Rediscovery of the Elements

Joseph Priestley

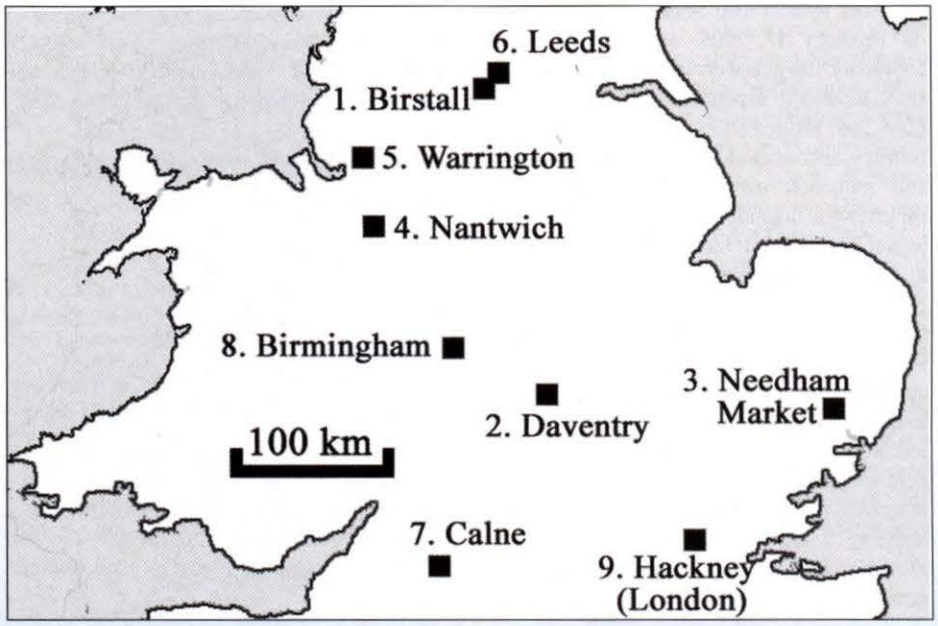

Figure 2. These locations are where Priestley lived in England before emigrating to the U.S. in 1794, sequenced chronologically.

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The play Oxygen, by Carl Djerassi and Roald Hoffmann, deals with three scientists. Previous articles in the HEXAGON discussed the lives of two of these scientists, namely, Scheele and Lavoisier.[6] We present the third member of the Oxygen trio, Joseph Priestley (1733–1804), who was the first to publish an account of the isolation of oxygen ("dephlogisticated air").

The European Enlightenment during the seventeenth and eighteenth centuries witnessed mankind's aspiring struggle to understand his place in the Universe. This process involved emancipation from the confining ideas of intolerant governments and religions as well as the development of science. Joseph Priestley (Figure 1) lived during the latter part of this period, passionately and tirelessly using both his pen and his pulpit to broadcast his ideas of religion, politics, education, and science.[1-5] (Note 1). He was quiet by nature and warm in companionship, modest and generous, with a cheerful spirit. He, however, fearlessly criticized what he considered to be shameful ideas and practices of the Establishment. He made both enemies and friends; no one could ignore him. He touched the course of history sharply and often.

During Priestley's career he lived in central England (Figure 2) for 61 years. His birthplace at Fieldhead still exists (Figure 3). During the period, 1741–1752, he lived with his father's older sister and husband, Sarah and John Keighley, at neighboring Old Hall, an Elizabethan manor house (Note 2). Priestley received his indoctrination of the Dissenter philosophy (those opposed to the established church of England) at Old Hall, both from the local church and in his home from a steady

Figure 1. This statue of Joseph Priestley stands in Birmingham. He is holding the lens used to discover oxygen (Chamberlain Square, N 52° 28.80 W 01° 54.28). Across the courtyard is a statue of James Watt, a fellow member in the Lunar Society. Four other statues of Priestley exist in England (see Note 7).

stream of visitors, "all the dissenting clergy in the country."[4] During this time he learned Latin, Greek, and Hebrew in school, and in private study he added Arabic and other Aramaic dialects. For a while he considered being a merchant, and studied French, German, and Italian; but experiencing a deep religious revival he dedicated his life to the ministry.

Priestley could not study at Oxford or Cambridge, where he would have to pledge allegiance to the Church of England. He could have attended a school in Scotland, Switzerland, or the Netherlands, but instead he chose the Dissenting institution of Daventry, and he studied there during the period 1752–1755 (Note 3). A stammer, which hindered him in public speaking, forced him to seek remedies; he developed a slow and conversational manner of delivery which audiences would find appealing. He also developed an aggressive style of writing to compensate for his linguistic handicap (he wrote clearly, boldly, and prolifically.) Philosophically, he believed that argument would expose falsehoods, and he fearlessly attacked any position that he believed incorrect. He came to believe that controversy was the best way to the truth, sometimes not realizing the bad impression it sometimes could create in those who did not know him.

After his training at Daventry, Priestley took a ministry at a Dissenting chapel at Needham Market (1755–1758). Dissatisfied with the lack of opportunities there, he moved to Nantwich where he was able to set up a school (1759–1761). Here he was able to acquire some "philosophical instruments" (air pump, electrical machine, etc.) to expand his teaching curriculum. He showed his genius for compiling confusing bits and pieces into an understandable whole (he wrote a grammar book *The Rudiments of English Grammar*, 1761, which was used by many subsequent scholars and teachers well into the 1800s). His power of keen observation and synthesis were exemplified by his recognizing, for example, the classical eight parts of speech (still the ones used to this day).

On the strength of his grammar book, Priestley was able to land a position as a teacher of languages at Warrington Academy (1761–1767), where he taught Greek, Latin, French, English, history, logic, and (showing his versatility) anatomy! (Note 4). Gleaning from his extensive readings, he wrote *A Chart of Biography*, a graphical timeline delineating the achievements of mankind during the period 1200 B.C.–1800 A.D. He advertised effectively and the *Chart* was popular and sold well. He became ordained at Warrington; and he married Mary Wilkinson. The University of Edinburgh, recognizing the merits of Priestley,

Figure 3. Priestley's birthplace near Birstall (Fieldhead, corner of Field Head Lane and Owler Lane, Birstall, Yorkshire, England; N 53° 44.58 W 01° 39.75). Priestley's father was a woolen cloth maker before the Industrial Revolution; hence he made his "cottage industry" living by weaving the cloth in his home. Inside the house the indentations in the floor can be seen where the loom originally stood more than 200 years ago. Inside, the owners proudly showed the authors original deeds and paintings of the household.

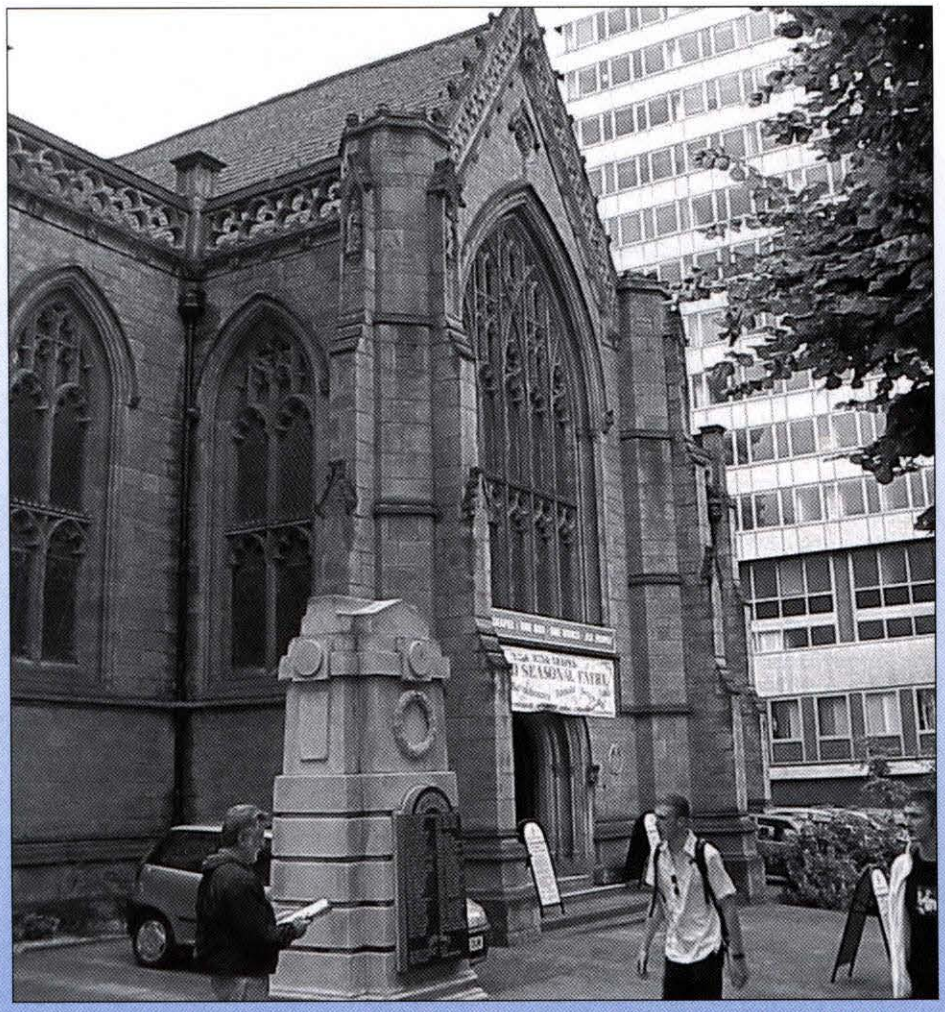

Figure 4. Mill Hill Chapel, City Square, Leeds, where Priestley preached 1767–1773 (N 53° 47.80 W 01° 32.85. Mill Hill is still a Unitarian church, and is marked with a "Blue Plaque."

Figure 5. Tetley's Brewery on Meadow Lane (N 53° 47.55 W 01° 32.43), the approximate site of Jacques' brewery in Leeds where Priestley first observed carbon dioxide being produced by the fermentation process, which excited his curiosity about gases. He lived next to this brewery for a year before moving closer to Mill Hill Chapel (Priestley Hall, 30 meters north of Mill Hill Chapel).

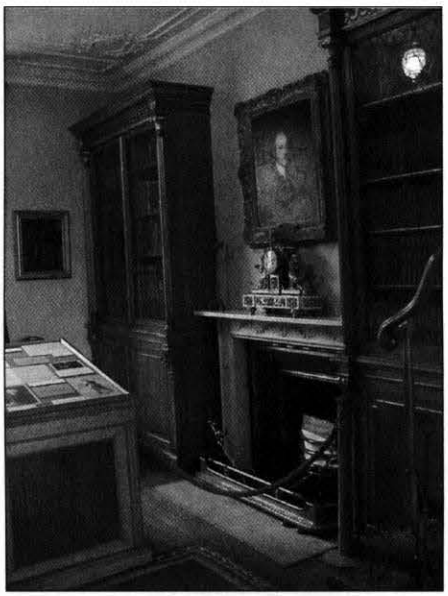

Figure 6. The laboratory-office of Joseph Priestley in Bowood House, 2 km southwest of Calne, (N 51° 25.70 W 02° 02.25). Calne, a historic landmark designated by both the American Chemical Society and the Royal Society, is a popular tourist site, boasting not only Lord Shelburne's manor, but also spacious beautiful gardens.

conferred on him a degree of Doctor of Laws, LL.D. (1764).

At Warrington he was able to acquire more scientific equipment, and recognizing the current popularity of electricity, he decided to write a book on it. With an intuitive sense of how to accomplish things, he journeyed to London and with his charm and wit befriended Benjamin Franklin and others at the Royal Society (Franklin lived in England until 1775, when political tensions caused him to return to the Colonies). Priestley persuaded the Royal Society to furnish him with books, academy apparatus, and advice on how to proceed with his project. Returning to Warrington, he built new equipment that he needed to reproduce old experiments and fashion new ones. In less than a year he had completed *The History and Present State of Electricity*. Impressed, the Royal Society elected him a Fellow (1766). Now Priestley had his full credentials (he could sign his name "Dr. Joseph Priestley, LL.D., F.R.S.;" (Doctor of Laws, Fellow of the Royal Society).

It was suggested that he write a second edition of *History of Electricity* with clarifying illustrations, but he could not find anyone to draw them. Hence, he learned perspective drawing on his own—and of course he wrote a book about it (*Introduction to Perspective*, 1770). In the preface, he recommended the use of "caoutchouc," recently brought from the New World, rather than the customarily used bread crumbs, to erase pencil lines (he named this new erasing agent "rubber").

Priestley was happy at Warrington, but he missed his primary calling, the ministry. He gladly accepted a position close to his original home in Yorkshire, at Mill Hill Chapel in Leeds (1767–1773) (Figure 4). His first house was next to a brewery (Figure 5), where he observed the carbon dioxide bubbles in the brewery process. He produced an artificial "Pyrmont Water" (an effervescent mineral water from Bad Pyrmont, 55 km southwest of Hanover) by impregnating water with "fixed air" (carbon dioxide). His product caused a sensation all across Europe. For his invention of soda water he received the prestigious Copley Medal from the Royal Society.

His curiosity about "airs" led him to collect fixed air over mercury, an improvement over older techniques that involved water, and which could often dissolve the gases. Modern "pneumatic chemistry" was born. By sheer curiosity and random experimentation, Priestley discovered "nitrous air" (nitrogen oxide, NO, prepared by reacting nitric acid and pyrites, metal sulfides) and "acid air" (hydrogen chloride, HCl, directly from hydrochloric acid solution).

In Leeds, with his predilection to organize and systematize, Priestley invoked the concept of phlogiston in his chemical discussions. Phlogiston was the universal flammability principle embraced by chemists of the eighteenth century.[8] Noticing that charcoal and metals conduct electricity, he thought that phlogiston must give rise to conductivity. Through the years Priestley developed and refined his interpretation of phlogiston, and he espoused this principle to his dying day.

By now Priestley's reputation had caught the attention of Lord Shelburne, who invited Priestley to Bowood (near Calne) to become his personal tutor-librarian. During his stay in Bowood (1773–1780), he discovered five more gases: ammonia, ("alkaline air," by heating aqueous ammonium hydroxide solution); nitrous oxide (N_2O; "diminished nitrous oxide," by reacting zinc in dilute nitric acid); sulfur dioxide ("vitriolic acid air," SO_2, by heating sulfuric acid and olive oil); nitrogen dioxide (NO_2, "nitrous acid vapor," by reacting nitric acid with bismuth); silicon tetrafluoride ("fluor acid air," prepared by heating fluorspar, CaF_2, with sulfuric acid with subsequent exposure to glass); and oxygen ("dephlogisticated air," by heating *mercurius calcinatus per se*, HgO).

At first when he prepared oxygen (August 1, 1774) he thought he had simply found another preparation of nitrous oxide, because it supported the combustion of a candle. During the autumn of 1774 he traveled with Shelburne to the Continent. In Paris, Priestley showed his

Figure 7. The home (Fairhill) of Joseph Priestley, being ransacked and burned by a mob July 14, 1791 (painting by Johann Eckstein; courtesy, Birmingham Public Library). At this time the home was in the country, 2.0 km southeast of New Meeting.

preparation of oxygen to Lavoisier; this visit has since has fueled the vigorous debate of how much Lavoisier depended upon Priestley for his understanding of oxygen.[7] Returning to Bowood, Priestley did further experimentation throughout the year and realized he had a new air. While nitrous oxide was just as "azotic" as nitrogen ("phlogisticated air"), his new air supported respiration. On March 23, 1775, a letter was read to the Royal Society announcing the "dephlogisticated air." Today his laboratory in Bowood is a National Landmark, designated by both the American Chemical Society and the Royal Society of Chemistry (Figure 6).

In Bowood Priestley made other significant scientific findings. He determined that both vegetation and light are necessary to "purify noxious air," thereby discovering photosynthesis. Experimenting *in vitro* with blood, he found it became bright red (i.e., became oxygenated) in the presence of dephlogisticated air and darkened when exposed to noxious air (i.e., became deoxygenated), thus recognizing the role of blood in respiration. All too often Priestley's imaginative experiments and sharp observations would serve as the spark leading to further discoveries by others.

By 1780 the differing political views of Lord Shelburne and Priestley led to their separation, and Priestley moved on to Birmingham (1780–1791). Here he resumed his beloved duties as a minister, and he joined the Lunar Society, a scientific society of exceptionally gifted intellectuals (Note 5). He called his stay in Birmingham the "happiest" of his life, principally owing to his joining the New Meeting House, one of the largest and affluent Dissenting congregations in England (Note 5).

Birmingham was a haven for Dissenters, who had a disproportionate amount of wealth in that city, even though they comprised only a tenth of the population. All through his career Priestley had been active in politics and the Dissenting religion, and things came to a head during the last decade of the eighteenth century. Other philosophers in the past, such as John Locke, had just as unorthodox views as Priestley, but they were never in mortal danger. Unfortunately, Priestley was the victim of bad timing—and a lack of discretion. The French Revolution had begun in 1789 and was alarming many in England who feared the revolution would spread across the English Channel. Priestley's vigorous support of the French Revolution (in conjunction with his advocacy of the American Revolution), his inflammatory rhetoric (he spoke of his arguments as "grains of gunpowder which would one day explode under the Anglican Church"), his attacks on Edmund Burke in the Parliament (once his friend), as well as the deepening ugly mood in the city, exploded in the Birmingham riots. The spark to the riots was a dinner (Note 5) commemorating the second anniversary of Bastille Day (July 14, 1791). At first it appeared the riots were spontaneous. There is a great deal of evidence, however, that they were planned and were encouraged by the local Establishment.[8] The mob destroyed the New Meeting House, Priestley's home, and the homes of other Dissenters (Figures 7, 8) in a three-day rampage. The Priestley family fled for their lives, never to return to Birmingham.

Priestley stayed three years in Hackney (1791–1794), in northeast London (Note 6) before continued fears for his family's safety prompted them to emigrate. During the eight-week transit (April 8–June 4, 1794) across the Atlantic, during which he witnessed "icebergs and waterspouts," Lavoisier was guillotined in Paris, France (May 8). There is no record of Priestley's response when he eventually heard of the news. We only can guess that his reaction was that of repose and serenity, as he showed when his own house was being destroyed.[2,5] While in Hackney he had wanted to return to Birmingham to preach in the ruins of his church, "forgive them for they know not what they do," but was dissuaded by friends who had a more realistic read on the city's temper.

Priestley settled in Northumberland, Pennsylvania, where he helped to organize the Unitarian church of America (Figure 9). He discovered one more gas, "heavy inflammable air" (carbon monoxide). Lavoisier's *Traité*, denouncing phlogiston and espousing the "New Chemistry"[6] had appeared in 1789. From then on Priestley's science was devoted not so much to new discoveries but instead to rearguard actions defending phlogiston. Priestley in 1800 wrote *The Doctrine of Phlogiston Established*, which he contended settled the matter; he quipped that hopefully the French political revolution "will be more stable than this chemical one."[2] Four years later he passed away, believing in phlogiston to his last breath.

Why did Priestley cling tenaciously to the theory of phlogiston?

"It was quite all right to be a phlogistonist in 1774, but to be one in 1803 was an outrage."[9]

Historians have agonized over the reasons why Priestley stubbornly adhered to the phlogiston theory in the face of mounting evidence supporting the New Chemistry. When Davy electrolyzed water, Priestley repeated the experiment and concluded the hydrogen and oxygen gases were not created during the process, but instead were originally dissolved in the water, because (among other reasons) they were produced in different amounts. Antiphlogistonists argued that inflammable air

Figure 8. The present location of Fairhill now resides in the city limits (10 Priestley Road) and boasts an apartment complex (N 52° 27.86 W 01° 52.68), identified with a plaque reading "This stone marks the site of Fair Hill where Joseph Priestley LL.D., F.R.S. Father of Pneumatic Chemistry lived and worked from 1780 to 1791." Ironically, across the street is a repair garage specializing in "Priestley's pneumatic tyres."

(hydrogen) came from water, but Priestley showed "heavy inflammable air" (carbon monoxide) could be produced when water was not present (and argued this was evidence that phlogiston united with different quantities of water to produce different forms of inflammable air). Partington[1] assails Priestley, stating that Priestley "displays what seems to us a perverse ingenuity in adapting the phlogiston theory to fit every new fact," and "ignoring facts that don't fit" (e.g., sulfur is full of phlogiston and yet is a nonconductor of electricity). Partington concludes "it would be tedious to follow him through this labyrinth of error."[1]

Schofield's analysis[2] is more balanced: he points out most people of Priestley's time, after all, *did* believe in phlogiston. Priestley, however, lacked a mind set that allowed him to grow with the changing science of chemistry. Lacking an appreciation of mathematics, and reasoning in terms of Aristotelian qualities, Priestley did not comprehend the significance of gravimetric analysis, and he ignored Conservation of Mass. He worked with gases, utilizing techniques before Dalton, noting only the sensible properties of substance. His idea of phlogiston as an inflammability principle pervading substances paralleled the commonly accepted idea of Newton's gravity being a fluid (ether) pervading the entire universe. In his frame of reference, all of his arguments were correct and logical.[2]

Tenney Davis agrees that Priestley's logic is self-consistent.[10] From his lifelong theological and philosophical perspective, Priestley viewed nature in terms of "unextended entities of the scholastic metaphysics" (i.e., intangible Aristotelian qualities). Tenney reminds us, "It is somewhat remarkable that this clergyman . . . was able to discover oxygen. . . , but it is not in the least remarkable that this intelligent clergyman, aware of his own mental processes, adhered to the doctrine of phlogiston."[10]

The Legacy of Priestley.

In languages and history, Priestley had a gift for learning fast, arranging and methodizing newly acquired knowledge, and creating useful and popular works. As a dedicated teacher-scholar he was constantly driven to write and convey newly-acquired knowledge to others. As a minister, his desire to use history as a basis for understanding led him to stress the importance of learning what the original Christians thought—leading to his Unitarian teachings. In science he created useful books on electricity and optics, and through his imaginative scientific research became known as the "father of pneumatic chemistry." Sir Humphry Davy placed him with Joseph Black, Henry Cavendish, and Carl Scheele as "one of the four greatest chemical discoverers" of the latter 18th century.[5] His contribution to mankind was massive and manifold.

His philosophical viewpoint, unfortunately, prevented Priestley from participating actively in the evolving new theories of chemistry. He had a vague notion that substances differed in their "mode of arrangement"[2] but could not understand Scheele's "compounds" and could not synthesize a self-consistent rationale for the behavior of his "airs." With his sharp thinking, however, Priestley had the knack for picking out weaknesses in the New Chemistry arguments. This proved to be important, because questioning the weaknesses of a new theory either strengthens it through revision, or disproves it if it is wrong. When Priestley discovered "heavy inflammable air" (carbon monoxide) he ridiculed the antiphlogistonists who had maintained "inflammable air" (hydrogen) came only from water. The antiphlogistonists were forced then to reckon with him—leading to William Cruikshank's determinative analysis in 1801 showing "heavy inflammable air" was in fact a "gaseous oxide of carbone." Thus, Priestley was an important participant in the self-correcting, modern science during the birth of the New Chemistry.

Perhaps Priestley simply attempted too much. Lavoisier was successful because he concentrated on quantitative studies of mass phenomena (although he glibly and incorrectly included "caloric" in his element list). Priestley, in his wish to understand everything, tried to incorporate the mysterious imponderable of combustion in his understanding of chemical philosophy. It was too early—it was many years later that scientists could recognize his concept of phlogiston as a "prototype" of nineteenth century chemical energy (enthalpy).[11] "Priestley's clinging to phlogiston . . . does not show an archaic viewpoint but . . . reveals an intuition of problems . . . beyond Lavoisier."[11]

Thomson suggests[4] that despite the Birmingham riots, perhaps fate was kind to

Figure 9. The Joseph Priestley House in Northumberland, Pennsylvania (472 Priestley Avenue, N 40° 53.43 W 76° 47.43). This popular tourist site is an American Chemical Society National Historic Landmark. Because of the 1876 centennial meeting of chemists commemorating the discovery of oxygen in Northumberland, this symbolic site aptly might be considered the "birthplace of the American Chemical Society."

Priestley after all, because he "had carried his research as far as it would go." If Priestley had continued his chemical research in Birmingham, his scientific reputation would have suffered and he might have gone down in history without "that eminent situation as a man of science which he had so long occupied."[1] Indeed, Schofield pointed out that American science well profited by the emigration of Priestley: "[His arrival] gave a spring to the study of chemistry on that side of the Atlantic."[2] In 1876, the centennial of the discovery of oxygen was celebrated in Northumberland by the First National Congress. This meeting inspired the founding of the American Chemical Society two years later. The Priestley Medal, first presented in 1923, is awarded by the American Chemical Society annually "for distinguished services to chemistry." On August 1, 1994, the American Chemical Society designated Priestley's house as a National Historic Chemical Landmark.

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Notes.

Note 1. It is impossible to review all of the work that Joseph Priestley accomplished in a short article. A polymath of incredible talent, he published about 50 works on theology, 13 on education and history, 18 on political, social, and metaphysical subjects, 12 books and about 50 papers on scientific subjects. It is always a formidable task to locate a single author to address the life of one accomplished in so many different areas, but fortunately an excellent complete account of his life and works have been written by Robert Schofield.[1,2] Not as detailed, Gibbs gives a more personalized biography.[5] Full histories concerning his chemistry contributions have been written by Partington[3] and Thomson.[4]

Note 2. Old Hall still exists, now as a pub, on New North Road in Heckmondyke (N 53° 42.69 W 01° 40.62), 3.6 km SSW of Fieldhead.

Note 3. The edifice of Daventry Academy still exists as "Joseph Priestley Court" on Sheaf St. in Daventry (N 52° 15.37 W 01° 09.77). For amusement the students of Daventry Academy would frequent Wheatsheaf Inn directly across the street; "Wheatsheaf" is now a retirement home under the same name.

Note 4. Warrington Academy once stood on the present Academy Way in Warrington (N 53° 23.31 W 02° 35.40).

Note 5. Birmingham notes. The Lunar Society met on the Monday night nearest the full moon, to allow lighting for the walk home. This Society included such notables as Erasmus Darwin (grandfather of Charles Darwin) and James Watt (inventor of the modern steam engine, 1769). Soho House, where they met, still exists on Soho Avenue and can be visited (N 52° 29.99 W 01° 55.34). The site of the New Meeting now is located at St. Michael's church, Carr's Lane, and displays a "Blue Plaque" (N 52° 28.79 W 01° 53.55). The location of the Bastille banquet (N 52° 28.88 W 01° 53.82) was the Royal Hotel (informally known as "Thomas Dadley's Hotel") on Temple Row, situated 350 meters northwest of the New Meeting location; today the site is unmarked, is supplanted by modern buildings and shops on a neat red-bricked street.

Note 6. Hackney notes. Gravel Pit Chapel, where Priestley preached, is marked with a "Blue Plaque" on Ram Lane (N 51° 32.80 W 00° 03.01). The site of his home at 130 Lower Clapton Road presently is marked with a plaque and was recently the site of a Mexican Restaurant (N 51° 33.13 W 00° 03.16).

Note 7. Priestley may hold the record for number of statues: they include not only the one in Birmingham (Figure 1), but also in Leeds, 200 meters south of the Mill Hill Chapel where he preached (City Square, N 53° 47.69 W 01° 32.83); Birstall, 1.2 km south of his birthplace (Market place, N 53° 43.92 W 01° 39.60); the Museum of Natural History (Parks Road, Oxford, N 51° 45.48 W 01° 15.33); and the Royal Society of Chemistry (Burlington House, Picadilly, London, N 51° 30.52 W 00° 08.35).

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