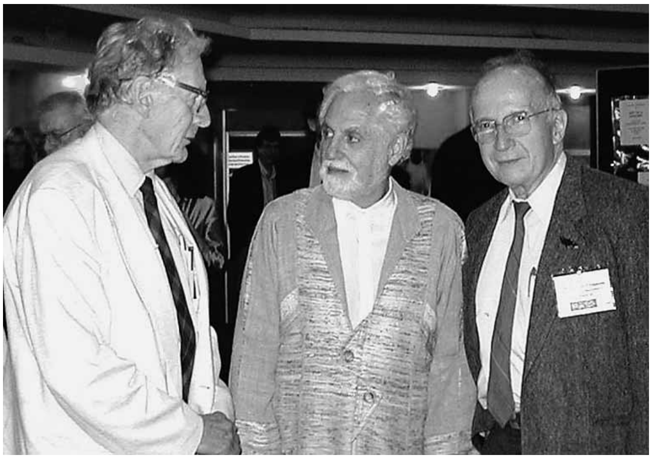

Fig. 4. John Severinghaus with Carl Djerassi (Chemistry, Stanford) and Roald Hoffman (Chemistry, Cornell, Nobel Prize 1982) at the premier of their new play 'Oxygen', San Diego, April 2, 2001.

I learned of its existence through the play, obtained photographs of it from Professor Roald Hoffman, and found it a highly relevant topic to present to Scandinavians.

Why did Lavoisier, usually so punctual in his correspondence, fail to respond to Scheele? Of course he was busy, but he had a reputation as an excellent correspondent. He was accused on several occasions by other scientists of failure to acknowledge other's work, and perhaps of hoping to claim their discoveries as his own. The present consensus is that he did receive Scheele's letter on October 15, 1774, probably immediately after discussing similar work directly with Priestley. If, as this suggests, Lavoisier tried to claim sole credit for the most important discovery in the history of science, perhaps he deserved to lose his head. The authors of the play suggest a fascinating alternative idea: that Madame Lavoisier hid the letter from her husband to allow him to claim credit for the discovery of oxygen.

Lavoisier was 28 when he married the 13-year-old Marie Anne Pierrette Paulze, daughter of his professional colleague and close friend Jacques Paulze. She was clever, multilingual, mathematically able, a trained draftsman and became secretary, book-keeper and laboratory assistant to her husband. She probably did receive Scheele's letter shortly after the visit from Priestley.

It is thus a plausible hypothesis that she, as her husband's laboratory assistant and partner, conceived the idea of not disclosing the letter to him to help him achieve the fame of the new discovery.

The historic materials belonging to Madame Lavoisier included a 'necessaire', a book-like box containing small things she would need such as sewing materials, pen, ink, paper and a mirror. This box was sold to Cornell University, and photos of it play an important role in 'Oxygen', as the location in which the missing letter had been hidden. The play includes a poetic presentation of the Phlogiston Theory, and an imaginary letter from Madame Lavoisier to her husband as he awaits the guillotine, asking his forgiveness for having secreted the letter.

There remains no doubt about the priority of Scheele, even though in his book he did not dare claim priority for discovering oxygen (lest he be accused of plagiarism). Do we now deny Priestley priority for chemistry's most important discovery?

How do we judge the scientific integrity of Lavoisier? Was Lavoisier's purpose to claim sole discovery of oxygen? His subsequent statements often suggest so. Priestley later accused Lavoisier of borrowing his ideas, and of making claims for experiments done by Priestley, not himself. Edmond Genet wrote that Lavoisier had read to the Academy, as his own work, a restatement of a letter Genet had written to Lavoisier describing Priestley's experiments. Between 1772 and 1777, Priestley's publisher Magellan wrote 13 letters through M. Trudaine for Lavoisier describing Priestley's research. Despite this, on March 26, 1775, Lavoisier announced at the Academy that he had identified the part of atmospheric air that was specific to respiration, without reference to either Priestley or Scheele. By April 1776, he stated that this eminently breathable air was one sixth of air. He coined the word oxygen in 1777 and then correctly stated that oxygen was one fifth of total air based on burning phosphorus. There is no doubt that Lavoisier was the first to understand that oxygen was a new highly reactive element mixed with nitrogen in air.

In retrospect

It has been a truly delightful and satisfying pleasure for me to be able to present to you, at the Scandinavian Anaesthesia Society, this relatively new solid evidence establishing the Swedish apothecary Carl Wilhelm Scheele as the discoverer of oxygen.

In anesthesia, the over-used catch phrase 'Publish or Perish' applied to Crawford Long, just as it did to Scheele.

Although both were first discoverers, neither contributed their discoveries to the waiting world. Only when others made the same discoveries and communicated them to scientists was science advanced. Priestley was an amateur but discovered nine new gases and wrote about each. Scheele was a great chemist who discovered seven elements but failed to add them to the body of knowledge and lost credit for most of his work. Neither Priestley nor Scheele ever understood what they had found. Lavoisier was well prepared to understand what Priestley found, and to build the whole edifice of chemistry on it. We should not judge him harshly, whether he knew of Scheele or not – he paid with his head.

Priestley's last word on this was written without knowing that Lavoisier had made most of his fortune in the manufacture of gun powder:

'In completing one discovery we never fail to get an imperfect knowledge of others of which we could have no idea before, so that we cannot solve one doubt without creating several new ones. Unitarian principles are gaining ground every day. We are, as it were, laying gunpowder, grain by grain, under the old building of error and superstition, which a single spark may hereafter inflame, so as to produce an instantaneous explosion.'

Joseph Priestley, 1785

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