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# James Woodhouse a study of his life and work

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# James Woodhouse

# A Study of His Life and Work

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Philadelphia in the latter half of the eighteenth century was the most advanced city in the new Republic. Besides being the seat of the new government, it was also the cultural and intellectual center, considerably ahead of other towns in population, in wealth, in fashion, in learning and in science. Its preeminence in medicine, humanitarianism, music and drama, and belles-lettres was unquestioned. It had established strong ties with the agricultural hinterland and industry was rapidly expanding.[1] There was in the American capital less provincialism, more religious tolerance and a closer connection not only with England, but also with France than existed in the other cities of the nation.

In 1750 the population of Philadelphia was 16,000 and by 1780 this figure had grown to 25,000. Few cities of its size had as large a proportion of institutions of learning or a larger proportion of citizens interested in science and culture. The Philadelphia Library had begun its career of usefulness in 1731, the College of Philadelphia in 1749, and the Pennsylvania Hospital in 1751. The Hospital was one of the "firsts" in the British colonies as was the medical school founded by the College of Philadelphia in 1765.[2]

To Philadelphia came the best minds of politics and science. Besides Benjamin Franklin, it was the home of such men as Benjamin Rush and David Rittenhouse. It was also the home of the American Philosophical Society, and the Chemical Society of Philadelphia, the first

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1. Brooke Hindle, Pursuit of Science in Revolutionary America (Chapel Hill, 1956), [illegible].
2. Francis Packard, "How London and Edinburgh Influenced Medicine in Philadelphia in the Eighteenth Century." Annals of Medical History, N.S., pp. 221-222.

chemical society in America and possibly in the world.[3] John Bartram, one of the foremost botanists in the world at that time, established a botanical garden near the Schuykill River. In addition to scientists, industrialists, roaming travelers, politicians and visiting scholars arrived in the city.

It is only natural that among this cultural and intellectual hegemony one would look to find the beginnings of chemistry in America. When traced through all its relations the early chemistry of America is found to be mainly dependent on those larger movements in European chemistry from which the American science derived its origin.[4] Alchemy, iatrochemistry, phlogiston, each had their followers in America and on their work arose the later science.

Chemistry came into being, in America, by way of medicine. For two hundred years after the first settlement at Jamestown, it was the physicians who were the devotees and practioners of chemistry. It was natural therefore that the physicians would be the first professors of chemistry in America, that they would write the books and spread the European ideas.[5]

In the eighteenth century there was no formal method for the education of physicians in the country. Rather a system of apprenticeships was set up where a man would work with a doctor for a time and then

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3. Henry Bolton, "Early American Chemical Societies", Journal of the American Chemical Society, XIX (1897), pp. 718-9. James Kendall, "The First Chemical Society in the World," Journal of Chemical Education, XII (1935), p. 565. Wyndham Miles, "Early American Chemical Societies," Chymia, III (1950), p. 95.
4. Charles A. Browne, "Some Relations of Early Chemistry in America to Medicine." Journal of Chemical Education, III (1926), p. 267.
5. Whitfield Bell, "Philadelphia Medical Students in Europe 1750-1800", Pennsylvania Magazine, LXVII (1943) pp. 1-29.

start out on his own. Those who could afford the expense of a medical education were forced to go to the European universities. Benjamin Rush, Thomas Cadwalader, John Redman, John Morgan, William Shippen Jr., Adam Kuhn, Philip Syng Physick, and Caspar Wistar were some of the more notable Philadelphia men who studied abroad, most of them receiving their degrees from the University of Edinburgh which was recognized, at this time, as being the foremost medical school in the world.[6] Franklin recognized the advantages of studying abroad and recommended it highly. The American students who studied medicine in Europe served as one of the main lines of communication between the scientists and teachers on both sides of the Atlantic.

One of the most influential teachers in Europe was Joseph Black who taught at the University of Edinburgh. Black commenced his studies in chemistry at a time when this science had not been emancipated from the shackles of an alchemical philosophy inherited from the Greeks. This was founded on the concept that the various kinds of matter were merely different forms of a primordial substance which had four qualities, or which assumed as a sort of a cloak the four properties of fire, air, earth, and water. He drew attention in a special manner towards the nature of gases and so opened the field of pneumatic chemistry for the subsequent work of Joseph Priestley, Henry Cavendish, and Antoine Lavoisier. Whereas his predecessors had considered gases to be ordinary air with various modifications, Black proved the distinct difference between carbon dioxide and air and their separability.[7]

6. Francis A. Packard, op. cit., pp. 229-241.
7. John Read, From Alchemy to Chemistry, (London 1957), p. 130.

One of Black's students was Benjamin Rush of Philadelphia. When Rush returned to the United States after completing his studies he was appointed to the Chair of Chemistry in the College of Philadelphia in 1769. At the time that he was appointed, he was only twenty-four years old and had no experience with chemistry beyond that which he had acquired under Black. Quite naturally, in his teaching he turned to his Edinburgh lecture notes and transmitted Black's course to his pupils.[8] The extant manuscript notebooks covering Rush's lectures have one striking feature--their dependence on Black's lectures.[9] A comparison of early manuscript versions of Black's lectures with those of Rush show them to be identical in many instances. Rush must have drawn freely from his own notes taken at Black's lectures. This parallelism in the Black and Rush chemical lectures is another instance of the direct transmission of Edinburgh and European teachings to Philadelphia.

Throughout his twenty years' career as professor of chemistry, Rush continued to use Black's system of chemistry and the extant notebooks indicate that he changed his course little, probably because his other activities left him too little time to keep abreast of the rapidly changing science.[10] Rush introduced chemistry to more young men than any other American teacher up to this time.

It is interesting to note here that although he taught Black's system of chemistry, which adhered to the phlogiston-theory, Rush's students in

8. Wyndham D. Miles, "Joseph Black, Benjamin Rush and the Teaching of Chemistry at the University of Pennsylvania." Library Chronicle, XXXII, p. 9-19.
9. Herbert S. Kickstein, "Short History of the Professorship of Chemistry of the University of Pennsylvania School of Medicine." Bull. of Hist. Med., XXVII, p. 43.
10. Wyndham D. Miles, "Benjamin Rush, Chemist," Chymia, IV, pp. 37-77.

the 1790's were to teach the newer French anti-phlogistic theories of Lavoisier, showing that access to the European ideas was, to a degree, easy.

The channels by which English and Continental ideas made their way to America and were disseminated here remain to be exhaustively explored. Among these channels, however, were the activities of the scientific societies, notably the Royal Society (to which nineteen Americans were elected before 1800) and the American Philosophical Society; the emigration to America of scholars trained in European universities; the international correspondence of scientists; American travelers abroad; books, almanacs and magazines; public lectures; and the schools and colleges which had Europe-trained men such as Rush teaching in them.[11]

The American Philosophical Society, as an example, served as one of the major links in the transmission of European ideas. It was very early, in fact, before the Society was truly organized, outstanding British and foreign scientists were elected to membership. The eagerness of the Society to do its part and to join the scientists of the world in a common effort, appears in a very striking manner in their observations on the transit of Venus over the sun.

After the observations had been made, the committee was instructed "to draw up an account of the transit of Venus and Mercury to be communicated to the Astronomers in Europe, to be transmitted to Dr. Franklin as President."[12]

11. Harry Hayden Clark, "Influence of Science on American Ideas from 1770-1809," Trans. Wis. Acad. Sci., Arts, Letters, XXXV, p. 307. See also F.E. Brasch, "Royal Society of London and Its Influence Upon the Scientific Thought in the American Colonies," Sci. Mo., XXXIII, pp. 336-355, 448-469.
B. Fay "Learned Societies in Europe and America." Amer. Hist. Rev., p. 37 (1931), pp. 257-58.
12. American Philosophical Society Proceedings, XXII, pt 3, p. 42

When it was contemplated to print the first volume of the Transactions including the observations on the transit as the main part, a list was drawn up of the foreign institutions to which the volume was to be presented. It included the Philosophical Societies of Stockholm, Upsala, Berlin, Göttingen, Petersburg, London, Edinburgh, Dublin, Paris, Bolonia, Turin, and Forence.

As he was to do many times, Benjamin Franklin in 1774 sent a considerable number of books from Europe,[13] mainly from France and soon after the following French scientists and philosophers were elected to membership in the American Philosophical Society: Condorcet, Daubenton, Dubourg, LeRoqx, Maquair, Abbe Raynal, Lavoisier, In addition to the books sent by Franklin, many other writings were sent by the scientists themselves.[14]

13. Among the many volumes which could be cited, Franklin, on December 17, 1774, sent them Buffon's Natural History and Lavoisier; on September 15, 1775, he delivered the Abbe Decquemare's Essay on Sea Anemones and Rozier's Physic; August 15, 1778, Franklin sent copies of Pallazani's Opuscules and Carminati's Recherches; September 19, 1778, Mandrillon's Fragmens de Politique et de Litterature. See Proceedings of the American Philosophical Society, XXII, part 3.

14. Among the volumes which could be cited are the Count de Gebelin's announcement on September 26, 1783, that he was sending the first four volumes of his Primitive World; July 15, 1785, the Society received three volumes of the Royal French Academy; December 7, 1787 Berlin de Villenouve, Moreau de St. Mery, and M. Grevel all presented books; November 21, 1788 Brissot de Warville sent a book on the relative situations of France and the United States; March 6, 1789, 22 volumes of Velly, Villaret and Garnier's History of France, a Histoire du Commerce in 2 volumes. The list could be extended indefinitely but the volumes cited are typical of the ones sent during this period.

As marking the closeness of the French and American scientists and philosophers, the communications of the Society are of great interest. Thus, on December 30, 1774, Franklin wrote from Paris forwarding a series of inquiries that Raynal wanted answered and on December 17, 1774, Franklin forwarded certain queries from Condorcet and a committee was appointed to answer them. December 10, 1779, the Society wrote a letter to Buffon expressing their appreciation of his great work and offering aid and October 17, 1788, M. de Marbois sent from Port au Prince a copy of his treatise on finances in Santo Domingo. For a fuller list of exchanges between the scientists and philosophers of the two countries, see American Philosophical Society, Early Proceedings, vol. 22, part 3.

The French had for some time been interested in the American colonies due in great part to the influence of Franklin. The War of Independence and the French alliance made the relations between the two countries closer.

Lavoisier, working in France in the latter part of the eighteenth century, laid the foundation for modern chemistry in his rejection of the phlogiston theory and subsequent formulation of the presently-held theory of combustion. His work stimulated further scientific study in both Europe and America. That he was held in high esteem by American scientists was shown in a speech delivered by Thomas P. Smith before the Chemical Society of Philadelphia in 1798:[15]

> His time and fortune were devoted to furthering discoveries in chemistry, and his house became a great laboratory filled with every species of apparatus necessary in this science....Here he made welcome men of science to whatever nation they might belong... and invited every person most eminent in geometrical or physical knowledge...
>
> The effect of these labours of Lavoisier are to be found in forty memoirs, replete with the grandest ideas relative to the various phenomena of chemistry, published by him...., in the transactions of the French Academy.

On January 19, 1774, Lavoisier sent a letter to American Philosophical Society including in it references to "the news of a new theory promising, as it seems, great discoveries in the field of chemistry,"[16] foreshadowing the news of his anti-phlogiston theory which was to arouse the debate between Joseph Priestley and James Woodhouse recorded in a later chapter.

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15. For a complete copy of the test see Edgar F. Smith, Chemistry in America, p. 31.
16. American Philosophical Society Proceedings, XXII, pt 3, p.87.

II

## LIFE OF JAMES WOODHOUSE

On November 17, 1770, James Woodhouse, a man who was to write extensively concerning the ideas of Lavoisier and help to bring about a complete acceptance of the new theory of chemistry, was born in Philadelphia.

Little is known of the ancestry of James Woodhouse. He was of English descent and the name Woodhouse was common in England and meant "dweller in the Wood,"[1] and could be traced back to 1170. His maternal grandfather was Dr. William Martin of Edinburgh, whose daughter Anna married William Woodhouse in 1766 in Alnwick, England. William Woodhouse had been an officer in the army of the Young Pretender, and fought for the Stuart cause at Preston Pans.

Shortly after their marriage the couple left England and came to America, settling in Philadelphia at 6 South Front Street, where William set up a business as a bookseller and stationer. He is reputed to have been an "eminent bookseller."[2]

James Woodhouse, the second son in the family, attended a private grammar school in Philadelphia and later enrolled in the grammar school of the University of Pennsylvania. In 1783, at the age of fourteen, he entered the University of Pennsylvania where he received his Bachelor of Arts degree in 1787, and the Master's degree in 1790.

Early in his life, young Woodhouse had decided upon chemistry as a career. At the time, the only method of obtaining a background in the science was to study medicine, since chemistry was not yet recognized as

1. P. H. Reaney, Dictionary of British Surnames, p. 359.
2. Henry Simpson, Lives of Eminent Philadelphians, p. 987.

a separate science.[3] Therefore, he enrolled in the Medical School of the University of Pennsylvania and began his studies under the doctor-chemist, Benjamin Rush.

However, before Woodhouse completed his studies for the M.D., he left school for a time to become a surgeon in the army of General St. Clair.[4] He received this post after Dr. James Mease resigned. Woodhouse was fortunate enough to escape the defeat which the United States troops suffered on November 4, 1791 when fighting the Indians. He had been ordered to accompany the first regiment which was sent after a band of deserters, and to meet a convoy of provisions which was expected.

During the time he spent in the army, Woodhouse was still able to communicate with his preceptor, Rush, on matters concerned with science. These letters, which are on file in the Ridgeway Library of Philadelphia, are concerned with the effect of a certain vine in connection with the malady known as consumption. He hoped that the vine might prove a cure for the disease and cites cases where an improvement was seen after the patients underwent a series of tests employing the vine.[5]

After four months in the Army, Woodhouse returned to the University to resume his studies. In May 1792, he received his degree of Doctor of Medicine after publicly defending his thesis "On the Chemical and Medicinal Properties of the Persimmon Tree, and the Analysis of Astringent Vegetables."[6]

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3. Charles A. Browne "Some Relations of Early Chemistry in America to Medicine", Journal of Chemical Education 3 (1926), p. 276.
4. Edgar F. Smith, James Woodhouse (1918), p. 11. Hereafter this work will be titled Woodhouse.
5. The complete text of the report is given in Smith, Woodhouse, pp. 13-16.
6. Published in Philadelphia by his father William Woodhouse, a copy of which is available in the E.F. Smith Collection at the University of Pennsylvania.

A short time after his graduation, Woodhouse conveyed a considerable portion of land in Northumberland County to Rush.[7] It is not known definitely whether this was done out of gratitude for many favors shown him by Rush, or whether it may have been in the nature of a fee for the preceptorial privileges enjoyed under his patronage. It seems probable that the land was in payment of a fee since Rush's usual charge for apprentices was one hundred pounds cash. In a letter written to John Dickinson in 1791, Rush, reluctant to reduce this amount, stated: "My usual fee with an Apprentice is £ 100 cash. I have in many instances lately, objected to reducing this sum, chiefly with a design to reduce the number of my apprentices."[8]

One of the most popular agencies in the young Republic for the advancement of chemical studies was the Chemical Society of Philadelphia which was founded in 1792. It was probably the first such society in the world, and it was the earliest which lasted for any length of time, and the first to publish a journal on chemical subjects.[9] It is not definitely known who founded the Society, but its founding had generally been credited to James Woodhouse.[10] Recently, however, a letter has been uncovered in the College of Physicians Library in Philadelphia which seems to show that the Society was founded by John Redman Coxe,[11] and that Woodhouse did not join the Society until after his appointment as Professor

7. Rush Collection, Ridgeway Library, Philadelphia.
8. Quoted from a copy of the letter as it appeared in Pa. Mag. Hist. & Biog., XXXV, p. 501.
9. For the history of the earlier societies see Wyndham Miles, "Early American Chemical Societies", Chymia, III(1950) pp. 95-96.
10. Smith, Woodhouse, p. 39.
11. Wyndham Miles, "John Redman Coxe and the Founding of the Chemical Society of Pennsylvania," Bull. Hist. Med., XXX, (1958) pp. 469-472.

of Chemistry at the University of Pennsylvania. Woodhouse, however, was very active in the Society, and, from 1797 until the demise of the Society around 1808, he served as President and was on several committees working on scientific subjects.[12]

Under his guidance, the Society undertook a program of analyzing any mineral specimen sent to it. This study began in 1797 when a notice appeared in several newspapers and journals in the country stating:[13]

> In consideration of the general utility that would result from the citizens of the United States being able to procure, free from expense, an analysis of any ores or mineral substances, The Chemical Society Of Philadelphia,...passed the following resolution:
>
> Resolved, that a committee of five members be appointed, whose business it shall be to notify, in the different papers of the United States, and by circular letters, that they will give an analysis of all minerals which may be sent them.
>
> In conformity to the above resolution we hereby give notice that we will analyze any mineral which may be sent to us...accompanied with an account of the place and situation in which it was found.

Woodhouse's name appears on this committee.

Between August first and November ninth 1793 the deadly and tragic yellow fever spread through the city of Philadelphia carrying away five thousand inhabitants.

At this time Woodhouse, who was living in the Southwark district of the city, was called upon by Rush to help with his patients.[14] After Rush was stricken with the malady, he depended more on his assistants, Woodhouse, John Porter, John Pennington, James Mease and William

12. Mention is made of Woodhouse serving as President from 1797 to 1801, The Philadelphia Directory, 1802.
13. Medical Repository I, 543-544, Weekly Magazine of Original Essays, Fugitive Pieces and Interesting Intelligence I, 32; Philadelphia Monthly Magazine I, 177.
14. John H. Powell, Bring Out Your Dead, (1949), p. 34.

Annan, to help with his patients. Throughout his letters to his wife Rush makes reference to the work of Woodhouse in combatting the disease.[15] Rush believed in a system of bloodletting, purging, and in having the patient swallow a mixture of ten grains each of calomel and jalap.[16] Rush said of Woodhouse that he had been "very useful to me in visiting a number of patients."[17]

The plague caused the death of James Hutchinson, Professor of Chemistry in the Medical School of Philadelphia and on Tuesday, January 7, 1794, Dr. John Carson was chosen as his successor. Unfortunately, before he could undertake his duties in the new position, the fever also struck him down.

On June 4, 1794, the renowned chemist Joseph Priestley arrived in America, and the Trustees of the Medical School offered him the vacant chair of Chemistry. However, Priestley, fresh from the riots of Birmingham, and seeking a quiet atmosphere that he might pursue his own research, declined the position and retired to Northumberland County, having written to Rush:[18]

> When I began to consider the difficulty and iresomeness of a journey to Philadelphia at this time of year, and especially the obligation I should be under of spending four months of every year from home,...my heart failed me.

It is interesting to note that the land upon which Priestley settled was the same land that Woodhouse had sold to Rush in 1792 for the sum of five shillings.[19] Rush, in turn, sold it to Joseph Priestley,Jr.,

15. L. H. Lyman Butterfield, ed., Letters of Benjamin Rush (1951, Princeton) II, pp. 712, 714, 715, 717, 718, 720, 723, 726, 729, 733.
16. Powell, Bring Out Your Dead, p. 80.
17. Letter to Mrs. Rush in Butterfield, Letters, vol. 2 p. 712.
18. Henry C. Bolton, ed., Scientific Correspondence of Joseph Priestley, p. 144.
19. Smith, Woodhouse, p. 244. Also see p. 11 of this report.

"for a valuable consideration" in 1794 and Dr. Priestley purchased it for a thousand pound sterling.[20]

As soon as Rush heard that Priestley had declined the Chair of Chemistry he was eager that one of his pupils should have this post. At the time he seemed to favor John Redman Coxe for the position.[21] However, when it had seemed likely that Priestley would accept the Chair, Rush had urged Coxe to study abroad to deepen his knowledge of chemistry. When Priestley refused the Chair, Rush had to look elsewhere, since Coxe was in London. He then sought to have Woodhouse elected to the position and on Tuesday, July 7, 1795, the election was carried out as he had hoped. Rush wrote the following message to Coxe on the election:[22]

> I have great pleasure in informing you that Dr. Woodhouse is elected Professor of Chemistry in our University...the appointment gives great pleasure to all the students of medicine. To me it is cordial. His conduct as my pupil, and above all, his kindness, humanity, sympathy and services to me during the glowing autumn of 1793 has endeared him to me in a high degree... I have no fears for his success and reputation. He had genius, industry, knowledge and great steadiness of character.

His appearance as a teacher had been described by Benjamin Silliman. He is said to have been short with a rather florid face. He was careful of his dress, "generally he wore a blue broadcloth coat with metal buttons; his hair was powdered, and his appearances were gentlemanly."[23]

Silliman was, however, more harsh in his evaluation of Woodhouse as a teacher for he said of him:[24]

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20. Rush recorded the transaction in the original deed.
21. See Smith, Woodhouse, p. 36. Priestley gives his figure in a letter to Rush, see Bolton, Scientific Correspondence, p. 142.
22. Smith, Woodhouse, pp. 61-62.
23. Benjamin Silliman, Reminisences as quoted in George P. Fisher, Life of Benjamin Silliman, vol. II, p. 101.
24. Ibid., vol. 2, p. 101.

> Our Professor has not the gift of a lucid mind, nor of high reasoning powers, nor of a fluent diction; still we would understand him, and I soon began to interprete phenomena for myself and to anticipate the explanations. Dr. Woodhouse was wanting in personal dignity, and was, out of lecture hours, sometimes jocose with the students. He appeared when lecturing, as if not quite at ease, as if a little fearful that he was not highly appreciated, as indeed he was not very highly.

Caldwell, in his Autobiography, presents a different picture of Woodhouse as a chemist. He states that as soon as Woodhouse had been elected to the Professorship he began to prepare himself for the duties of his new post, and soon became so proficient in his experiments that Priestley tendered a compliment and "did not hesitate to pronounce him equal, as an experimenter, to anyone he had seen in either England or France."[25]

The extant manuscript notebooks of Woodhouse's lectures show that he depended upon Rush to only a slight extent.

Three student manuscript notebooks of Woodhouse's chemical lectures have been found.[26] Two are undated, one bears the date 1809, the year he last lectured. Two of the notebooks have fifty-nine lectures transcribed, the full course that Woodhouse presented. The lectures are principally on strictly chemical subjects, e.g., Soda, Acids, Gold, Silver, Borax, etc. Of the fifty-nine lectures only two are on animal substances. This is in marked contrast with Rush who attempted to spend as much time as possible on topics mutually related to medicine and chemistry. It can be definitely stated that Woodhouse's lec-

25. Smith, Woodhouse, p. 67.

26. Ms twenty-nine lectures signed by Clifford Clark in library of the University of Pennsylvania School of Medicine. Ms two volumes containing fifty-nine lectures in library of the College of Physicians, Philadelphia. Two volumes containing fifty-nine lectures signed S. Sommer in the E.F. Smith Collection at the University of Pennsylvania.

tures departed from the Rush tradition of interrelating chemistry and medicine.

Woodhouse, it appears, was more concerned with chemistry as a science in itself than in its utility to the physicians. This outlook by Woodhouse prompted Rush to state in his "Commonplace Book" that "Though a medical Professor he (Woodhouse) scouted the utility of medicine upon all occasions."[27]

Early in his career Woodhouse accepted the "new" chemistry of the French School in preference to the Scottish and English ideas as expressed in Rush's notes. That he firmly believed in the theories he taught will be seen in a later chapter discussing his writings.

The constant activity of Woodhouse in chemical pursuits, and the knowledge that under his direction it was possible to conduct actual laboratory experiments, had their effect. Not only students of medicine, but also students who preferred chemistry, seeking advancement in the science alone, gradually caused a number of eager and capable young men to gather around him in search of a deeper insight into their favorite subject.

Among these students was Robert Hare, destined to become one of America's leading chemists of the nineteenth century; Benjamin Silliman, John Bryant, Thomas P. Smith, Thomas Brown, and George Lee. The names of all these students do not appear in the Alumni Records Office of the University but are preserved in other records in the archives.[28] These students did not pursue an entire medical curriculum, but purchased

27. Benjamin Rush, Commonplace Book as contained in his Autobiography (Princeton, 1948), p. 20.
28. Edward P. Cheyney, History of the University of Pennsylvania, p.211.

"tickets" for the courses given by Woodhouse, and, doubtless, spent more time on chemistry than did regular medical students.[29] All of these men were members of the Chemical Society of Philadelphia.

The lectures of Woodhouse were given in Anatomy Hall. The lower story was the chemical laboratory and the upper story served as a lecture hall. Silliman has given us a description of the building.[30]

> Neither of these establishments was equal to the dignity and importance of the Medical School, and the accommodations in both were limited; the lecture-rooms were not capacious enough for more than one hundred or one hundred and twenty pupils, and there was a great deficiency of extra room for the work, which was limited to a few closets.

Woodhouse emphasized the laboratory part of his course. This is one of the directions in which he was an innovator and is one of the reasons that explains the popularity of his course.[31] In 1797 he collected a number of the experiments and published them in a volume entitled "The Young Chemists' Pocket Companion" which was "in all probability the first published guide in experimentation for chemical students."[32]

The Medical Repository, reviewing the book, said:[33]

> The performance before us affords a new proof of the prevalence of a taste for chemical researches in the United States. And it is one of the circumstances of recommendation of the "Young Chemists' Pocket Companion", that it is intended to advance the knowledge of that science by facilitating the means of making experiments and of interpreting and understanding them.

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29. Smith, Woodhouse, p. 72.
30. Silliman, Reminisences from Fisher edition, Benjamin Silliman, vol. 1, p. 100.
31. Smith, Woodhouse, p. 76. Also Theodore Hornberger, Scientific Thought in the American Colleges, 1638-1800, p. 10.
32. Smith, Chemistry in America, p. 76.
33. Medical Repository, vol. I, p. 235.

> The number of detailed experiments which Professor Woodhouse has given, is one hundred; in which he explains the properties of air, of gases, of alkalies, of acids, of earths and metals.
>
> We recommend it to the students...especially if they pursue it in connection with such systematical works as those of Lavoisier, Fourcroy and Chaptal.

In addition to guiding the Chemical Society, Woodhouse was elected to the American Philosophical Society in 1796, and became active in its affairs until his death. He served at various times as Secretary, and Councilor and on one occasion was chosen annual orator.[34] Also, at the request of the Society, he repeated a series of experiments in connection with a communication presented by E. J. DuPont De Nemours, "On the utility of the oxygenated muriatic acid gas in recovering animals from asphyxia."

In 1802, when he held the position of Dean of the Medical School, Woodhouse made a trip to Europe and came to know many of the Continental scientists. Studying their work provided him with the opportunity of broadening his interests and he returned to Philadelphia in the fall of 1802 with many notes and some new apparatus which he used in demonstrations in his lectures.[35]

The year 1802 also saw the publication of an American edition of "Parkinson's Chemical Pocket Book" edited by Woodhouse. In 1807 he revised Parke's "Chemical Catechism", and published the fourth edition of Chaptal's "Elements of Chemistry". To the latter works he had added

34. Woodhouse served as councilor in 1802, 1805, 1808, and as Secretary in 1799. See *Proceedings American Philosophical Society* XXII, pt. 3, *Early Proceedings*, pp. 277, 320, 369.
35. Smith, *Woodhouse*, p. 185; also see Silliman, *Reminisences* in the Fisher edition, p. 102.

many notes and additions not found in the original edition.

Throughout the first years of the nineteenth century Woodhouse devoted himself to his experiments, and, no doubt, if he had lived longer would have contributed much to the chemistry of America. However, when in the prime of his life--only thirty-eight years old--and after a career of only fourteen years, he died on Sunday, June 4, 1809 after a short illness. The cause of death was officially listed as apoplexy.

Although his career was short, Woodhouse in those few years had performed many and varied experiments ranging from the highly theoretical work on oxidation to the practical value of Lehigh antracite over the coal of other regions.

The following chapters will be devoted to a study of his major areas of work and a short evaluation of his place in the history of American chemistry. Since his controversy with Joseph Priestley contains his most noted series of experiments, it will be discussed first and his other experiments will follow.

## III

## THE PHLOGISTON THEORY

Science attempts to generalize, this is, to accommodate a large number of seemingly diverse phenomena under broad theories which will explain the observed events. In the eighteenth century this tendency to generalize was centered on the problems connected with combustion and from it arose the theory which is known as phlogiston, the principle of inflammability.

The phlogiston theory had first been enunciated by J. J. Becher who died before the theory was well formulated. His work was taken over and continued by G. E. Stahl. It was left to Stahl to systematize and formalize the theory and he accomplished this to such a degree that the theory was generally received with favor and was able to dominate chemistry for over half a century. It commanded the assent of chemists and was adopted and defended by some of the most respected chemists of the century. In fact, Joseph Priestley was to defend the theory into the nineteenth century, and he died believing in the truth of phlogiston, even though Lavoisier had come forward with an alternate, simpler theory by 1789. Although the phlogiston theory is erroneous in the light of modern knowledge it did serve to systematize many of the chemical phenomena of the eighteenth century, especially in a qualitative manner.[1]

The lineage of the theory could be traced back to the alchemists and according to the theory there was only one substance which was capable of being burned, and this hypothetical substance was a constituent of all matter. This principle of combustion was termed by Stahl

1. James Bryant Conant, "The Overthrow of the Phlogiston Theory", Harvard Case Histories in Experimental Science, Case, 2, p. 13-14.

phlogiston. According to the theory, when metals are calcined (heated in air) they give off phlogiston, which is absorbed by the surrounding air, leaving behind a residue of unburnable material (metallic oxide). Conversely, from a metallic calx (oxide) the metal could be recovered by burning it in the presence of charcoal; the metal was believed to have absorbed phlogiston in the process from the charcoal which, having almost completely disappeared, was regarded as almost pure phlogiston. The fact that combustion soon stopped in an enclosed space was used as evidence that the enclosed air could only absorb a definite amount of the phlogiston. Once the air had become completely saturated with phlogiston it would no longer serve to support combustion of any material, nor could air saturated with phlogiston support life, for the role of air in respiration was to remove phlogiston from the body.[2]

In general, any substance which would burn in air was said to be rich in phlogiston. Thus phlogiston satisfied the chief requirement imposed on any new theory, namely, that it must account for the experimentally observed facts, and be able to fit the diverse phenomena into a unified whole.[3]

The phlogiston theory was generally accepted at the time of the American Revolution and served as the basis of the chemistry taught in the colleges of the emerging nation.[4] The lecture notes of Professor Samuel Williams as preserved in the Harvard University Archives can well serve as an illustration. The following is a quote from a lecture read

2. John Read, Through Alchemy to Chemistry, pp. 120-121 and also see Abraham Wolf, A History of Science, Technology and Philosophy in the Eighteenth Century, pp. 343-344.
3. William Wightman, The Growth of Scientific Ideas, p. 182.
4. Conant, Overthrow of Phlogiston, pp. 14-15.

to the undergraduates in May every year from 1785 to 1788.[5]

> Among the various kinds of permanently elastic Fluids we may begin with Common or Atmospherical Air. Atmospherical air is that which we breathe, with which is common to every country and place...with which we are constantly surrounded, what is worthy of particular observation, common or atmospherical air is generally charged with a large quantity of Fire of Phlogiston....By Phlogiston we mean no more than the principle of Inflammability; or that by which bodies become combustible or capable of burning--and that there is such a principle...may be easily represented.
>
> Take some combustible substance and let it be inflamed or set on fire: In this state enclose it in a vessel containing a small quantity of atmospherical air. Effect. The combustion will continue but a small time and then cease. Part of the combustible substance is reduced to ashes and the other part remains entire. And the Air appears to be changed or altered....Here then we have a representation of what the chemists call Phlogiston and of the Air's being loaded with it. In the confined air the combustible matter continues burning until the air becomes loaded with something that prevents any further combustion. And being confined by the closeness of the vessel whatever the matter be with which the air is loaded it is confined within the vessel and cannot escape....
>
> It seems therefore from this Experiment that Phlogiston must be a real Substance and that the air is loaded or saturated with it...is it not evident that so long as the air can receive this substance from the combustible matter so long will the body continue burning; and that as soon as the Air is saturated and can receive no more of the Phlogiston, the combustion must cease for no more Phlogiston can escape or be thrown out from the burning body. And therefore when fresh air is admitted to receive Phlogiston, the combustion will again take place. And hence are derived the phrases of phlogisticated and dephlogisticated air. By phlogisticated air is intended air which is charged or loaded with Phlogiston and by dephlogisticated air is meant Air which is free from Phlogiston; or which does not contain this principle or element of inflammability.

The phlogiston theory ran into difficulty in attempting to explain the increase in weight of a metal when it was burned. When heated in air the metal was thought to give up phlogiston to the air leaving be-

5. Conant, op. cit., p. 15-16; also see I. B. Cohen, "The Beginning of Chemical Instruction in America: A Brief Account of the Teaching of Chemistry at Harvard prior to 1800" Chymia, III (1950),p35

hind only the unburnable residue. This residue was found to weigh more than the original metal. Since it had lost phlogiston, the chemists were forced to state that the phlogiston levitated, that is, possessed the property of negative weight. Thus to the hypothetical undiscovered substance phlogiston was added another even more hypothetical idea of phlogiston exhibiting negative weight.[6]

The phlogiston theory had been formulated and accepted during a period marked by a rapid increase in chemical knowledge. Elements were no longer thought of as being different from the material employed in laboratory experiments. With the growth of the concept that elements were the same as compounds, chemists came to believe that they should obey the same laws and rules. It became increasingly more difficult to disregard inconvenient facts when formulating a general theory.

It was impossible to ignore the question of the increase of weight when a metal was burned and a great amount of work was expended to explain the phenomena. The theory which satisfied many was put forth by Boyle and Boerhaave, namely that fire particles were taken up during the calcination process. Others confused density and absolute weight and since the calx had a lower density some substance must have been lost. However, it was not until gases were recognized as distinct, chemical compounds, possessing individual characteristics, that a valid attack could be made on the concept of phlogiston. But the disagreements, constant revisions and the new knowledge hurried the demise of the concept.

6. Henry M. Leicester, The Historical Background of Chemistry, p125; also William Wightman, The Growth of Scientific Ideas, p. 183-184.

The history of the rejection of the phlogiston theory begins with the experiments of Joseph Black. Up to this time gases had been thought to be nothing but varieties of air differing slightly but all essentially the same. In 1755, Black was able to isolate a gas which differed markedly from ordinary air and this he called 'fixed air' (carbon dioxide). He showed that it was produced in the combustion of charcoal and in the process of respiration. Then Henry Cavendish in 1766 discovered the existence of another air which he termed 'inflammable air' (hydrogen) and beginning in 1772 Priestley isolated seven other gases, among them oxygen. But he refused to recognize them as being essentially different from air and described them as different kinds of air, oxygen being 'dephlogisticated air'.[7]

Meanwhile in France, Lavoisier had been considering the problems of calcination (oxidation) and combustion and he thought that air must somehow be involved in the combustion process and that such substances as sulfur and phosphorous combined with air when they were burned and that the increase in weight observed in the residue must be due to this combination with air.

In a sealed note which he gave to the Secretary of the French Academy in November 1772, he stated:[8]

> About eight days ago I discovered that sulfur in burning, far from losing weight, on the contrary gains it; it is the same with phosphorous; this increase of weight arises from a prodigious quantity of air that is fixed during combustion and combines with the vapors.

7. John Read, From Alchemy to Chemistry, 127-128; also see J. R. Partington, A Short History of Chemistry, 95-98; and Henry M. Leicester, The Historical Background of Chemistry, 132-134.
8. As quoted in Conant, Overthrow of Phlogiston, p. 16.

> This discovery, which I have established by experiments, that I regard as decisive, has led me to think that what is observed in the combustion of sulfur and phosphorous may well take place in the case of all substances that gain in weight by combustion and calcination and I am persuaded that the increase in weight of metallic calxes (oxides) is due to the same cause.

Lavoisier continued his experiments and in 1774 when Priestley visited him, the English scientist described his latest discovery 'dephlogisticated air' (oxygen); relating how he had obtained it from heating the calx (oxide) of mercury.

This communication fitted in with the experiments of Lavoisier and provided him with the clue he needed to unravel the true cause of combustion. He knew that a metal will absorb air as can be seen in his communication quoted above. The metal after it had been burned left the residue of unburned substance after it (an oxide). Now Priestley had shown him that if this oxide were burned, it could produce 'dephlogisticated air'.

Lavoisier repeated both his own and Priestley's experiments employing mercury. He took a sample of mercury metal, heated it in an enclosed space and noted the amount of air that disappeared inside the vessel, and the amount of residue (mercuric oxide) that remained after the combustion. He removed the residue and heated it still further and noted that an air was given off and metallic mercury produced. Thus it was shown that air was both taken up and released by heating the mercury and that no hypothetical substance, phlogiston, was needed to explain the phenomenon.[9]

9. Conant, Overthrow of Phlogiston, pp. 18-21.

By 1777 Lavoisier had completed the essentials of the anti-phlogistic theory and it can be stated in his own words:[10]

1. In every combustion there is disengagement of the matter of fire or of light.
2. A body can burn only in pure air.
3. There is destruction or decomposition of pure air and the increase in weight of the body burnt is exactly equal to the weight of air destroyed or decomposed.
4. The body burnt changes into an acid by addition of the substance that increases its weight.
5. Pure air is a compound of the matter of fire or light with a base. In combustion the burning body removes the base which it attracts more strongly than does the matter of heat, and sets free the combined matter of heat, which appears as flame, heat, and light.

His theory was not received without opposition, even by his contemporaries in the French Academy as is recorded in the Memoirs of the Royal Academy for June 1787. Instead of rejecting it, however, they agreed that it should be submitted to the trial of time, and the Academy gave it to the world without commenting on its validity.[11]

It was not only the doctrines of chemistry that called for reform but also the nomenclature of the compounds was becoming inadequate and inaccurate. Prior to this time the number of objects studied had been few and easily remembered. But with the discoveries of Black and Cavendish, the number of substances in chemistry began to expand at a rapid rate and some systematic method for naming the newly discovered compounds was needed. Four chemists, deMorveau, Antoine Lavoisier, Claude Berthollet and DeFourcroy laid the basis for a new nomenclature and Hassenfratz and P.A. Adet, who was later to become Ambassador

10. A. Lavoisier, *Mem. Acad. Roy. Sci.*, 1777, 592; *Oeuvres*, II, 225; also see J.R. Partington, "Berthollet and the Anti-Phlogistic Theory", *Chymia* V, 130, and *A Short History of Chemistry*, 3rd edition, 131.
11. Conant, *Overthrow of Phlogiston*, p. 41.

to the United States, published a table of the new symbols and chemical characters formed on the principles of the new system.

Within a short time the new chemistry and its nomenclature was being discussed in the countries of Europe, Asia, and the American states. Many of the outstanding chemists of the period refused to believe in the new theory, Tobias Lowitz in Russia, Black and Priestley in England, Bethollet in France.[12] Gradually, however, most of these men were won over with the outstanding exception of Priestley. Generally, the younger generation of chemists accepted the new chemistry much more readily, and soon began to teach it in the colleges.

This pattern was followed in the United States. It is known from the writings of Brissot de Warville's New Travels in the United States of America performed in MDCLXXXVIII that Aaron Dexter, the first professor of chemistry at Harvard, accepted the French system of chemistry. On Dexter he wrote that he was a "man of extensive knowledge and great modesty. He told me, to my great satisfaction, that he gave lectures of the experiments of our school of chemistry. The excellent work of my respectable master, Dr. Fourcroy, was in his hands, which taught him the rapid strides that this science has lately made in Europe."[13] The book used by Dexter was probably Fourcroy's Lecons elementaires d'histoire naturelle et de chimie, which had been translated into English in 1785.

At Kings College, later known as Columbia University, S. L. Mitchell soon began to teach the new system of chemistry and the new nomenclature.

12. Henry M. Leicester, "The Spread of the Theory of Lavoisier in Russia", Chymia, V, 138; and "J.R. Berthollet and the Anti-Phlogistic Theory", Chymia, V, 130.
13. Brissot de Warville, Quoted from the English translation, 2nd edition, I, 83-85.

## IV

## REJECTION OF PHLOGISTON IN AMERICA

No American chemist wrote or commented extensively on the phlogiston and anti-phlogiston theories before the arrival of Priestley.

After Priestley had declined the position of Professor of Chemistry at the University of Pennsylvania and retired to his home in Northumberland, he began to experiment in a small laboratory he had built.

In 1796 Priestley published his Considerations on the Doctrine of Phlogiston and the Decomposition of Water which opened the discussion of the relative merits of the two systems of chemistry.

In this pamphlet Priestley maintained that while the new chemistry holds that metals are simple substances and on heating change to calxes because of the absorption of oxygen and not to the departure of phlogiston, this is not universally true. Turbith mineral, which he held to be an oxide of mercury, does not undergo such a change but requires the presence of inflammable air, charcoal or some substance that contains phlogiston. When iron metal is heated by the rays of the sun passing through a lens, the air inside the vessel is diminished, the iron becomes a calx, and something possessing a very strong odor is emitted. Priestley maintains that the iron not only attracts something but at the same time it gives up something, and the substance that it gives up is phlogiston. He also states that the change in the confined air is not due to the separation and fixation of the oxygen and that the phlogisticated air (nitrogen) is produced by the combination of phlogiston and dephlogisticated air (oxygen). When metals are disolved in acid,

1. Joseph Priestley, Considerations on the Doctrine of Phlogiston published at Philadelphia in 1796.

the inflammable air (hydrogen) produced does not come from the decomposition of water but from the phlogiston emitted from the metal and that in the case of the supposed decomposition of water by hot iron, the inflammable air comes from the decomposition of the iron and not from the water.*

Priestley also states that all the experiments that have been performed upon the decomposition of water can be explained by the phlogiston theory. According to him, the classic experiment of passing water through a red-hot iron tube, the finery cinder (iron oxide) formed is a combination of iron and water and not iron and oxygen and that the inflammable air produced is phlogiston from the iron united to the undecomposed water and is not hydrogen from the water. Further, he states the same principle that allows inflammable air to reduce the calx of a metal exists in charcoal and in other combustible substances since they also reduce the calx to the metal and that this common principle is phlogiston.

In the first volume of the Medical Repository, Samuel Latham Mitchell reviews the pamphlet and sets the scene for the coming discussion.[2]

> The worthy and indefatigable author of the pamphlet before us, since his arrival in America, continues his chemical labours, and appears as zealous as ever to promote the progress of science. It must give pleasure to every philosophical mind to find the United States becoming the theatre of such interesting discussion as now occupies some of the leading chemists of the day...

* In these statements Priestley is of course wrong. The modern theory of Lavoisier being the correct version.

2. Medical Repository, I, (1798), 215. The Medical Repository a journal initiated under the auspices of Samuel Latham in 1797, was the primary means of communication between the American chemists and Priestley. It carried most of the articles concerning the phlogistic and anti-phlogistic ideas prevalent at this time.

> Although the Lavoisierian theory had made proselytes of the greater part of the philosophers in Europe and America, and though Dr. Priestley had observed his friends and acquaintances deserting the standard of phlogiston, not merely one by one, but frequently going over to the other side in whole troops, he was never yet found himself disposed to change sides and engage in this revolutionary scheme. Firm in his original persuasion, that the doctrine of STAHL is perferable on the whole, he adheres to it upon principle; professing at the same time, with perfect candour and willingness and readiness to adopt the sentiments of his opponents whenever they shall convince him he is wrong...
>
> We feel a degree of satisfaction in ascribing a considerable part of theincreasing taste and prevailing fashion for chemical pursuits in this country...to the influence and example of Dr. Priestley.

P. A. Adet, the Ambassador from France to the United States, was the first to answer Priestley's attack on the "new" chemistry, he published a pamphlet entitled "Reponse aux Reflexions sur la Doctrine du Phlogistique et sur la Decomposition de l'Eau."[3] Adet holds that metals are simple substances and that their conversion to oxides (calces) by absorption of oxygen has been proved beyond doubt by many experiments. His pamphlet is confined chiefly to the second part of Priestley's statements, namely on the decomposition of water. Adet states that he felt driven to state once again:

> (1) That in causing water to pass through a red-hot gun-barrel, the iron becomes oxydated by the oxygen of the water; (2) notwithstanding the difference which exists between the black oxyd of iron, produced by the decomposition of water, and the common red oxyd of the same metal they are still both of them oxyds, for these reasons: that, like other oxyds they both dissolve in acids without disengaging anything, and metallic bodies are incapable of combining with acids unless they are previously united to oxygen; (3) although there is some difference between this oxyd and the common red oxyd, it does not follow that they are not both oxyds; the difference between the two being only owing to the different circumstances under which they have combined with oxygen.*

3. Medical Repository, I, (1798), p. 220.

* Medical Repository, I, (1798), p. 220-221. The last statement also reflects the modern notion that a difference in appearance does not mean a difference in composition, which is opposite the alchemical idea that qualitative difference meant a change in composition.

In general Adet maintained that any of Priestley's objections to the compound nature of water could be explained without employing the phlogiston concept.

Another answer came from Dr. John MacLean of Princeton. MacLean reviewed the pamphlet in "Two Lectures on Combustion Supplementary to a Course of Lectures".[4] This review by MacLean was published, with the following advertisement:

> Owing to other engagements a part only of the first of these lectures was read to the students...
>
> P.S. It was not till after they were sent to the press that I was informed Mr. Adet had published an answer to Dr. Priestley's pamphlet.

He recommended the anti-phlogiston theory to his students in the following manner:

> From the view which has been given of the different explanations of the phenomena of combustion, it appears that Becher's is incomplete; Stahl's though ingenious, is defective; the anti-phlogistic is simple, consistent, and sufficient; while Dr. Priestley's resembling Stahl's but in name is complicated, contradictory, and inadequate. You, doubtless, therefore, will be inclined to prefer the anti-phlogistic doctrine: Indeed, you may adopt it with safety; for, from being a plain relation of facts, it is founded on no ideal principle, on no creature of the imagination; it is propped by no vague supposition, by no random conjecture; it is dependent upon nothing whose existence cannot actually be demonstrated; whose properties cannot be submitted to the most rigorous examination; and whose quantity cannot be determined by the tests of weights and measures.

In a review of the Medical Repository, Mitchell wrote that MacLean had arrived at differing experimental results than had Priestley; then he states:[5]

4. Originally the lectures were to be delivered at Nassau Hall of Princeton but instead were published in Philadelphia in 1797.
5. Medical Repository, I, (1798), p. 514.

> 1. Turbith mineral may be reduced to running quicksilver, by heat alone, without addition. 2. Quicksilver, revived from its calces and inflammable air, does not differ at all from that recovered by increase of the temperature only. 3. Though hot iron may so affect the air as to be smelled, this is no evidence of the separation of phlogiston from it. 4. Azotic air (nitrogen) cannot be formed from the union of oxygen, with any matter which hot iron emits...

MacLean reiterates Adet's statements that the inflammable air (hydrogen) obtained from water and iron comes not from the iron but from the decomposition of water. He further states that the same oxide of iron is formed whether the iron, is acted upon by hot steam, or burned in air.

The reviewer for the Repository, Samuel Latham Mitchell, attempted to resolve the differences between Priestley and MacLean with an article entitled, "An Attempt to Accommodate the Disputes among the Chemists Concerning Phlogiston. In a letter from Dr. Mitchell to Dr. Priestley, dated November 14, 1797."[6] The letter which attempted to show that the difficulty between the phlogistians and the anti-phlogistians was a matter of definitions was not successful. He wrote Priestley:

> Your opposition to the new doctrine has been serviceable to the cause of science. It has prevented too easy and sudden acquiescence in the novel system of the anti-phlogistians, whose difficulties and paradoxes have been admitted by many, without having been subjected to due examination...Perhaps even now my labours are but of little avail; or if they were capable of bringing about a coalition of parties, I might say to you, after all, in the words of Prior in his Alma:
>
> For, Dick, if we could reconcile  
> Old Aristotle with Gassendus  
> How many would admire our toil!  
> And yet how few would comprehend us!

Priestley answered this letter of Mitchell's giving his thanks for the reviewer's efforts to "promote a peace between the present belli-

6. Medical Repository, I, (1798), p. 521.

gerent powers in chemistry". And in a postscript he added:

> Dr. MacLean did not, as the laws of war require, ever send me a copy of his pamphlet; and as I never saw it advertised, it was only by the accident of my son's being in Philadelphia that I got it.

Up to this time Woodhouse had not entered the controversy, but in Volume II of the Medical Repository he rebukes MacLean saying:[7]

> A judgement may be formed (as to the) right you have to condemn the experiments of Dr. Priestley in the authoritative manner you have done, having made none yourself... You are not yet the conqueror of this veteran in philosophy..
>
> You agree with the French chemists, that turbith mineral is an oxyde of mercury, and have asserted, that any substance into which it may be converted by a red heat, does not require any addition to constitute it a metal.
>
> Now the very contrary of this is true; for we have the most conclusive proofs, that turbith mineral is not an oxyde, but a sulphate of mercury...
>
> Your opinion, then, according to these experiments... is void of foundation.
>
> You have also declared that Dr. Priestley is mistaken, in saying that finery cinder will not acquire rust, and assert that it contracts rust sooner than common iron...The rust which finery cinder appears to contract is owing to iron filings with which it is frequently mixed.
>
> You have answered the Doctor, on the part of the controversy by informing him that inflammable air is a constituent part of other bodies besides water...and lastly, you tell him in what manner the experiment ought to have been performed, and declare it is of no value, as reported in his experiments on different kinds of air.
>
> I have repeated this famous experiment, and the result is exactly as stated by Dr. Priestley.
>
> Should you consider the objections of Dr. Priestley once more, and advance nothing but what is found upon your own experiments you may hear from me again; and I promise not to be the first to drop the subject.
>
> Mere assertions only serve to fix errors deeply in the mind, and do not advance the cause of truth.

MacLean answered this letter in one that added nothing new to the dis-

7. Medical Repository, II, (1799), p. 398.
8. Medical Repository, III (1800), p. 138.

cussion, and then dropped out of the controversy.[8]

Volume III of the Repository recorded that "Professor Woodhouse has returned an experimental answer to Dr. Priestley's pamphlet on phlogiston...It will be given to the public in...the Transactions of the American Philosophical Society."[9]

In this long article Woodhouse reviews all of the arguments of Priestley and discusses each of them in the light of the experiments that he himself has done. He states that[10]

> When the focus of a burning lens is thrown upon a calx of mercury, confined in hydrogenous gas, according to anti-phlogistic theory of chemistry, the oxygen of the calx unites to the hydrogen, and forms water; but according to Dr. Priestley, the hydrogen enters into the metal, while the oxygen is found mixed with that part of the hydrogenous gas which remains behind...
>
> Having performed the experiments...twenty times,...I concluded that Dr. Priestley's inflammable air must have been mixed with atmospheric air.

He also covered the experiment on the preparation of fixed air ($CO_2$) from iron filings and mercuric oxide:

> Priestley had said that large quantities of it (carbon dioxide) could be obtained from heating a mixture of iron filings and red precipitate...

concluding with the statement that the experiment was always successful, Woodhouse answered "and I say that it had never succeeded with me" and adds "in my opinion, the proofs that fixed air is composed of oxygen and carbon are as strong as that Glauber's salt is composed of sulfuric acid and soda."[11]

9. Medical Repository, 3, (1800), p. 63. The article appeared in the Transactions of the American Philosophical Society, O.S. IV, p. 452-475. A review was published in the fifth volume of the Medical Repository
10. Trans. Am. Phil. Soc., IV (1799), p. 456.
11. Trans. Am. Phil. Soc., IV (1799), p. 463.

At this point the controversy had become settled on minor points, but Priestley stirred in anew with a confident pamphlet titled, The Doctrine of Phlogiston Established, and that of the Composition of Water Refuted.[12]

He goes back over the old arguments of the phlogistians by discussing the following points:

> 1. That metals are compound substances, and contain phlogiston. 2. That finery cinder is not a proper oxyd of iron, but a combination of water with iron. 3. That the inflammable air produced from finery cinder and charcoal heated together, is formed by the union of the water of the finery cinder with a portion of the charcoal while the other part of this substance furnishes phlogiston to revive the metal... 6. That the calces of mercury are reducible in inflammable air, which is absorbed during the process, and that metal reduced thereby, it must contain phlogiston; and when the calces of the quicksilver are reduced without addition, the phlogiston necessary for substituting the metal must pass through the red-hot glass from without. 7. That the antiphlogistian experiment of the decomposition of water, by causing steam to pass over red-hot iron is utterly inconclusive; and that when an electric spark is passed through a mixture of oxygenous and inflammable airs, not water but nitrous acid is instantly produced... 10. That fixed air is formed without the presence of carbon, and consists of dephlogisticated air and phlogiston.

After this outburst even the reviewer of the Medical Repository, S. L. Mitchell could offer no support for the Priestley views and ends his review of the pamphlet by declaring:[13]

> After these reflections on what appear to us the radical and insuperable difficulties of Dr. P's doctrine, we decline to enter into a minute examination of his experiments, as few of his recitals of them are free from the triune mystery of phlogiston, which exceeds the utmost stretch of our faith; for according to it, carbon is phlogiston, and hydrogen is phlogiston, and azote (nitrogen) is phlogiston; and yet there are not three phlogistons, but one phlogiston!

12. Published at Northumberland in 1800. A review appeared in volume III of the Medical Repository written by Samuel Mitchell.
13. Medical Repository, III (1800), p. 379.

This rebuke did not stop Priestley from sending more letters to the *Repository* describing additional experiments he had run in an attempt to preserve the old doctrine.

With the appearance of this pamphlet of Priestley's, Woodhouse must have been somewhat disturbed for he answers it at length citing many experiments that he had performed in evidence of the validity of his views. This paper appeared in the fourth volume of the *Medical Repository*, under the title "An Answer to Dr. Joseph Priestley's Arguments Against the Anti-phlogistic System of Chemistry, published in the *Medical Repository*, and a Vindication of the Principles contained in the 72nd Essay of the fourth Volume of the *American Philosophical Transactions*." In it he stated the reasons why the antiphlogistic chemists rejected phlogiston;

> First. Because it appears to be a mere creature of the imagination, whose existence has never been proved.
>
> Secondly. Because all of the phenomena of chemistry, can be satisfactorily explained, without the aid of this hypothesis.
>
> They believe metals to be simple substances, because they have never been proved to be compound bodies.
>
> They consider a metallic calx, to be a union of metal and the base of a vital air, called by them oxygen, as it is the principle of universal acidity. The proofs that metals in being converted into calces, absorb oxygen, are:
>
> First. That all calces of mercury give out oxygenous gas when exposed to a red heat, without any addition.
>
> Secondly. If a metal is calcined in oxygen gas, the whole of it will be absorbed.
>
> Thirdly. If the process of calcination is performed in a variety of gases, containing some oxygenous air, the oxygen only will be imbibed by the metal, and the others will be left unaltered.
>
> Fourthly. If any substance is added to a metallic oxyd, and the calx is revived, a compound body will be produced, formed of the agent used and the oxygen contained in the calx.
>
> Thus, if the filings of pure bar iron are mixed with red precipitate, and exposed to a red heat, the iron will be converted into a calx and the mercury will be revived. If pure

charcoal is mixed with the precipitate, carbonic acid will be produced; and if the mercurial calx is revived in hydrogenous gas, water will be formed.

The first objection of Dr. Priestley, to this theory of calcination of metals is as follows:

He says, that if turbith mineral is exposed to a red heat, a calx remains which cannot be revived in any degree of heat, without the aid of some substance, supposed to contain phlogiston. Before we proceed any further in this investigation, it is absolutely necessary to determine the real composition of turbith mineral.

According to the French philosophers, this substance is a pure oxyd of mercury.

Fourcroy and Baume declare, that it does not contain one particle of sulphuric acid. Dr. Priestley is doubtful whether it is a salt of a calx; and in the Edinburgh Dispensatory and London Pharmacoepia Chirugica, it is called hydragyrus vitrolatus flavus.

The following experiments were made to ascertain the composition of this substance:

He then describes three experiments which he performed in the determination and concludes that his tests "clearly prove, contrary to what has been advanced by Lavoisier, Monnet, Bucquet, Fourcroy, Chaptal and other French chemists, that turbith mineral, is not a pure oxyd of mercury, but contains some sulfuric acid, and may be considered as a sulphate of mercury...Thus sulphate of mercury is the supposed calx of mercury to which Dr. Priestley refers."

This, he says, is why after the mineral has been heated the substance which remains is a salt, and not a metallic calx and

we see that the first objection of Dr. Priestley, to the theory of the calcination of metals, adopted by the antiphlogistic chemists, loses all of its force, for certainly it does not follow, that because the sulphate of mercury requires to be deprived of its sulphuric acid, before running mercury can be procured from it, that therefore all mineral calces require the addition of phlogiston to be converted into mercury.

The second refutation contained in the paper is the statement of Priestley that "when a metal is reduced to a calx, it throws out something which forms phlogisticated air." Thus when a burning lens (magnifying glass) is thrown upon iron metal, the phlogiston arising from the iron joins with the dephlogisticated air and forms azotic gas. Again Woodhouse cites careful experiments to show "that when a metal, containing no foreign substance, is calcined in oxygenous gas, the pure air only is imbibed, no substance is emitted from the metal, and no azotic gas is formed."

Another point that Priestley had repeatedly brought up since the publication of his Considerations on the Doctrine of Phlogiston, was that when a metal was immersed in an acid, the inflammable air produced had come not from the decomposition of water but from the phlogiston escaping from the metal. In answer to this, Woodhouse reviews a number of the experiments performed by European scientists; and then lists the experiments he, himself, conducted. He worked not only with iron, but also with mercury, lead, manganese and copper and concludes from each of them that "in all these experiments nothing but water was produced. The carbonic acid was not produced, unless it previously existed in the calces." Priestley had also maintained that hydrogen entered into the metal when the metal calx was heated in a hydrogenous atmosphere and that some of the oxygen is found to mix with the hydrogen that remains behind. Woodhouse shows that he has performed the experiments at least twenty times and has never found any such results.

In a further argument concerning finery cinder, Woodhouse mistakenly stated that finery cinder contains some water. This error was due to the prevalent idea that inflammable air contains hydrogen. Woodhouse, however, correctly, showed that the cinder does contain oxygen, a fact that Priestley would not admit.

After the publication of this article, Priestley seemed to retreat slightly from his former position and in a letter to the editors of the Medical Repository stated:

> I think myself obliged to the writer of your review of books for his candour and impartiality with respect to my late tract on phlogiston; but I hope I may be allowed to observe, that he has mistated my opinion, when he says that I make inflammable air, phlogisticated air, and fixed air, to be only different modifications of phlogiston; whereas, I uniformly suppose that phlogiston is only a constituent part of them all, as he himself acknowledges...
>
> At the same time I have no objection to saying, with this writer, that phlogiston may be defined to be the base of inflammable air, provided that the same thing be allowed to be a necessary part of all metals, and also of sulfur, phosphorous &c. That phlogiston cannot be exhibited alone is nothing extraordinary. Indeed, few things in nature can be so exhibited. Certainly not the principle of acidity or alkalinity. These are always to be found combined with some other substance. But do we, therefore, say that such principles do not exist, or that their existence cannot be demonstrated?

From this letter a sign of retreat can be seen over the formerly held theory that phlogiston was a definite substance to that of Phlogiston being only a property of a substance.

Finally, in the fifth volume of the Medical Repository a short letter by Woodhouse concerning the decomposition of water, the end of the debate is reached.[14] After this, except for short notices from Priestley, the affair concerning the relative merits of the two doctrines ceased as all of the American scientists were abundantly satisfield on the points at issue. From this point on, no defenders of the phlogiston theory were to be found writing in the journals, or advocat-

14. Medical Repository, V, (1802), p. 91.

ing it in the classroom.

Although others contributed, it was the work of Woodhouse that decided the matter. In conclusion, it may be said that Priestly initiated the controversy and that if he had not come to America, the debate would not have arisen. The French chemistry had been widely accepted in the United States before his publication of the Considerations on the Doctrine of Phlogiston and Priestley never gained a supporter among the American scientists. To Woodhouse must be given credit for clarifying the situation and, by his methods, pointing up the necessity for an experimental basis on which to answer chemical disputes.

# V

# FURTHER WORK OF JAMES WOODHOUSE

In addition to his research and statements on the phlogiston theory, Woodhouse actively pursued studies in many additional fields of chemistry.

While on his trip through Europe in 1802 he was able to communicate to Nicholson's Journal a paper on the chemical actions of plants. He had seriously doubted Priestley's theory concerning vegetables growing in light helping to correct impure air and by a series of experiments, as elaborately communicated to the Journal, he contended that plants do not purify air but produce oxygen by ingesting the coal of carbonic acid for food leaving the oxygen in the form of pure air. Also he made a set of experiments on the production of oxygen from the leaves of plants which had been exposed to carbonic acid and sunlight. From these experiments he was convinced of his conclusion, and denied the statements that vegetables emit oxygen, absorb nitrogen or decompose water as had been believed.[1]

It was also on the same journey that he had the opportunity of meeting Sir Humphrey Davy, of the Royal Society, who was to influence Woodhouse in his later work. It was Davy who did extensive work on galvanic batteries and on the effects of nitrous oxide, commonly called laughing gas. Upon his return to Pennsylvania, Woodhouse made a series of experiments with both the galvanic battery and the nitrous oxide.

He relates that he prepared the oxide in the morning before his students and that several of these same students were to inhale the

1. "Experiments and Observations on the vegetation of plants which show that the common opinion of the amelioration of the atmosphere, by vegetation in solar light is ill-founded". Nicholson's Journal, II, 150-162, 1802.

gas that afternoon. However, shortly before the students arrived he found that the gas had gone bad and not having time to prepare a new sample of the gas, he simply allowed the vessels to be filled with pure air. This did not seem to stop the students for, he reports, upon inhaling it they were seized with "quickness of pulse, dizziness, vertigo, tinnitus aurium, difficulty of breathing, anxiety of the breast, etc.,"[2] even though they were inhaling air. This made Woodhouse feel that the effects of the gas had probably been due, in great part, to the mental state of the person inhaling it. In 1806, though, he made another series of experiments with the nitrous oxide, allowing the subjects to inhale two to four quarts of the gas and noted their reactions.[3] He was pleased to note that their reactions were the same as had been reported in Davy's experiments although the effect seemed to wear off rapidly. In a later letter to the Medical Museum, Benjamin Silliman, a former student of Woodhouse's and now Professor of Chemistry at Yale, stated that Woodhouse had not allowed the subjects to inhale enough of the gas. He maintained that for the full effect of the gas to be felt they should inhale "six or eight quarts" of the oxide.[4]

In 1807, Davy had succeeded in isolating potassium by the use of the galvanic battery. The following year Gay-Lussac and Thenard had

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2. On nitrous oxide. Philadelphia Medical Museum, 4, p. 180. The Philadelphia Museum began publication in 1805, under the direction of John Redman Coxe, and was published in Philadelphia by Thomas Dobson. It was an "attempt to establish a Periodical Publication, in some measure analogous to the New York Medical Repository" said Coxe in the opening page of volume I.
3. Medical Museum, 4, p. 182-183.
4. The letter from Silliman is in volume 4, page 208, of the Medical Museum.

accomplished the same feat employing the different method of exposing the alkaline base of potassium to a white heat. In the same year, Woodhouse observed that on exposing soot, mixed with pearlash, in a covered crucible to the heat of an iron-furnace, he obtained a mass which when it was cooled and covered with cold water, had caught fire. He speculated on whether it could be the same element as had been discovered by Davy. He was also able to obtain the same metal from potash.[5] It is doubtful that Woodhouse was acquainted with the work of Gay-Lussac and Thenard as his experiment was performed at so close a date to theirs, credit must be given him for his novel work.

There is recorded in the Medical Museum, an extract of a letter from W. H. Pepys, of the Royal Society, to Woodhouse, and is concerned with some galvanic experiments made by Davy.[6] Along with the extract is a short note outlining some experiments with galvanic batteries made by Woodhouse. Of interest in his experiments is the use of copper sulfate solution. "It had never been tried in Europe" and was preferred by him to the nitric and sulfuric acid solutions commonly used, for it did not liberate any nitrous oxide or hydrogen.[7]

As was the usual case among scientists in the late eighteenth and early nineteenth century, when American natural history was developing, Woodhouse evinced an interest in the natural phenomena of the country.

5. Account of an Experiment in which potash calcined with charcoal took fire on the addition of water and ammoniacal gas was produced. Nicholson's Journal, 21, 290-291, 1808.
6. For Pepys' letter, see Medical Museum, 4, LXXXI, 180.
7. Medical Museum, 4, LXXXI-LXXXIII.

His thesis, as has been stated, was on the persimmon tree. He was also able to obtain honey, "of an exquisite taste," from the ripe fruit of the "Dyospyros Virginiana", American prune, date palm, or persimmon tree.[8] He also studied the effects of the blistering flies.[9] On the fourteenth of December, 1807, a meteor fell near the town of Weston, Connecticut, and in the fifth volume of the Medical Museum, Woodhouse recorded his analysis of the meteor. It was found to contain iron pyrites, magnesia, silex, nickel, and sulfur.[10]

Woodhouse had an interest in analyzing different ores sent him. Many of his tests were performed on ores from the different sections of Pennsylvania. On the Lehigh coal he recorded that "this coal is found in immense quantities in Pennsylvania, in the county of Northampton, near the river Lehigh."[11] He then described the properties of the anthracite coal and the tests he performed on it and its comparison with the coal found near the James river in Virginia. "The smith, his journey men, and bystanders were convinced that the heat was much cleaner and greater than that of the James river coal."[12]

He recorded his tests and findings on a "specimen of a black colored mineral, weighing five ounces, which was found in the country of Northampton...about thirty miles from Bethlehem, in the neighborhood of the Lehigh."[13] The mineral which could be found in such quan-

8. Medical Museum, 4, CXI
9. Of American blistering flies (Meloe Clematides and Nigra Chapmani). Medical Repository, 3, 213-214.
10. On meteoric stones. Medical Museum, 5, 131-133, 1808.
11. Observations on Lehigh coal, Medical Museum, 1, 441, 1805.
12. Ibid., 443.
13. On the discovery of manganese in Pennsylvania, Medical Museum, 5, 449, 1808.

tities was found to contain manganese in a high degree of purity and he "urges gentlemen residing in the country, to pay some attention to the mineral production of their fields" and offers to make an analysis of any ore free of charge.

In 1808, he recorded his observations on the ore from a Perkiomen zinc mine "situated on the side of a high hill on the bank of the Perkiomen Creek, about twenty miles from Philadelphia."[14] There were found in the mine three varieties of ore"lead coloured, the yellow, and the deep black."[15] He gave an analysis of each ore and in his concluding statements said:[16]

> Can this ore be worked to advantage in the United States?
> No information on this subject can be obtained from any book with which I am acquainted. Mr. Meade, a gentleman possessed of extensive knowledge of mineralogy informed me that it is never worked in England. Dr. Bruce, professor of science in the College of Physicians, New York, told me that it is reduced in Wales, and Mr. Gordon, of Boston, who is extremely well acquainted with subjects relating to this business, had declared that the zinc cannot be obtained from this kind of ore, but with the utmost difficulty.

No sooner had this article appeared than Woodhouse was attacked for his opinions by Adam Seybert, in an article questioning the statement "Can this ore be worked to advantage in the United States?"[17]

> From the observations which immediately follow the question proposed, it is evident that peculiar difficulties are not supposed to attend the working of this ore in the United States but the principle that blende is not and cannot be worked to advantage is assumed and acted upon. We will consider the question in this light.

Seybert then stated that "I do maintain that this ore can be worked in America with advantage."[18] He cited many authorities to

15. Ibid., 133.
16. Ibid., 136-137.
17. Facts to prove that Blende, or the Sulphuret of Zinc may be worked with advantage in the United States. Medical Museum, 5, 209, 1805.
18. Ibid., 210.

show that the ore could be extracted profitably and closed his article with the statement that "when erroneous opinions are propagated and unfounded doubts are excited, it is a two-fold duty to place facts in a true point of view...No one can now hesitate as to the propriety of working abundant and rich sulphurets of zinc."[19]

Woodhouse, however, did not see the matter as presented by Seybert and in his most vituperative piece of writing answered the arguments.

> In a work dedicated to the interests of science, it ought certainly to be expected that those whose leisure and opportunity permit them, occasionally, to throw their contributions to the general stock of knowledge would discard everything like asperity in their remarks and the opinions advanced by others; and that the little passions of envy and jealousy would never actuate the minds of those, whose real object is the pursuit of truth...
>
> I shall proceed to show that his essay improperly titled "Facts (when it entirely consists of quotation) to prove that this metallic ore can be worked to advantage in the United States," proves nothing, except that the doctor's misplaced rancour against myself, and which my former essay has furnished him a pretext for exhibiting.
>
> I shall show,
>
> 1st, That there is an evident want of candour in the conclusions he has drawn from my paper.
>
> 2nd, That some of his quotations from chemical writers are unfairly given.
>
> 3rd, That what he has advanced bears no direct relation to the subject in question.
>
> 4th, That the observations in his concluding paragraph are highly personal and improper.[20]

In reference to the paragraph concerning the statements Woodhouse printed about different opinions over the working of the ore, he states that "for thus merely stating the information derived from three men of eminence without advancing any opinion of my own, Dr. Seybert has taken the liberty of asserting that I assume the principle blende is not and cannot be work any where to advantage."[21]

19. Ibid., 216.
20. In reply to Seybert. Medical Museum, 6, 44-45, 1808.
21. Ibid., 47.

Woodhouse also asserts that Seybert misquoted the authors he had cited in his article and Woodhouse shows how prejudice has colored the Doctor's use of quotations. He also states that "as Dr. Seybert has made no experiments on the Perkiomen ore, it is absurd for him to give information to others on this subject, when he possesses none himself."[22]

No further replies were forthcoming from Seybert. One of the more interesting statements made by Woodhouse appeared in his article on the methods to be used in refining camphor. He stated that

> It must afford sincere pleasure to every true friend of America to view the establishment and rapid increase of manufactures, in the United States.
>
> Too long have our citizens been dependent upon other nations, for many articles, to purify and fabricate which, require but a small capital, and a very slight degree of chemical knowledge.
>
> Among the subjects which we may consider as coming under this head, is the obtaining of refined camphor.[23]

He then described the method which appears in the French Encyclopedia and "in the twelfth volume of Ars and Metiers by DeMachy," and concluded by "hoping that this endeavour to make a useful process, generally known in the United States may succeed."[24]

In addition to his experiments and articles describing his work, Woodhouse, published several books, mainly new editions of chemical books appearing in Europe. Among his publications, besides the already mentioned Young Chemists' Pocket Companion are:

1. Parkinson's Chemical Pocket Book which was published in Philadelphia in 1802 and is a revision of the second edition of the

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22. Ibid., 54-55.
23. Observations on the Mode of Refining Camphor. Medical Museum, 1, 197, 1805.
24. Ibid., 198-200.

book originally published in London.

2. Parke's <u>Chymical Catechism</u> was a revision of the original and was published in Philadelphia in 1807.

3. Lastly, Chaptal's <u>Elements of Chemistry</u> was published in Philadelphia in 1807. This was originally a work published by a former Minister of the Interior of France, and of the four American editions that appeared, the last was due to Woodhouse.

Although he died at the age of thirty-eight without contributing any new or lasting theory, Woodhouse's work was of importance to the development of chemistry in America. The young nation was not in a position to contribute to theoretical chemistry while it was still laying the groundwork for chemical studies. Woodhouse's contribution lies in his insistence on experimentation and analysis which is amply shown in his writing and method of teaching.

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## Vita

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