

Joseph Priestley, oxygen, and the Enlightenment

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West JB. Joseph Priestley, oxygen, and the Enlightenment. *Am J Physiol Lung Cell Mol Physiol* 306: L111–L119, 2014. First published November 27, 2013; doi:10.1152/ajplung.00310.2013.—Joseph Priestley (1733–1804) was the first person to report the discovery of oxygen and describe some of its extraordinary properties. As such he merits a special place in the history of respiratory physiology. In addition his descriptions in elegant 18th-century English were particularly arresting, and rereading them never fails to give a special pleasure. The gas was actually first prepared by Scheele (1742–1786) but his report was delayed. Lavoisier (1743–1794) repeated Priestley's initial experiment and went on to describe the true nature of oxygen that had eluded Priestley, who never abandoned the erroneous phlogiston theory. In addition to oxygen, Priestley isolated and characterized seven other gases. However, most of his writings were in theology because he was a conscientious clergyman all his life. Priestley was a product of the Enlightenment and argued that all beliefs should be able to stand the scientific scrutiny of experimental investigations. As a result his extreme liberal views were severely criticized by the established Church of England. In addition he was a supporter of both the French and American Revolutions. Ultimately his political and religious attitudes provoked a riot during which his home and his scientific equipment were destroyed. He therefore emigrated to America in 1794 where his friends included Thomas Jefferson and Benjamin Franklin. He settled in Northumberland, Pennsylvania although his scientific work never recovered from his forced departure. But the descriptions of his experiments with oxygen will always remain a high point in the history of respiratory physiology.

dephlogisticated air; discovery of gases; liberal views; Warrington Academy; forced emigration

FOR MANY OF US INTERESTED in the history of respiratory physiology, Joseph Priestley (1733–1804) has a special place (Fig. 1). Not only was he the first person to produce the gas we now call oxygen, but his description of his discovery was so arresting that rereading it always gives special pleasure. As we shall see, Carl Wilhelm Scheele (1742–1786) actually produced the gas earlier, but his description appeared after Priestley's and his style was more laconic. Antoine Laurent Lavoisier (1743–1794) repeated Priestley's critical experiment and then went on to clarify the nature of oxygen that eluded Priestley who adhered to the erroneous phlogiston theory. But Priestley has the distinction of first describing some of the properties of this gas from which much of respiratory physiology devolves. He was a talented writer with an enormous output of papers and books. His descriptions in late 18th-century English remain a delight to read, reflecting as they do his enthusiasm and wonder. Revisiting his reports of his great discovery never fails to evoke a certain frisson.

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Although Priestley's discoveries in the area of oxygen and a number of other important gases are naturally the focus of this article, it should be made clear at the outset that most of his writings were in an entirely different area. First and foremost he was a minister of religion with a lifelong emphasis on a humanist philosophy that resulted in him being a fierce non-conformist. This led to severe criticism from the established church in England. He was an ardent liberal who strongly supported both the French and American revolutions, and it was these political attitudes that ultimately led to his undoing in England and his subsequent emigration to America. By far the largest part of Priestley's writings is on theology, and, for example, in the definitive biographies such as those of Schofield (15, 16), Priestley's work on the respiratory gases occupies only a small section. He was also a man of prodigious energy, and apart from his studies of religion and oxygen and other gases he made important contributions to the topic of electricity, particularly its history. He produced some 50 books and when once asked how many he had written he replied "Many more, Sir, than I should like to read" (8).

Not surprisingly, there is a large literature on Priestley, especially in relation to his work on oxygen. The chief purpose of this article is to give graduate and medical students (and perhaps their mentors) some insight into the color and excitement of his discoveries. In addition it is revealing to compare Priestley with his contemporary, Lavoisier, because of their very different personalities and writings. Finally, there is a discussion of Priestley as a product of the Enlightenment that had such an enormous influence in Europe in the 18th century and beyond, that resulted in Priestley's interactions with Benjamin Franklin (1706–1790) and Thomas Jefferson (1743–1826), and that still resonates with many of us today.

Brief Biography

Priestley was born near Leeds, a major city in Yorkshire in the north of England. The family was rather poor but strongly religious, albeit not in conformity with the established Church of England. Priestley showed precociousness from an early age and, as noted by several biographers, at the age of four he could flawlessly recite all 107 questions and answers of the Westminster Shorter Catechism. As an example, question 1 was "What is the chief end of man?" with the answer "Man's chief end is to glorify God, and to enjoy him forever." This cerebral, analytical attitude was to remain with Priestley for the whole of his life.

Priestley studied theology at the Daventry Academy where liberal, enlightened emphases were strong. As a nonconformist, or dissenter from the established Church of England, he was precluded from attending most higher institutions including Oxford and Cambridge. In Daventry he developed his belief in tolerance, abhorrence of dogma, and a passion for the rational analysis of the natural world. Later Priestley moved to the prestigious Warrington Academy, where he tutored in



Fig. 1. Joseph Priestley (1733–1804), by Ellen Sharples. © National Portrait Gallery, London. Reproduced by permission.

languages because of his broad knowledge of French, Italian, and German, and his liberal leanings increased. He wrote an English grammar (9) that still makes enjoyable reading with its rigorous analytical style. He also produced several essays on the importance of a liberal education with an emphasis on its development. Another strong interest was electricity, particularly its history, and he published a 700-page book titled *The History and Present State of Electricity* (10) that went through five editions and translations into French and German. He made several discoveries in this area, including the conductivity of charcoal, and he proposed that electrical force was similar to Newton's gravitational force in following an inverse square law.

Priestley then returned to Leeds where he became the minister of the Mill Hill Chapel. There he wrote his book "Institutes of Natural and Revealed Religion" (12), which further emphasized his liberal views and set out his conviction that religious beliefs should be consistent with a scientific view of the world. As a result he challenged a number of basic Christian principles, and this evoked a great deal of savage criticism. Priestley questioned the divinity of Christ and the Virgin Birth, and he was one of the founders of the Unitarian Church in both England and America.

Priestley's financial position was never particularly secure and in 1772 he entered the services of Lord Shelburne, who was immensely wealthy and had a large country estate in Wiltshire and a house in London. Shelburne stated that he

needed a tutor for his children, a librarian, and an assistant, but in fact the duties were light and some of Priestley's best experimental work on oxygen was carried out at this time. The country estate known as Bowood House is a grand English stately home that can be visited today.

In 1780 Priestley moved to Birmingham where he continued his teaching and research. While he was there he became a member of the famous Lunar Society that included inventors, scientists, manufacturers, and others who met together once a month at the time of the full moon to discuss their work. The many members included the engineer James Watt, the physician and philosopher Erasmus Darwin, and the botanist William Withering, known for his work on the foxglove and digitalis. However, Priestley increasingly faced resistance because of his extreme liberal views. This came to a head in July of 1791 when a dinner was arranged to celebrate the anniversary of the storming of the Bastille in Paris, and this provoked a riot. A mob torched Priestley's house, destroying all of his belongings including his scientific equipment (Fig. 2). Priestley and his family eventually escaped to London, where he lived for a period in the district of Hackney.

The criticism surrounding Priestley became so virulent that in 1794 he sailed with his family to America, where they initially lodged in Philadelphia, the capital at that time. Before leaving England he wrote, "I cannot refrain from repeating again, that I leave my native country with real regret, never expecting to find anywhere else society so suited to my disposition and habits" (8). While Priestley was on the high seas in 1794, his contemporary, Lavoisier, was executed by guillotine in Paris. Priestley was offered a professorship at the University of Pennsylvania but declined. The family eventually moved to Northumberland County in Pennsylvania where Priestley's son and others purchased 300,000 acres. Priestley built a new house and laboratory, which is now a national monument. However, his scientific work never completely recovered from his rejection in England. Priestley died in 1804 and is buried in Riverview Cemetery in Northumberland.

First Production of Oxygen

August 1, 1774 is a red letter day for respiratory physiologists because this was when Priestley first produced oxygen. He did this by heating red mercuric oxide (known at the time as *mercurius calcinatus per se*) by focusing the sun's rays using a convex lens of 12 inches diameter. The experiment was not trivial. First, to produce red mercuric oxide it was necessary to heat mercury exposed to air to near its boiling point for several months. Next was the problem of collecting the gas released from the mercuric oxide when it was heated to a very high temperature. Priestley did this by using glass containers shown in Fig. 3. He placed some of the red mercuric oxide in the bottom of the container, filled it with mercury, and then inverted it over a basin of mercury. Stephen Hales (1677–1761) had previously used glass containers filled with water inverted over a water bath for collection of gases (5). When Priestley heated the mercuric oxide by focusing the sun onto it he found that a gas was evolved, causing the mercury in the glass vessel to fall.

He then collected a sample of this gas (which he called dephlogisticated air) and subjected it to several tests. First he found that it was insoluble in water. This was important



Fig. 2. Rioters Burning Dr. Priestley's House at Birmingham, 14 July 1791 (1791), by Johann Eckstein. From the Susan Lowndes Marques Collection.

because he had previously produced a gas that had some of the same properties but was water soluble. This was nitric oxide (NO), which oxidized to nitrogen dioxide (NO_2). Next he placed a candle in the new gas and reported in his immortal statement “but what surprized me more than I can well express, was, that a candle burned in this air with a remarkably vigorous flame . . . I was utterly at a loss how to account for it” (Fig. 4). He also reported that “a piece of red-hot wood sparkled in it . . . and was consumed very fast” (14).

Because it is interesting to see the actual printed version, Fig. 4 reproduces the passage in Priestley's chapter from his book *Experiments and Observations on Different Kinds of Air* volume II published in 1776 (14). This is frequently quoted as the first record of the discovery. However, Fig. 5 reproduces the first actual statement in print (13). The circumstances of this are interesting. Very soon after his first experiment on August 1, 1774, Priestley set out with his patron, Lord Shelburne, for a tour of the European continent. In October they were in Paris and met with members of the Académie des

Sciences and also had dinner with Lavoisier. During this Priestley told Lavoisier about his extraordinary results, and in retrospect it was perhaps strange that he would reveal these to one of his potential competitors before he had published them. However, Priestley did not believe in secrecy. In the account of his discovery (14) he wrote, “As I never make the least secret of any thing that I observe, I mentioned this experiment also, as well as those with the *mercurius calcinatus*, and the red precipitate, to all my philosophical acquaintance in Paris, and elsewhere, having no idea at that time, to what these remarkable facts would lead.” Conversely, Lavoisier put a great deal of importance on secrecy and precedence and was guilty at times of not citing the work of others whose work he had exploited. In the event Lavoisier was quick to repeat Priestley's experiment before the latter could return to England and continue his work.

Priestley was back in England in November 1774 but did not return to working on the new gas until March 1, 1775. In the meantime he worked on other gases that he had discovered.

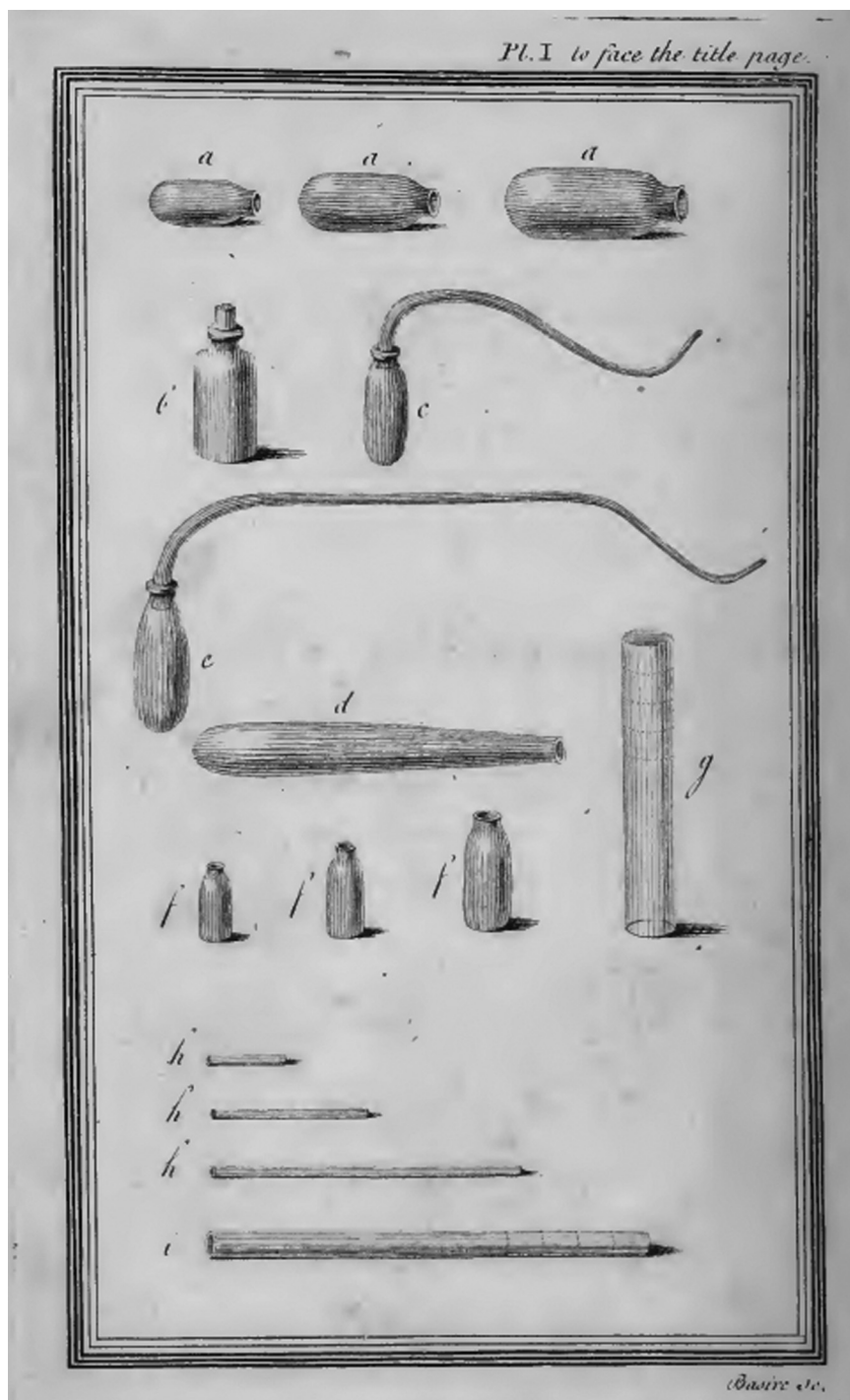


Fig. 3. Apparatus used by Priestley for the production of oxygen and other gases. From Ref. 14.

However, on March 8 Priestley decided to test the effects of the new gas on a mouse. He found to his delight that whereas the animal could live only a quarter of an hour in common air, it survived for an hour in his new gas on two different occasions. Furthermore when the mouse was taken out it was still quite vigorous. At this point Priestley realized the importance of getting the new work into print and on March 15 he wrote a letter to Sir John Pringle, the President of the Royal Society. This was published later in 1775; an extract is reproduced in Fig. 5. Note that Priestley reiterated the effect of the gas on a

burning candle and a piece of red-hot wood but he also went on to describe its effect on a mouse.

Priestley then speculated in his typical engaging way that his new gas might be useful for patients of lung disease. He stated "From the greater strength and vivacity of the flame of a candle, in this pure air, it may be conjectured, that it might be peculiarly salutary to the lungs in certain morbid cases, when the common air would not be sufficient to carry off the phlogistic putrid effluvia fast enough" (Fig. 6). He continued with another wonderful paragraph "My reader will not wonder,

With this apparatus, after a variety of other experiments, an account of which will be found in its proper place, on the 1st of August, 1774, I endeavoured to extract air from *mercurius calcinatus per se*; and I presently found that, by means of this lens, air was expelled from it very readily. Having got about three or four times as much as the bulk of my materials, I admitted water to it, and found that it was not imbibed by it. But what surprized me more than I can well express, was, that a candle burned in this air with a remarkably vigorous flame, very much like that enlarged flame with which a candle burns in nitrous air, exposed to iron or liver of sulphur; but as I had got nothing like this remarkable appearance from any kind of air besides this particular modification of nitrous air, and I knew no nitrous acid was used in the preparation of *mercurius calcinatus*, I was utterly at a loss how to account for it.

Fig. 4. Priestley's account of his discovery of oxygen on August 1, 1774. From Ref. 14.

that, after having ascertained the superior goodness of dephlogisticated air by mice living in it, and the other tests above mentioned, I should have the curiosity to take it myself. I have gratified that curiosity, by breathing it, drawing it through a glass siphon, and, by this means, I reduced a large jar full of it to the standard of common air. The feeling of it to my lungs was not sensibly different from that of common air; but I fancied that my breast felt peculiarly light and easy for some time afterwards. Who can tell but that, in time, this pure air may become a fashionable article in luxury. Hitherto only two mice and myself have had the privilege of breathing it" (Fig. 6).

Priestley warned in his disarming fashion "but, perhaps, we may also infer from these experiments, that though pure dephlogisticated air might be very useful as a *medicine*, it might not be so proper for us in the usual healthy state of the body; for, as a candle burns out much faster in dephlogisticated than in common air, so we might, as may be said, *live out too fast*, and the animal powers be too soon exhausted in this pure

A candle burned in this air with an amazing strength of flame; and a bit of red hot wood crackled and burned with a prodigious rapidity, exhibiting an appearance something like that of iron glowing with a white heat, and throwing out sparks in all directions. But to complete the proof of the superior quality of this air, I introduced a mouse into it; and in a quantity in which, had it been in common air, it would have died in about a quarter of an hour, it lived, at two different times, a whole hour, and was taken out quite vigorous; and the remaining air appeared to be still, by the test of nitrous air, as good as common air.

Fig. 5. Priestley's first description of his production of oxygen in a letter to Sir John Pringle. From Ref. 13.

From the greater strength and vivacity of the flame of a candle, in this pure air, it may be conjectured, that it might be peculiarly salutary to the lungs in certain morbid cases, when the common air would not be sufficient to carry off the phlogistic putrid effluvia fast enough. But, perhaps, we may also infer from these experiments, that though pure dephlogisticated air might be very useful as a *medicine*, it might not be so proper for us in the usual healthy state of the body: for, as a candle burns out much faster in dephlogisticated than in common air, so we might, as may be said, *live out too fast*, and the animal powers be too soon exhausted in this pure kind of air. A moralist, at least, may say, that the air which nature has provided for us is as good as we deserve.

My reader will not wonder, that, after having ascertained the superior goodness of dephlogisticated air by mice living in it, and the other tests above mentioned, I should have the curiosity to taste it myself. I have gratified that curiosity, by breathing it, drawing it through a glass siphon, and, by this means, I reduced a large jar full of it to the standard of common air. The feeling of it to my lungs was not sensibly different from that of common air; but I fancied that my breast felt peculiarly light and easy for some time afterwards. Who can tell but that, in time, this pure air may become a fashionable article in luxury. Hitherto only two mice and myself have had the privilege of breathing it.

Whether the air of the atmosphere was, in remote times, or will be in future time, better or worse than it is at present, is a curious speculation; but I have no theory to enable me to throw any light upon it.

Fig. 6. Priestley's conjecture on the possible use of oxygen in patients with lung disease. From Ref. 14.

kind of air. A moralist, at least, may say, that the air which nature has provided for us is as good as we deserve."

He later wondered about possible changes in the atmosphere, thus giving his reflections a distinctly modern flavor when he pondered "Whether the air of the atmosphere was, in remote times, or will be in future time, better or worse than it is at present, is a curious speculation; but I have no theory to enable me to throw any light upon it." A little later he states "Philosophers, in future time, may easily determine, by comparing their observations with mine, whether the air in general preserves the same degree of purity, or whether it becomes more or less fit for respiration in the course of time; and also, whether the changes to which it may be subject are *equable*, or otherwise; and by this means may acquire *data*, by which to judge both the past and future state of the atmosphere. But no observations of this kind having been made, in former times, all that any person could now advance on this subject would be little more than random conjecture. If we might be allowed to form a judgement from the length of human life in different ages, which seems to be the only *datum* that is left to us for this purpose, we may conclude that, in general the air of the atmosphere has, for many ages, preserved the same degree of purity. This *datum*, however, is by no means sufficient for an accurate solution of the problem."

Oxygen Is Produced by Green Plants

The experiments described above with their dramatic findings and colorful descriptions assured Priestley's place in the history of respiration. However, he made another remarkable discovery about oxygen, that is that it is produced by green plants. Interestingly this observation took place several years before the work described above.

Back in 1771 Priestley had an interest in "noxious air" or "air infected with animal respiration." For example he tried various ways of improving the air produced in a closed vessel when a candle had burned out. However, every intervention such as cooling the air or compressing it had no effect. But in August 1771 he made an extraordinary serendipitous discovery. First he pointed out that everybody knew that animals in a confined space caused the air to become noxious with the result that they died. He assumed that the same would be true for plants but he was in for a big surprise. He wrote "I own I had that expectation, when I first put a sprig of mint into a glass jar, standing inverted in a vessel of water: but when it had continued for growing there for some months, I found that the air would neither extinguish a candle, nor was it at all inconvenient to a mouse, which I put into it." On August 17, 1771 he put a sprig of mint into the noxious air that had been produced when a candle burned out. To his delight, he found that 10 days later, a candle burned in the air perfectly well. He added that he carried out the experiment about 10 times during the summer of 1771 and repeated the experiments in the summer of 1772. He found that the best results occurred when spinach was used.

The experiments of 1772 are particularly interesting because of Priestley's distinguished guests. He reported that on June 20 he generated some noxious air by keeping mice in an enclosed space until they died. He then put a sprig of mint into the vessel and found that the air had been restored to such an extent that a candle could burn in it, and a mouse could also live. This experiment was seen by Benjamin Franklin and Sir John Pringle, President of the Royal Society, who were visiting Priestley. Franklin made the droll remark that "I hope this will give some check to the rage of destroying trees that grow near houses." Incidentally sometimes historians claim that Priestley discovered photosynthesis but this is perhaps an unwarranted extrapolation.

Who Discovered Oxygen?

This question is posed so frequently that it seems appropriate to devote a few lines to it here. In fact it is not a particularly useful question because the answer depends on semantics, for example what is meant by the word "discover." The facts are as follows. Priestley was clearly the first person to describe the production of oxygen. As we have seen, he produced it on August 1, 1774, and described it in his letter to Pringle dated March 15, 1775, which was published later that year. It is true that Priestley called the new gas "dephlogisticated air" because he was wedded to the phlogiston theory expounded by Georg Ernst Stahl (1659–1734), and he interpreted his findings in the light of this erroneous theory. Therefore, although he was clearly the first person to produce the new gas, he did not understand its true nature. Scheele produced oxygen as early as 1772, also by heating red mercuric oxide, and called it "fire-air." However, although he sent his report to the printer in 1775, it was not published until 1777, that is two years after

Priestley's report. Scheele also interpreted his finding according to the phlogiston theory.

As we have seen, Lavoisier learned of Priestley's critical experiment in October 1774 and he immediately repeated it. Also Scheele had written to Lavoisier on September 30, 1774 describing his own experiments with heated mercuric oxide, although it is likely that the letter reached Lavoisier after Priestley's visit. Incidentally Lavoisier never acknowledged receiving Scheele's letter, and this is consistent with Lavoisier's pattern of not acknowledging the work of his competitors. Both Scheele and Priestley remarked on this failing of Lavoisier.

Lavoisier communicated a memoir to the Académie des Sciences at Easter 1775 titled "On the nature of the principle which combines with metals during calcination and increases their weight," published in May 1775 in a journal edited by Rozier. This is sometimes referred to as the Easter Memoir. He reported on the gas produced by heating red mercuric oxide but mistakenly thought that this was common air (2). Lavoisier's critical memoir to the Académie des Sciences titled "Expériences sur la respiration des animaux..." in which he clearly described the three respiratory gases, oxygen, carbon dioxide, and nitrogen, was not published until 1777 (6).

Incidentally, some historians give the credit for the discovery of oxygen to earlier scientists such as John Mayow (1641–1679), who believed that air had a component that he called "nitro-aerial spirit" and that was used up in a flame. He discovered that both burning lamps and animals expire in a closed space "for want of nitro-aerial particles" but he did not himself produce oxygen.

Other Gases Discovered by Priestley

Priestley isolated and characterized eight gases in all including oxygen. This record has not been equaled before or since. In 1772 Priestley discovered no less than four new gases. One of these was nitric oxide (NO), although in his terminology this was called "nitrous air," which can lead to confusion. He produced the gas by the action of nitric acid (called by him *spirit of nitre*) on brass or other metals. This gas played an important role in his early work on the "goodness" of air. When he added nitrous air to ordinary air in a tube above a water bath there was a reduction in volume of the air by one-fifth. The reason was that the oxygen in the air combined with the nitrous air to form nitrogen dioxide (NO₂), which dissolved in the water. Priestley performed this test with other samples of air, for example the air expired from the lung, and found that the reduction in volume was less. He therefore used the test to show that the "goodness" of the air had been reduced by the lung. In fact it was the use of this test that misled Lavoisier in his Easter 1775 memoir referred to above.

The next gas that Priestley discovered was nitrous oxide (N₂O). He called this "dephlogisticated nitrous air" and produced it by heating iron filings with nitric acid. Another discovery was hydrogen chloride (HCl), which he called "marine acid air." This was made by heating copper with spirit of salt, but he eventually realized that the marine acid air was simply the fumes of the spirit of salt. Finally in 1772 he produced carbon monoxide (CO), which he called "combined fixed air." This was done by heating charcoal. For some time

this was confused with “inflammable air,” that is hydrogen, and also with methane since all three gases were flammable.

In 1773 Priestley discovered ammonia (NH_3), which he called “alkaline air.” This was prepared from the action of hydrogen chloride (spirit of salt) on sal ammoniac [a mineral composed of ammonium chloride (NH_4Cl)]. In 1774 Priestley produced oxygen as we have already seen. In the same year he discovered sulfur dioxide (SO_2), which he called “vitriolic air.” This was done by burning sulfur in a vessel and collecting the effluent gas.

Priestley also worked with two other gases but these had been discovered by others. The first was carbon dioxide (CO_2), which was known as “fixed air.” This had been discovered by Joseph Black (1728–1799), who worked in Scotland. When he was at the Mill Hill Chapel Priestley collected carbon dioxide from an adjacent brewery where it was evolved during fermentation. He also prepared it by adding oil of vitriol (sulfuric acid H_2SO_4) to chalk. Finally, Priestley worked with hydrogen (H_2) which was called “inflammable air.” This had previously been discovered by Henry Cavendish (1731–1810), who made it by adding diluted oil of vitriol to steel filings. Priestley observed that when a mixture of inflammable and common air was exploded with an electric spark, the glass vessel “became dewy.” He told Cavendish about this, who later burned large quantities of the two gases and obtained pure water.

Two Revolutionaries: Lavoisier and Priestley

The discovery of oxygen and the ensuing overthrow of the phlogiston theory that occurred in the latter part of the 18th century is often referred to as a scientific revolution. It certainly freed the confusion surrounding the respiratory gases from the stranglehold previously held by the phlogiston theory, and progress in this area of science was subsequently rapid. Two of the principal players in this revolution were Lavoisier and Priestley, and it is interesting to briefly compare and contrast these two major scientists.

First the similarities. These two men were scientific contemporaries in that, as we have seen, they worked on the discovery and elucidation of oxygen at the same time in the 1770s and 1780s. Indeed it was Priestley’s description of his August 1, 1770 experiment when he had dinner with Lavoisier in October of that year that apparently was a crucial turning point in Lavoisier’s research. It is true that Priestley was actually 10 years older than Lavoisier but Priestley’s interests in theology and electricity delayed his work on oxygen. Of course both Lavoisier and Priestley were outstanding scientists and both were enormously productive. Having said that, both men had major interests outside those of chemistry. Lavoisier was a successful businessman who became wealthy principally as a result of his work with the Ferme Générale, a tax collecting organization. Priestley made major contributions in the area of theology. Sadly it was Lavoisier’s links with the Ferme Générale that ultimately resulted in his execution, and it was Priestley’s extreme liberal attitudes in theology that forced him to leave his native country. In a sense the final years of both were equally tragic. Lavoisier was guillotined in 1794 at the age of 51, while in the same year Priestley was subjected to such violent persecution in England because of his nonconformist theology that he was forced to leave the country, and his scientific career never recovered.

However, there were important differences between the two men. From a scientific point of view it has to be said that whereas Priestley’s discovery of oxygen as recounted above was so dramatic and such a delight to read, Lavoisier’s contributions were more important in terms of the advancement of science. Priestley never freed himself from the erroneous phlogiston theory and continued to espouse it until his death. It was Lavoisier who was responsible for overturning the theory and making possible the subsequent advancement of science. Another important difference was the attitudes of the two men to their new discoveries. As we have seen, Priestley showed an almost boyish delight in recounting exactly what he did, and he freely gave his information to Lavoisier to the latter’s great advantage. By contrast Lavoisier was secretive about his discoveries and placed a great emphasis on precedence. As an example, when he discovered in 1772 that burning phosphorus resulted in a substantial increase in weight, he realized that this was a crucial observation that was inconsistent with the phlogiston theory. The reason was that substances that burnt were thought to release phlogiston and therefore would be expected to lose weight. So to assure precedence, Lavoisier secretly deposited this finding as a sealed note in the Académie des Sciences with the date so that subsequently he could prove precedence. Such an action would have been unthinkable to Priestley. If, as sometimes happens in a television show, we were asked whom we would prefer to have dinner with, most of us would choose Priestley although the fare would likely be less lavish.

Lavoisier was a consummate chemist and indeed is often referred to as the father of chemistry. By contrast some historians have argued that Priestley’s footing in chemistry was insecure. Indeed at one point Priestley himself stated that he was not “a professed chemist.” An amusing anecdote is that in 1777 he wrote to Benjamin Franklin (1706–1790) stating that he “did not quite despair of the philosopher’s stone” (an alchemical substance that turned base metals into gold) whereupon Franklin advised him by return, if he found it, “to take care to lose it again” (8).

Finally, the social backgrounds of the two scientists were very different. Lavoisier was born into a well-to-do family, had the advantages of an excellent education in some of France’s best schools, and became wealthy partly through his work with the Ferme Générale. At his death he owned a substantial amount of property. By contrast, Priestley was born into a poor family, never showed a particular interest in making money, and indeed had limited means throughout his life. His circumstances were recognized by Lord Shelburne who, as we saw earlier, offered him a post with an associated income. The duties were light and it is generally believed that they were listed by Shelburne to avoid giving the impression that an important objective was to improve the financial situation of Priestley though in fact this was the case.

Priestley’s Contributions to Electricity

As mentioned earlier, Priestley made important contributions to the study of electricity, which was a topic of great interest in the scientific world at that time. This is peripheral to the main subjects of this article but deserves a brief mention. His major contribution was a 700-page book on *The History and Present State of Electricity* (10) that had five editions and

apparently is still read by people today for its insights into the development of the subject. Today when we think of electricity we envision topics such as voltage, current, and resistance. However, in Priestley's time these were unknown. The emphasis was on electrical charges that could be developed by rubbing a material such as glass against a fabric. In fact Priestley invented an electrical machine in which a rotating glass sphere was in contact with leather or soft flannel and thus produced a charge that could be conducted along a wire (Fig. 7). Priestley made the important observation that there was no charge inside a hollow cylindrical vessel or cup connected to the wire and he concluded "May we not infer from this experiment, that the attraction of electricity is subject to the same laws with that of gravitation, and is therefore according to the squares of the distances: since it is easily demonstrated, that were the earth in the form of a shell, a body in the inside of it would not be attracted to one side more than another?" Franklin, whose work on electricity particularly that associated with lightning is well known, had suggested this approach (8).

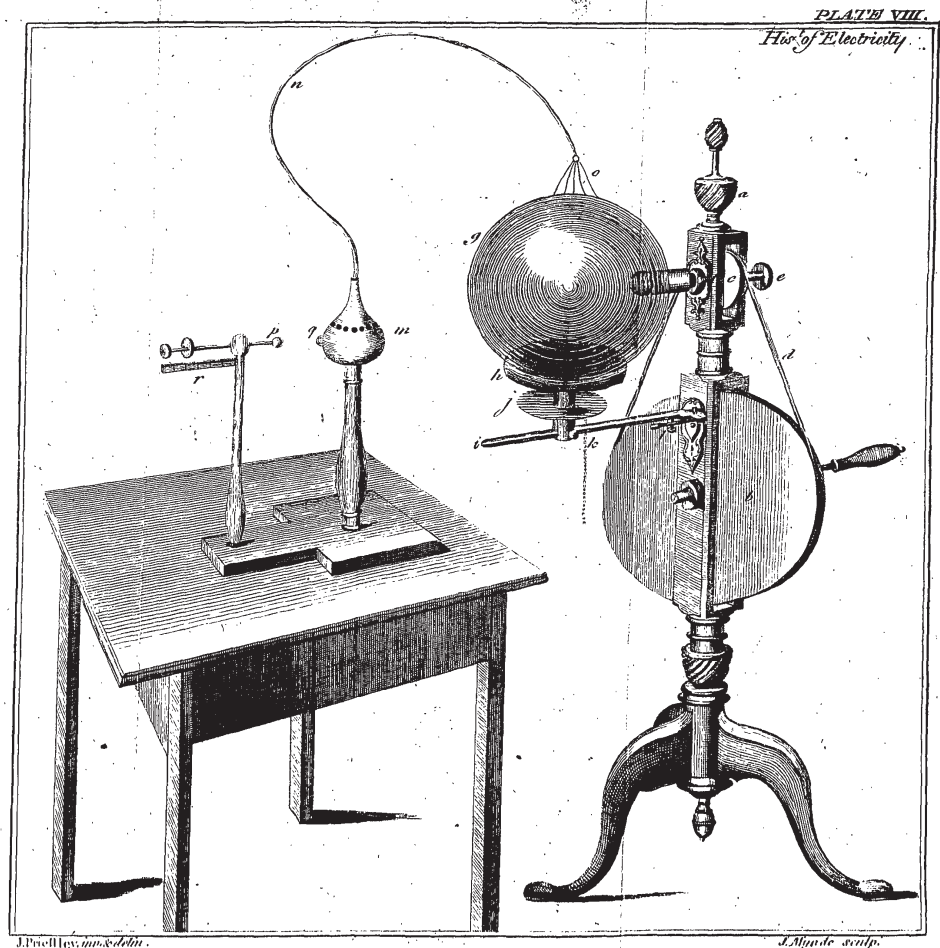
Priestley and the Enlightenment

The Enlightenment was a major change in attitudes about science, philosophy, and religion that occurred mainly in the late 17th and 18th centuries. Many names are associated with its beginning including those of the Dutchman Baruch

Spinoza (1632–1677), the Frenchman Voltaire (1694–1778), and the Englishmen John Locke (1632–1704) and Isaac Newton (1643–1727). It can be thought of as a late product of the Renaissance with its emphasis on the power of human reason, individualism as opposed to institutions, and an opposition to tradition, intolerance, and superstition. Priestley was very much a child of the Enlightenment and is some ways an example of its extremes. This was very evident in his theology. As we have seen, from an early age he was a dissenter from the established Church of England, and his attitudes became more liberal during his lifetime. Although he was a committed clergyman, he gradually estranged himself from his congregations because of his very liberal attitudes.

Priestley argued that all beliefs should be able to stand the scrutiny that he used for scientific investigations. This attitude was consistent with writings from the Warrington Academy, where a typical statement was that if any idea that is "embraced, shall upon impartial and faithful examination appear to you to be dubious and false, you either suspect or totally reject, such principle or sentiment" (1). The upshot was not to draw a distinction between the validity of a scientific belief and of religious belief. Clearly this attitude would lead to difficulties in traditional Christianity. Priestley therefore found himself moving further and further away from the established church

Fig. 7. Priestley's machine for generating static electricity (subsequently modified). From Ref. 11.



and ultimately allying himself with the emerging Unitarian Church first in England and later in America.

These new attitudes resonated with some people in the new colony in America including Benjamin Franklin and Thomas Jefferson. They also found sympathy with people connected with the revolution in France, which had a strong anti-Church element. However, as we have seen, these liberal attitudes met with violent opposition in England and eventually resulted in Priestley being forced to leave for America.

It might be added that many scientists today are aware of tensions between the rigorous attitudes of their profession to evidence on the one hand, and the traditions of organized religion on the other. For a robust contemporary account see Richard Dawkins' book *The God Delusion* (3), whereas a more conciliatory approach is described by Stephen Jay Gould (4). Opposing views come from many including McGrath (7).

In conclusion, Priestley will always be remembered as the man who first reported the discovery of oxygen with its remarkable properties of reigniting an ember of wood and increasing the survival of mice in a closed container. In addition, he discovered that the gas he called dephlogisticated air was produced by green plants. Unfortunately he never fully understood the nature of his new gas because he was wedded to the erroneous phlogiston theory. It was left to his contemporary, Lavoisier, to describe the nature of the respiratory gases. Priestley was a dedicated clergyman who developed very liberal views because of the influence of the Enlightenment. As a result his theology was subjected to vitriolic criticism and ultimately his house and equipment were destroyed, forcing his emigration to America. While Priestley was on the high seas, Lavoisier was executed by his own countrymen. These two scientific revolutionaries changed the face of respiratory physiology but both had tragic endings. But

Priestley's writings continue to give pleasure even after repeated readings. His attitude to work was summed up in his sentence "Human happiness depends chiefly upon having an object to pursue, and upon the vigour with which our faculties are exerted in the pursuit" (10). We could do worse than have this displayed on our work desk.

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