Chapter 5

JOSEPH PRIESTLEY: TRAIL-BLAZING EXPERIMENTER

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The First Thirty-one Years

Joseph Priestley was born near Leeds in Yorkshire on 13th March 1733, and continued to live there until he became, at the age of 19, the first student to enrol at the new dissenting academy in Daventry. By the time he left about three years later, along with his main discipline, theology, he had studied philosophy, history, mathematics and science. Furthermore he had gained a working knowledge of six ancient and three modern languages. This formidable intellect was to become one of the most influential men of his time. His varied career took him to Needham Market in Suffolk (1755-58), Nantwich in Cheshire (1758-61), Warrington (1761-67), Leeds (1767-73) and Bowood House in Wiltshire (1773-80) before he came to Birmingham in 1780 for what he described as the happiest period of his life. This ended with the notorious Birmingham Riots of 14th July 1791, which forced Priestley and his family to flee to London. They remained there for two years before the continuing hostility

Print of Joseph Priestley, 1782, showing examples of scientific equipment beneath the portrait. Priestley Collection by Samuel Timmins, Birmingham City Archives.

towards his political and religious views led them, in August 1793, to emigrate to Northumberland, Pennsylvania. There, on 6th February 1804, Priestley died, never having returned to his native England. The same strong religious views were at the heart of Priestley's decision, at the age of 31 in 1765, to devote a considerable portion of his working life to science.

Before this, Priestley, an ordained minister, already had an international reputation for his contributions to the fields of language, history and education. In 1764, this was recognised when Edinburgh University awarded him a Doctor of Laws. He had by this time published the *Rudiments of English Grammar* (1761), which was in print for 50 years, and also *The Theory of Language, and Universal Grammar* (1762). His 1764 *Chart of Biography* – a very large sheet of paper, with the arrow of time running from left to right, upon which the famous names of history were meticulously placed in their appropriate places – was a huge success and was still in print in 1820. According to F W Gibbs:

> *...had he done no more than he had achieved by this time, he would have done enough to ensure a place in the annals of education … Later, in his hands, the three main influences in education - the religious, the intellectual and the utilitarian – were combined to give what became the basic grammar school education over a long period.*
>
> *The subjects he included as essential were Latin, English, French and mathematics, together with physics (natural philosophy) and chemistry. To the arts subjects he added history, to the sciences geography* [1].

Our story begins in 1765 when we find the Reverend Joseph Priestley LL.D looking for a new challenge. He chose to embark on a history of science by beginning with a history of electricity. This was far more successful than Priestley had anticipated because he made important discoveries which launched him into the mainstream of the science of his day. Subsequent discoveries in what we now call biology, chemistry and respiratory physiology put him amongst the greatest scientific discoverers of history.

This paper, which analyses Priestley's science chronologically, begins with a brief discussion of his religious and metaphysical views, without which one cannot hope to do him justice. There follows a setting of the scientific scene in Priestley's time, emphasising the key ingredient, missing from Greek thought, that is at the heart of science as we now know it – experiment is the sole arbiter of scientific truth. We then follow Priestley from Warrington, where his pioneering work led to the first publication of the inverse square law of electrostatics, one of the few fundamental laws of physics, known today as Coulomb's law after the Frenchman who published it eighteen years later; to Leeds, where his work on gases, including the discovery that "plants purify air made noxious by animals breathing" led to his gaining the Copley Medal of the Royal Society; to Bowood House in Wiltshire, the home of the Earl of Shelburne, later Prime Minister, where he discovered oxygen and laid the foundations of the science of respiration; to Birmingham, where he performed the first recorded demonstration that water is not an element and continued his work on respiration.

Priestley's Religion and Metaphysics

First and foremost, Joseph Priestley was a minister of religion with views that were very unconventional in his day – he was a Unitarian, a Christian who rejected many of what he called the 'corruptions of Christianity' [2] taught by the Church of England. In the Unitarian tradition, he believed that theology should encompass the discovered truths of science, a position that is now quite acceptable to the Church of England. In view of the current interest in the relationship between religion and science, it is perhaps of interest to look in a little detail at one of the outstanding theological and scientific characters of his day. According to John Money [3], Priestley's beliefs were based on two tenets. Firstly, the existence of a benevolent God, whose works were not yet completed and who, therefore, manifested himself in a continuous act of infinite creation. Secondly, he denied absolutely that there was any difference between matter and spirit. Here Priestley is taking on board David Hartley's doctrine of the association of ideas. Hartley, influenced by the works of Newton, saw mental and emotional processes as having physical causes, just like the behaviour of inanimate planets. As pointed out by Jack Lindsay [4] in the introduction to Priestley's autobiography, in the 18th Century order in nature was considered as evidence for the existence of God. Money goes on to show that the first tenet implies to Priestley that God will be beneficent to mankind, which will eventually reach a state of unlimited happiness. For him, the pinnacle of this euphoric state is to act in conformity with the divine will. To arrive at this state, the Hartley doctrine (the second tenet) implies to Priestley that one must learn more and more about nature, not by theorizing, but by revealing nature through experimental discoveries. Eventually, a state will be reached when everyone, through this "pure revelation" of experiment, will know all things equally, what philosophers might term a state of absolute, utopian epistemological egalitarianism [5].

For Priestley then, the natural philosopher was something of a missionary explorer seeking the "hidden powers which the Deity had impressed upon matter." Again in his own words, "I view with rapture the glorious face of nature and I admire its wonderful constitution, the laws of which are daily unfolding themselves to our view." All this tells us that, to understand Priestley, it is essential to appreciate that, because of his religious belief about the divine nature of experimental revelation, he felt that he could best serve the community by moving rapidly from one discovery to another. As Gibbs points out[6]: “It was not his purpose to be side-tracked by any incidental observations, however intriguing. He was setting a trail. Others would pick it up, and in this way, natural knowledge would grow faster.”

In fact, many clearly recorded important discoveries - in biology, chemistry, physics, and physiology – were left virtually untouched. Undoubtedly, one reason for this was the prejudice against his religious and political views – he was a liberal – that eventually led to the notorious 1791 Priestley Riots in Birmingham, during which his place of worship, his home, his laboratory and all his manuscripts were systematically destroyed. The absence of manuscripts may partly be responsible for the fact that Priestley’s contributions are under-appreciated.

Setting the Scientific Scene

The natural philosopher or physicist of today has a very different picture of the universe from that of the Greeks. Aristotle taught that the universe was divided into two parts: the earthly region, a sphere with the earth motionless at its centre, extending almost to the moon; and the celestial region, again spherical, surrounding the earthly region. These regions were very different.

In the inner, earthly region, all things were made from four elements – earth, water, air and fire – and these were arranged in their proper places: earth, being the heaviest, at the core; next water, air and finally, uppermost, fire, being the lightest. Things are in a state of constant change and decay.

In the outer (celestial) region, there was but one, fifth element, sometimes called “quintessence” and sometimes “aether”. All things being made of this, Aristotle argued that there could be no change or non-uniformity in the stars and planets. This region, also referred to as the “heavenly” sphere, is eternal and has divine qualities. It is composed of concentric divine spheres, beginning with the lunar sphere, the lowest and least divine, and working upwards through the solar sphere and the planetary spheres to the sphere of the fixed stars; outside this is the sphere of the Prime Mover or God.

This hierarchical natural philosophy of the Greeks, with everything having its designated place, was incorporated into the teachings of the Church, mainly by Saint Thomas Aquinas in the 13th Century, and is seen in the language of Shakespeare. In *King Lear*, Gloucester utters the words: “These late eclipses of the sun and moon portend no good to us”. Adherence to the teachings of Aristotle hindered progress in science for about 2000 years. Even Galileo’s discoveries establishing that there were mountains on the moon, that the sun had “blemishes” which we now call sun-spots, and the observation of Copernicus that the planets went round the sun, were not enough to eliminate Aristotle’s influence. In 1624, a law was passed in France, which compelled the chemists of the Sorbonne to conform to the teaching of Aristotle on pain of death and confiscation of goods [7].

Nowadays, we do not divide the universe into two regions. We believe that matter out there in the cosmos and here on earth is made from the same constituents, governed by the same rules throughout. It was not always so: 400 years ago, in 1600, Giordano Bruno was burnt at the stake for arguing, on the grounds that the universe was created by one God, that physics here on earth and out in the cosmos should be the same.

So, atoms everywhere are made of negative electrons bound to positive nuclei by the Priestley/Coulomb electrical attraction, their detailed behaviour being governed by the rules of quantum mechanics and relativity. Nuclei are made up of neutrons and protons, which, in turn, are composed of even smaller particles called quarks. It is not known whether quarks are made of even more elementary building blocks. Discussions in modern biology without our knowledge of atomic behaviour would be unimaginable. Not only did Priestley first state the law that keeps the electrons near the atomic nucleus, he also had a hunch that electricity played an important part in chemistry.

Within the grand transition from the Greek view of matter to our current picture, there are several great sub-plots of science. In an attempt to put Priestley's discoveries into perspective we will mention three: firstly, the developments in astronomy made by people such as Copernicus, Kepler and Galileo were finally brought together by Newton in his *Principia*; *s*econdly, there was the emergence of modern chemistry from alchemy in the latter half of the 18th Century; thirdly, in the same period, biology split into botany and zoology.

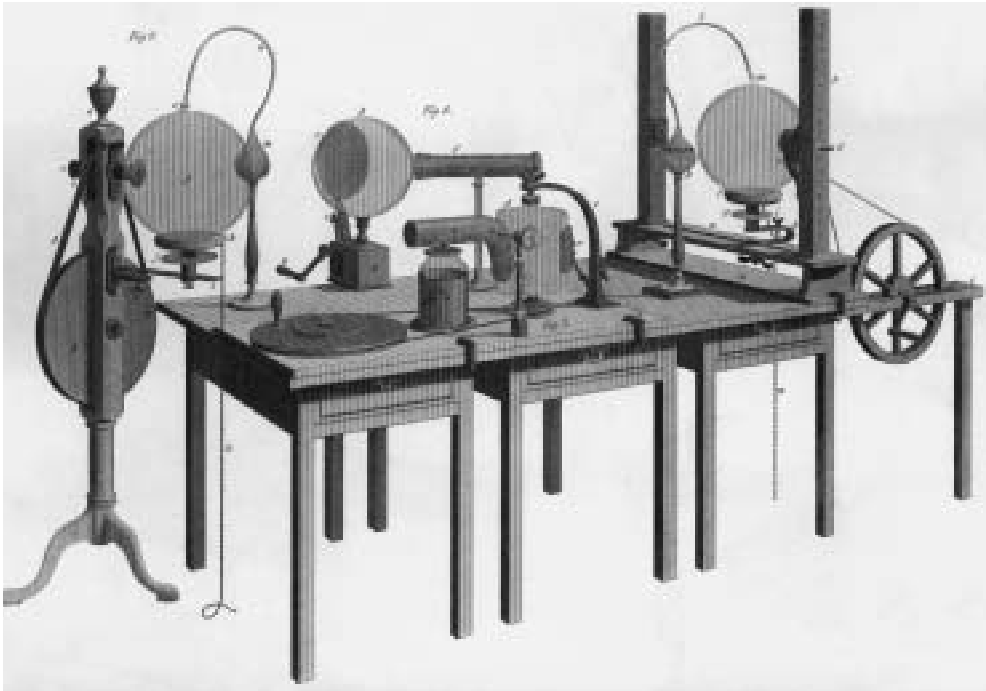
This emergence of modern science from Greek natural philosophy occurred around the time of the Reformation. The key ingredient that eluded the Greeks was experiment. Rationalism, based on logic and mathematics that the Greeks developed to a high level, is not enough. Science is based on the idea that any statement that disagrees with experiment is wrong. Experimental results, repeated and checked, are treated as objective truths. The cornerstone of science is experiment. No theory can ever be deemed absolutely true because not all experiments can ever be performed. When physicists talk of "laws of nature" such as Newton's "laws of motion", they no longer regard them as "universal laws", somehow obeyed by nature; how could a planet know Newton's "laws"? Rather, the scientists' "laws" are usually mathematical statements that summarise the results of experiments performed; particularly powerful "laws" also have a predictive power.

It is from the point of view of his contribution to making experimental discoveries about nature that we return to Joseph Priestley. "Let others *reason* better from the facts with which I supply them if they can: I shall listen to them with attention. But I cannot forbear observing, that I should be more obliged to them for the delivery of *more facts* from which to reason. *Speculation* is a cheap commodity. *New and important facts* are most wanted, and therefore of most value.”

We will take things in chronological order, beginning with his work on electricity in Warrington.

Electricity in Warrington

After meeting Benjamin Franklin over the Christmas of 1765, and receiving great encouragement, Priestley set about his work with incredible energy. Based on his progress, he was elected to a Fellowship of the Royal Society in June 1766. By the end of the year, his 750-page book [8] *The History and Present State of Electricity, with Original Experiments,* was finished. In it, he records that on the 21st of December, “following the instructions of Dr Franklin” he verified that he could not take electricity from the inside of a charged metal cup, whereas he could from the outside.



Electricity. Electric Machines Plate VII from Abraham Rees, The Cyclopaedia or Universal Dictionary of Arts, Sciences, and Literature. Plates vol II. (London, Longman, Hurst, Rees, Orme and Brown, 1820). The illustration shows examples of machines for generating static electricity used by Priestley.

He then went on to interpret this by suggesting an inverse square law of electricity, by analogy with gravitation: "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" [9]. Since atoms consist of negative electrons held in the vicinity of positive nuclei by the inverse square law of electricity, a physicist must see this as a major contribution to science - even to the biological sciences since we are all made of atoms.

Earlier in the year, on 4th May 1766, Priestley recorded his discovery that charcoal conducts electricity. This was a significant discovery because, at the time, it was thought that only water and metals were conductors. From a biologist's point of view it is of interest to know why he was testing the electrical properties of charcoal. He had been using the charcoal to produce "mephitic air", a term used for unwholesome air in general and specifically for "fixed air" or carbon dioxide (CO_2). Priestley was trying to see if nature had a way of purifying "mephitic air", and had tried passing electricity through it – after all, we have lightning in the atmosphere. It did not, but Priestley, true to his quest to reveal the "secret powers which the Deity has impressed upon matter", did not miss the chance to study the electrical properties of charcoal.

We now move from Warrington to Leeds where Priestley embarked on the work on gases for which he is best known.

Leeds: Soft Drinks; Photosynthesis; Biology becomes Botany and Zoology

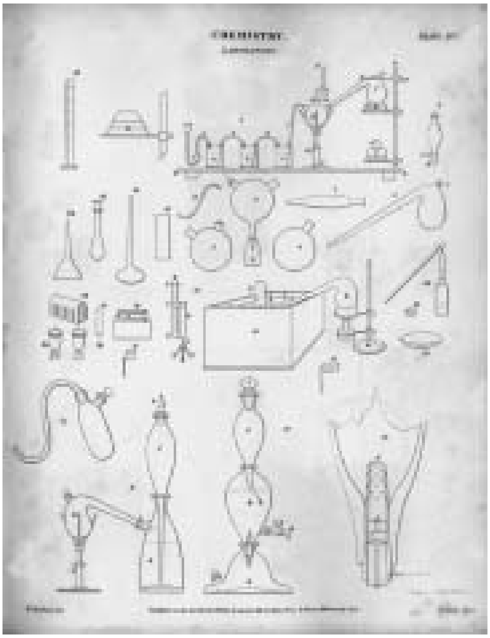
> *"It was a little after Midsummer in 1767, that I removed from Warrington to Leeds: and living, for the first year, in a house that was contiguous to a large common brewery, so good an opportunity produced in me an inclination to make some experiments on the fixed air that was constantly produced in it. Had it not been for this circumstance, I should, probably, never had attended to the subject of air at all."*

Priestley's first major publications on gases created considerable excitement in the medical world. The unlikely source of this excitement was Priestley's discovery of how to "impregnate water with fixed air" (make fizzy drinks!) [10]. The reason for the excitement is explained in Priestley's pamphlet:

> *Sir John Pringle first observed, that putrefaction was checked by fermentation, and Dr. Macbride discovered that this effect was produced by the fixed air which is generated in the process, and upon that principle recommended the use of*

> *'wort', as supplying a quantity of this fixed air, by fermentation in the stomach, in the same manner as it is done by fresh vegetables, for which he, therefore, thought that it would be a substitute; and experience has confirmed his conjecture.*

At that time, Priestley's discovery of how to dissolve fixed air suggested that, "this great antiseptic principle may be administered in a variety of agreeable vehicles." Later, it was felt that fixed air might prevent scurvy, and Captain Cook took improved versions of Priestley's soda water making apparatus on his voyages. Fixed air does not cure scurvy but we can still remember Joseph Priestley as the father of the soft drinks industry.



Chemistry Laboratory Plate XVI from Abraham Rees, The Cyclopaedia or Universal Dictionary of Arts, Sciences, and Literature. Plates vol. II (London, Longman, Hurst, Rees, Orme and Brown, 1820). The illustration shows examples of the chemical equipment that Priestley would have used for handling gases.

We now come to the paper that gained Priestley the Copley Medal – the highest honour of The Royal Society. He had narrowly missed it for his work on electricity – because the relevance of the inverse square law was not yet fully appreciated. In the first paragraph of this paper entitled *Observations on Different Kinds of Air* [11], Priestley announces that "a considerable number of facts, which appear to me to be new and important, are sufficiently ascertained; and I am willing to hope, that when philosophers in general are apprised of them, some persons may be able to pursue them to more advantage than myself."

To put these discoveries in perspective it is helpful to have a picture of what was known at the time. It is remarkable that air was still, in 1772, generally regarded as a simple elementary substance – despite the fact that a considerable amount had been discovered about its properties. On the physics front, Galileo had shown that air had weight, Torricelli had measured the pressure of the atmosphere, and von Guericke had invented the pump. In chemistry, Boyle and others had shown that air had two components, one of which supported life. Various chemically different gases had been discovered. For example, Black had shown that "fixed air" (CO_2) was part of a solid – chalk – and could be obtained from it by the action of acids; the well-known test for fixed air was that it turned lime-water milky due to the chalk being restored. In addition, Cavendish had discovered "inflammable air" or hydrogen, as we now know it.

What was needed according to Brownrigg [12] was a systematic programme of research into the various "chemically different elastic fluids (gases) that were known; to consider those substances from which they are produced; by exact experiments to detect their properties when native and simple; to inquire what changes may result from their coalitions and combinations amongst one another…" This was the challenge that Priestley accepted: a voyage of discovery into the largely uncharted world of gases, almost all of which were invisible.

To begin with he made major improvements to the technology of handling gases and developed tests for recognising gases. This led to the discovery of new gases: "nitrous air" (nitric oxide or NO), "dephlogisticated nitrous air" (nitrous oxide, N_2O or laughing gas), "red nitrous vapour" (nitrogen dioxide or NO_2) and hydrochloric acid gas. Over the last decade, scientists have been surprised to find that nitric oxide has crucial physiological properties, the discovery of which led to the 1998 Nobel Prize in Medicine or Physiology. Although Priestley is mentioned in the Nobel Lectures as the discoverer of NO, there is no mention of his discovery that it had antiseptic properties.

Photograph of the statue of Joseph Priestley sculpted by Francis Williamson and unveiled in Birmingham in 1874. The statue symbolises Priestley conducting the scientific experiment which led to his discovery of "dephlogisticated air" or oxygen. Priestley focuses the rays of the sun through a lens which he directs towards a crucible which contains red oxide of mercury. He holds a test-tube above the crucible to collect the gas which is released during the experiment. Priestley Collection by Samuel Timmins, Birmingham City Archives.

While studying nitric oxide, Priestley observed that two volumes of nitric oxide and one volume of oxygen would yield two volumes of nitrogen dioxide. Here is an example of an important lead being left while Priestley continued his trail-blazing: a quarter of a century later we encounter “Gay-Lussac’s Law of Combining Volumes” which states that when gases combine in a chemical reaction, the volumes involved are in the ratio of small numbers: Priestley had shown that two volumes of nitric oxide combine with one volume of oxygen to give two volumes of nitrogen dioxide. In the language of GCSE chemistry:

$$2NO + O_2 \rightarrow 2NO_2.$$

We now come to what is perhaps the major discovery of this classic paper: “Plants restore air that has been injured by respiration and burning.” Let us enjoy Priestley’s own description:

> *Accordingly, on the 17th of August 1771, I put a sprig of mint into a quantity of air, in which a candle had burned out, and found that, on the 27th of the same month, another candle burned perfectly well in it…*
>
> *Several times I divided the quantity of air in which the candle had burned out, into two parts, and putting the plant into one of them, left the other in the same exposure, contained, also, in a glass vessel immersed in water, but without any plant; and never failed to find, that a candle would burn in the former, but not in the latter.*

Later, on page 198:

> *These proofs of a partial restoration of air by plants in a state of vegetation, though in a confined and unnatural situation, cannot but render it highly probable, that the injury which is continually done to the atmosphere by the respiration of such a number of animals, and the putrefaction of such masses by both vegetable and animal matter, is, in part at least, repaired by the vegetable creation.*
>
> *And, notwithstanding the prodigious mass of air that is corrupted daily by the above mentioned causes; yet, if we consider the immense profusion of vegetables upon the face of the earth, growing in places suited to their nature, and consequently at full liberty to exert all their powers, both inhaling and exhaling, it can hardly be thought, but that it may be a sufficient counterbalance to it, and that the remedy is adequate to the evil.*

Priestley’s old friend and mentor, Benjamin Franklin had seen this work in progress, and his enthusiastic letter to Priestley is included in the paper:

> *I hope this will give some check to the rage of destroying trees that grow near houses, which has accompanied our late improvements in gardening, from an opinion of their being unwholesome. I am certain, from long observation, that there is nothing unhealthy in the air of woods; for we Americans have everywhere our country habitations in the midst of woods, and no people on earth enjoy better health, or are more prolific.*

So, when you next go to the garden to get a sprig of mint to boil with your potatoes, remember that it was with one of these that mankind realised that it will not suffocate in its own carbon dioxide!

This discovery also heralds a turning point in our understanding of the nature of life. Up until this time it was assumed that all living things made use of the air in a similar manner. This appreciation that plants use what we breathe out (CO_2) and we breathe in what they give out (O_2) captures the historic moment when biology split into botany and zoology. All this happened before Priestley and, independently, the Swede, Scheele, had isolated that constituent of air, which supports animal breathing and combustion – the gas we know as oxygen, but named "dephlogisticated air" by Priestley.

Bowood House, Wiltshire: Discovery of Oxygen; Respiratory Science

Priestley vividly describes how he heated what we now call mercuric oxide with his new 12-inch *burning lens* to discover *the most remarkable of all the kinds of air I have produced*[13]. He went on to say:

> *...this air is of exalted nature… A candle burned in this air with amazing strength of flame; and a red hot wood cracked and burned with a prodigious rapidity, exhibiting an appearance something like that of iron glowing with a white heat, and throwing sparks in all directions. But to complete the proof of the superior quality of this air, I introduced a mouse into it; and in such a quantity that, had it been common air, it would have died in a quarter of an hour; it lived, at two different times, a whole hour, and was taken out quite vigorous.*

Priestley is best known for isolating the life-supporting element in the air, itself a truly romantic discovery. It was, however, more than that. The discovery of oxygen was a turning point in the quest to understand matter. Since the latter part of the 17th Century, the interpretation of experiments was influenced by the "phlogiston theory" of Becher and Stahl. It hardly deserves to be called a theory, but a last attempt to keep fire – the word phlogiston comes from the Greek word for fire - as an element.

Although he was aware of its limitations, Priestley continued to use the phlogiston idea, possibly because Lavoisier's formulation was also not the whole story, and said of the exalted gas (oxygen) that it “may not improperly be called dephlogisticated air”. We shall see how Lavoisier improved Priestley’s experiment to gain extra information, which enabled him to refute the phlogiston idea. This crucial experiment of Lavoisier’s was one of two, both improvements on pioneering efforts by Priestley, which led to his foundation of modern chemistry [14]. The idea behind the phlogiston doctrine was that substances were made of phlogiston (the essence of fire) and ash. Good fuels such as candle-wax were rich in phlogiston and their burning was pictured thus:

$$\text{fuel} \xrightarrow{\textit{burning}} \text{ash + phlogiston} \quad (1)$$

Here we can see why Priestley called oxygen “dephlogisticated air” – it *attracts* phlogiston. The age-old process of getting metal from ore was pictured thus:

$$\text{ore + phlogiston (from fuel)} \xrightarrow{\textit{burning}} \text{metal} \quad (2)$$

It is ironic that the discovery of oxygen, which led to the overthrow of the phlogiston doctrine, was made by Priestley, one of the most eminent scientists to resist the demise of the old way of thinking. Cavendish was another.

What Lavoisier did first was to heat some tin with air in a sealed container (slow burning). He made two observations:

1 When he opened the container, air rushed in; he did not notice anything – phlogiston in particular – rushing out as (1) above would suggest.
2 The ash weighed more than the tin he started with – so phlogiston would need negative mass, which is impossible.

This marked the end of the phlogiston era, and with it the Aristotelian idea of fire as an element. The result of the experiment suggested to Lavoisier that when a substance burns in air it combines in some way with part or all of the air.

The next phase of his study sets out to determine something quantitative about the role played by air in the burning process. Lavoisier heated mercury in contact with a measured volume (V) of air and watched to see if the volume changed. He found that after the volume had gone down to 4/5 V, no further change took place. The remaining gas extinguished a lighted taper and suffocated animals put in it – he called the gas “azote”, meaning “without life” in Greek; we now call it nitrogen. Lavoisier next took the residual ash (mercuric oxide) and heated it in the manner used by Priestley in his discovery of oxygen, and found that the volume of gas collected was 1/5 V – he had recovered what he had lost on heating the mercury. This gas vigorously supported life and burning - it was oxygen. So, at last, we have something that looks like modern science: when metal is heated or burnt, it combines with oxygen to form ash (oxide).

For those who like summaries:

A man called Priestley from Brummagem
Made his name by discovering oxygen.
This paved the way
For Lavoisier to say:
Zut, on n'a pas besoin de phlogiston!

It was inevitable, that having isolated oxygen, Priestley would turn to the question of respiration. In 1776, and still at Bowood House, Priestley published a paper [15] entitled *Observations on Respiration and the Use of Blood*, which Gibbs refers to as the "beginnings of a scientific account of respiration". After a fascinating review of historical ideas on respiration, Priestley described experiments which show that "… respiration is a phlogistic ("chemical" in modern language) process affecting air in the very same manner as … another phlogistic process… calcination ("oxidation") of metals…diminishing the quantity of it in a certain proportion, rendering it unfit for respiration or inflammation…" In this paper he shows that blood absorbs air, and even better, oxygen; this absorption takes place through serum and through animal membrane; blood goes red when it absorbs oxygen, and black if deprived of it. So, a large amount was established, much of it by Priestley, before Lavoisier began work on respiration (1777). Priestley was not even mentioned in several books on respiratory physiology, selected from the ones which were most used in the University of Birmingham's Medical School Library.

We now come to Priestley's spell in Birmingham, which he refers to as the happiest period of his life.

Birmingham: Water; more on Respiration

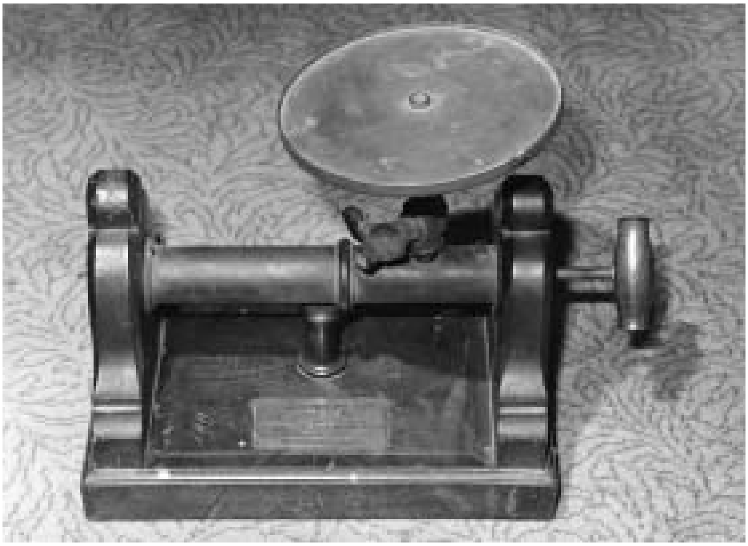
One of the reasons why Priestley was happy in Birmingham was that he had been invited to become a member of the Lunar Society of Birmingham, which became the leading scientific group in England in the decade between 1781 and 1791.

The story of the synthesis of water is one that has been surrounded by controversy because of its important role in the overthrow of the Greek view of the matter. This synthesis, together with the isolation of oxygen, were the crucial experiments that enabled Lavoisier to lay down the foundations of modern chemistry, ending the traditions of alchemy and phlogiston. [16] It would seem, therefore, appropriate to summarise the story of the water controversy by listing some key publications in chronological order.

In 1775, Priestley [17] reported on exploding a 1:2 mixture of oxygen and hydrogen: "with little more than one-third of highly dephlogisticated air, and the rest inflammable air, in the same phial, the report will be almost as loud as that of a small pistol; being, to judge by the ear, not less than forty or fifty times as loud as with common air." Anyone contemplating this experiment should take great care; ordinary test tubes will shatter! In 1781, Priestley [18] described repeating this "as a random experiment, made to entertain a few philosophical friends, who had formed themselves into a private society, of which they had done me the honour to make me a member." It was reported that, when the experiment was carried out in closed, clean, dry glass vessels, a dew was observed on the inside after the firing. The private society was the Lunar Society of Birmingham.

According to Schofield [19], "Cavendish caught the possible significance of some casual experiments made by Priestley and Warltire and instituted a series of experiments which might naturally lead him to a conclusion about the nature of water. These experiments were performed later in 1781 but were not published then."

On 26th April 1783, Watt interpreted an experiment by Priestley [20], which included the following: "Are we then not authorized to conclude that water is composed of dephlogisticated air and inflammable air, or phlogiston, deprived of their latent or elementary heat, and that dephlogisticated air or pure air is composed of water deprived of its phlogiston…?" [21]. Controversy exists about this letter, but the consensus seems to be that Watt was the first to postulate that water is a compound, without fully appreciating what it was a compound of.



Priestley's Airpump. The information on the brass plate notes "The airpump was made for Dr Priestley by Mr Harrison the employer of Sir Josiah Mason when a young man. Presented by Josiah Martyn Smith Esq". The pump was formerly in the possession of the University of Birmingham.

In June 1783, Priestley made public Cavendish's result – an accurate demonstration of the composition of water. Later in 1783, Lavoisier, who repeated Cavendish's experiment, came to the correct conclusion about the compound nature of water. Schofield concludes: "The experiments then were Cavendish's, the ultimate understanding was Lavoisier's … Cannot Watt, at least, be granted his due: that he independently saw and reported the significant consequences of important experiments?" What about Priestley? There is no doubt that he was the first to synthesise water, no later than 1781. Priestley did not feel directly concerned in this controversy. He was more concerned with providing more experimental evidence. "In this business I am little more than the bellows blower."

Priestley, the trail-blazer, had already moved on. He was, by this time, getting involved with a new problem, arising from his activities using hydrogen: the iron from which it was being produced came in different forms - cast iron, steel, etc. – with different properties which he later showed were related to the amount of foreign matter in the iron; Priestley the metallurgist!

Cavendish and Lavoisier are usually credited with demonstrating that water is a compound, but the first recorded synthesis of water was in Birmingham. It may even have taken place in Soho House, the home of Matthew Boulton, which, in 1995, was renovated and opened to the public, looking as it did two centuries ago.

We finally come to a short paper [22] on respiration, which appeared in the Philosophical Transactions of the Royal Society in 1790, the year before Priestley was hounded out of Birmingham by an establishment-incited mob. Here Priestley recorded measuring the amount of oxygen breathed in and the amount of carbon dioxide breathed out: "I proceeded to ascertain how much fixed air (carbon dioxide) was actually formed by breathing a given quantity both of atmospherical and of dephlogisticated air (oxygen), in order to determine whether any part of it remained to enter the blood, after forming the fixed air." His discovery that the blood absorbed oxygen remained largely ignored for half a century because of Lavoisier's conjecture that respiration consists of combustion in the lungs, specifically the tubules, into which the blood secretes a humour (fluid) containing carbon and hydrogen, which yield carbon dioxide and water on combustion.

Conclusion

Some of Priestley's contributions to science have been presented, emphasising his outstanding contributions as an experimental scientist. His discoveries across the board, in biology, chemistry, physics, and physiology played a major part in those early days of science. They include: the first publication of one of the basic laws of physics, the Inverse Square Law of Electrostatics; the discovery that plants purify air made noxious by fire and animals breathing; the discovery of oxygen; the first recorded synthesis of water; pioneering experiments on the properties of blood.

A final word from Priestley:

> *The greater is the circle of light, the greater is the boundary of the darkness by which it is confined. But notwithstanding this, the more light we get, the more thankful we ought to be, for this means we have the greater range for satisfactory contemplation. In time, the bounds of light will be still farther extended: and from the infinity of the divine nature, and the divine works, we may promise ourselves. An endless progress in our investigation of them: a prospect truly sublime and glorious.*

Notes

1 F. W. Gibbs, *Joseph Priestley* (Thomas Nelson and Sons, Ltd, London, 1965).
2 J. Priestley, *An History of the Corruptions of Christianity* (printed by Piercy and Jones for J Johnson, No. 72 St Paul's Churchyard, London, 1782).
3 J. Money, *Enlightenment and Dissent* 7 (1988) 69-89, and 8 (1989) 57-81.
4 J. Priestley, *Autobiography of Joseph Priestley* (Adams and Dart, Bath, England, 1970).
5 It is tempting to compare this with a statement from the epilogue in Stephen Hawking, *A Brief History of Time* (Bantam Press, London and New York, 1988).
However, if we do discover a complete theory, it should in time be understandable by everyone, not just a few scientists. Then we shall all, philosophers, scientists, and just ordinary people, be able to take part in the discussion of the question of why it is that we and the universe exist. If we could find the answer to that, it would be the ultimate triumph of human reason – for then we would know the mind of God.
6 Gibbs, *op.cit*.
7 L. Hogben, *Science for the Citizen* (George Allen and Unwin Ltd., London, 1959), p. 402.
8 J. Priestley, *The History and Present State of Electricity* (J Doddsley, J Johnson, B Davenport, and T Cadell, London, 1767).
9 For a detailed discussion see G. Tudor Jones, "In Praise of Joseph Priestley – the Particle Physicist!", *Physics Education* 26, 1991, pp.147-152.
10 J. Priestley, *Directions for Impregnating Water with Fixed Air: In order to communicate to it the peculiar Spirit and Virtues of Pyrmont Water, and other Mineral Waters of a Similar Nature* (London, 1772. Dedication dated Leeds, 4th of June 1772).
11 J. Priestley, "Observations on different Kinds of Air", *Philosophical Transactions of the Royal Society* , 62, 1772, pp.147-264.
12 Gibbs, *op.cit.*

13 Priestley, "Observations on different Kinds of Air", op.cit.
14 A-L. Lavoisier, *Traite elementaire de chimie* (Paris, 1789).
15 J Priestley, in *The Philosophical Transactions of the Royal Society*, 1776, pp.226-248.
16 J. R, Partington, *A History of Chemistry*, Volume 3 (Macmillan and Co Ltd, London, 1962); R. E. Schofield, "Still more on the water controversy", *Chymia* 9, 1964, pp.71-76.
17 J. Priestley, Experiments on Different Kinds of Air, Volume 2, (J. Johnson, No. 72 St. Paul's Church-yard, 1775), p. 99.
18 J. Priestley, Experiments and observations relating to various branches of natural philosophy, Vol 2, (Printed by Pearson and Rollason, for J Johnson, No. 72, St. Paul's Church-yard, London, 1781) pp. 395-398.
19 Schofield, *op. cit*.
20 *ibid*.
21 Letter, James Watt to Joseph Priestley, 26th April 1783, Birmingham City Archives.
22 J Priestley, *The Philosophical Transactions of the Royal Society*, 1790.