Henry Cavendish: The Catalyst for the Chemical Revolution

To the Memory of Glenn T. Seaborg (1912–1999)

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Whatever else may be said regarding the relative status of Henry Cavendish and Antoine Lavoisier in connection with the great chemical revolution that finally occurred at the end of the eighteenth century, I believe it is entirely proper to state that Lavoisier would not have had as sound and convincing a basis on

1 This brief biography of Henry Cavendish was inspired by a visit to Cambridge University in June of 2000 in order to obtain information concerning James Clerk Maxwell. As might be expected, I could not avoid the special thrill of a return journey to view the old Cavendish Laboratory, now no longer used as the primary center for research in physics as it had been from 1874 to 1974, when the new, more functional Cavendish opened. On the way home, I made a decision that I would try to learn more about the work and times of Henry Cavendish, for whom the building was named. That goal was greatly aided by the appearance of a new book, Cavendish, The Experimental Life (Bucknell University Press, 1999) by Christa Jungnickel and Russell McCormmach, two professional historians. The book is an expansion of an earlier version, prepared by the same authors and published by the Society in 1996 under the title Cavendish. The newer book, somewhat more than seven hundred pages long, is a marvel, for it gives an excellent account of the details of Cavendish’s life, family background, and work as well as the settings in which his activities took place. Moreover, it is heavily illustrated with copies of portraits of many relatives and associates, diagrams and photographs of scientific equipment, and maps and pictures of places where he lived and worked. I found it to be more than a pleasure to read and in fact very enriching. Nevertheless the book did cause me to do some between the lines thinking, particularly about Cavendish’s precise place in scientific history. This essay is a well-meaning attempt to throw light on that issue. As is apparent, I have concluded that he was one of the great pathfinders at a critical point in the evolution of science, not least in the field of chemistry. I am inclined to regard him as the greatest English scientist active in the period from the death of Newton (1727) to the emergence of the generation that included Thomas Young (1773–1829).

In discussing the status of Henry Cavendish with fellow American physicists, I have found that they know him best for his involvement in the first relatively accurate measurement of the gravitational constant. McCormmach has made this measurement the subject of an excellent essay, “Mr. Cavendish Weighs the World,” Proceedings of the American Philosophical Society 142.3 (September 1998): 355–66. As McCormmach points out, Cavendish’s role in the experiment was to complete the well-developed project of a close friend (the Reverend
which to advance his theory of the chemical elements at the time he did
in 1789, had it not been for the exceedingly precise experimental work
of Cavendish on the gaseous elements, not least his revelation regard-
ing the true nature of water as a compound formed of hydrogen and
oxygen rather than an element, as had been believed for millennia.
That discovery provided the special key needed to open the door to a
new world by giving Lavoisier the courage to dismiss flatly the concept
of phlogiston and to proceed with a new basis for the structure of mat-
ter. Much of great importance that Cavendish discovered would in-
evitably have come to light in the next century with the development of
electrolysis. But Lavoisier would not have been a participant after 1794,
when he was guillotined. The glory associated with the chemical revo-
lution would have gone to others. Lavoisier’s reputation as the father
of modern chemistry depends significantly on the work of Cavendish, a
scientist of different temperament but comparable stature.

Henry Cavendish (1731–1810) was born in Nice, where his mother
had gone as a convenience for her first childbirth. His father, Charles
Cavendish (1704–1783), was the third surviving son of William Caven-
dish (1672–1729), the second duke of Devonshire and head of the fam-
ily. His mother’s maiden name was Anne de Grey. She was the fourth
surviving daughter of Henry de Grey (1671–1740), the duke of Kent.
The Cavendishes and the de Greys were not direct descendants of
England’s royal families. Rather, they earned noble status by rendering
special service to the government, particularly the Crown, in times of
serious troubles through use of their political convictions, personal cour-
age, and wealth.

Charles and Anne had a second son, Frederick, who was born two
years after Henry. Unfortunately, Frederick suffered serious brain dam-
age as a result of an accidental fall at the age of twenty-one during his
final year at Cambridge University. The evidence suggests that he was
trying to repeat Benjamin Franklin’s famous experiment on the nature
of lightning with a kite during an approaching storm, and fell from an
upper window of a building. He needed special care throughout the
remainder of his life. He was relatively unproductive and outlived Henry
by two years. The two brothers were close but not intimate friends,
being of different personality. Anne died, presumably of tuberculosis.

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John Michell), who died before he was able to do so. Knowing of Cavendish’s high standards,
we can assume that the experiment benefited much from his participation.
McCormmach has also written the biographical essay on Henry Cavendish for the
I should add that I also found much valuable material in various editions of the
Encyclopedia Britannica, particularly the eleventh.
soon after Frederick’s birth, so neither of the boys really knew their mother. They were raised mainly by their father and servants.

The de Greys, who had held the title earl of Kent for eleven generations, had supported Parliament during the Cromwellian Revolution (1642–53) in which Charles I was beheaded. As a result they avoided political activity after the restoration of the Stuarts for reasons of personal safety as well as economics. Their attitude changed somewhat after the so-called Glorious Revolution of 1688 replaced the Catholic Stuart James II with his Protestant daughter Mary and her husband, William of Orange. The latter carried the title and some of the prestige of William “The Silent,” who prior to his assassination had led the Dutch portion of Flanders in its successful eighty-year struggle for independence from Spain and the Inquisition (1568–1648).

Anne’s paternal grandfather participated formally in the coronation of William and Mary, and her father, a close friend of Charles Cavendish, became an influential official in the court. In 1710 he succeeded in having his rank of nobility raised from earl to duke. (In descending order, the ranking of English nobility is duke, marquis, earl, viscount, and baron.) Unfortunately, he had no surviving male heir who could inherit the new title. The highest rank in the family reverted to that of earl.

The Cavendish family, in contrast, had played a major role in bringing about the revolution that disposed of James II, so it stood very high in both prestige and power at the time of the birth of Henry Cavendish, the future scientist. The Georges of the Hanoverian line, then successively on the throne, recognized the family as both friendly and supportive.

The structure and role of the nobility were changing markedly in England and elsewhere in Europe in the eighteenth century as a result of the expansion of political activity, and the wealth gained through various commercial enterprises, including those related to the dawning industrial revolution. Nevertheless, those who gained a noble title were expected to live by a special code that reflected the spirit of earlier times. They were expected to possess as much property as they could afford. Whatever form of city living was necessary, it was highly desirable to have at least one country estate with as much grandeur and land as circumstances allowed. Practical affairs such as the management of wealth and land were preferably left to professional advisers, while nobles devoted their attention to more gentlemanly matters such as country social life, including local sports, hunting, military service, intellectual pursuits such as writing and cultivation of the arts, and—not least—politics both national and local. They were free, indeed privileged, to serve in the House of Lords, which still retained somewhat
more than symbolic influence in the eighteenth century. It was also
appropriate to run for local office and to represent a constituency in
Parliament. As might be expected, old inherited wealth had more pres-
tige than new money, although all was welcome. It is estimated that
about two thirds of English land was in the hands of the nobility at the
time discussed here.

The second duke of Devonshire, William Cavendish, possessed great
wealth and a magnificent estate as well as influence. His son Charles,
Henry’s father, was neither very rich nor poor. He had the essentials for
the relatively modest life he expected to live. At the time of his mar-
riage he and Anne acquired a country estate in a community midway
between London and Cambridge, planning to live there while their
family matured. Following her unanticipated early death, however, he
sold the country estate and purchased a handsome town house with
adjuncts in London.

Charles took his role in politics very seriously, but developed a par-
allel and abiding quasi-professional interest in science, becoming a de-
voted member of the Royal Society in 1727 at the age of twenty-three.
Isaac Newton had died shortly before he joined the Society, so Charles
found himself encircled by individuals who had been closely associated
with the great man. From them he learned much. Laymen with such a
serious interest in science were not unusual in upper-class England as
a result of rapid changes in technology, and expanded knowledge of the
natural world due to the scientific revolution. Charles Cavendish’s con-
tributions to the Society earned him the Copley Medal in 1757, the
thirtieth year of his membership, for an essay describing a self-registering
thermometer of his own design. While his extensive service and his
prestige may have played some role in the award, his detailed, almost
professional, interest in scientific research and his native creativity
were substantial. For example, he made a careful study of the relative
values of weights and measures in the European countries that were se-
riously engaged in science. The standardization provided by the metric
system did not yet exist; it would emerge from the French Revolution.

At that time, commoners were rarely considered for membership in
the Royal Society; preference was given to the nobility. “Philosophers
of wealth” could be admitted with the expectation that they would
make a generous monetary contribution.

Charles also rendered much service to his community. For example,
he became a member of the governing board overseeing the construc-
tion of the first Westminster Bridge across the Thames, a stone bridge
that generated much controversy. He also gave help to his cousins in
matters related to drawing up or probating wills.

Henry, along with his brother, Frederick, received his primary edu-
cation at home until he was eleven. His father had attended Eton, the
famed English public school, traditionally the breeding ground for fu-
ture statesmen. Neither Henry nor his brother, however, was destined
for a career as a statesman, so their father decided to send them to a
more specialized institution. He finally settled on the Hackney Acad-
emy, a private school conveniently located two miles north of London.
While proper attention was given to the classics, Hackney also empha-
sized more modern subjects. Some of the instructors were intimately
conversant with the advancing frontier of science. Henry and Frederick
were the first members of the Cavendish family to attend Hackney, al-
though the school became popular with later generations of the family
and with other members of the English aristocracy.

Normally, students entered the Hackney Academy at the age of
seven, but young Henry was delayed until he was eleven. He then took
a special series of courses, some in the sciences, that were regarded as
essential for his needs or desires. Readily available sources do not ex-
plain this delay in entrance. Perhaps his father thought tutoring was
preferable up to that age. Perhaps the delay involved the emergence of
the prominent, essentially psychiatric, personality quirks that were to
be the hallmarks of Henry’s behavior for the rest of his life. It is quite
possible that even then he displayed an intense shyness and a strong
tendency to focus interest on science. He did not make friends easily.
Those with whom he managed to become in any way close were almost
exclusively scientists involved in work of interest to him. If a stranger
approached him to start a discussion, Henry was apt to flee before any
conversation started. He was particularly fearful of women. Unfortu-
nate was any maidservant in his household who by accident came into
his view. She was likely to be discharged immediately.

The one woman who managed to break through this barrier was
Duchess Georgiana of Devonshire (1757–1806), the first wife of the
fifth duke of Devonshire. She had a fashionable but serious interest in
science and became a reasonably close friend. Henry would actually
seek her out on occasion to describe important new developments. She
was twenty-six years younger than Henry and a beautiful woman if
one can trust the portrait by Joshua Reynolds.

Henry greatly disliked altercations. Some of the manuscripts de-
scribing his research were left unpublished because he felt they might
lead to controversy. His reaction to Joseph Banks illustrates this trait.
Banks, a naturalist and explorer who served as president of the Royal
Society from 1778 until his death in 1820, came under attack from a
group of members who were dedicated, productive scientists. They ob-
jected to his dictatorial behavior and his tendency to prefer individuals
of wealth and social standing when selecting new members, as was the
president's prerogative at the time. One might have expected Cavendish to side with the scientists. Instead, he supported Banks. He felt that such disputes were out of place in the Society, which should focus on scientific research.

In keeping with his other eccentricities, Henry paid little attention to the stylishness of his clothing as time went on, wearing garments that were out of date and often well worn, even at a time when he had become very wealthy through a special inheritance. He also refused to sit for a portrait. The only such representation of him (fig. 1) was obtained by stealth. A draftsman with artistic skill, William Alexander, surreptitiously made a sketch of his head, hat, and topcoat while he was dining nearby. The artist later added a reasonable representation of his body and the type of clothing he normally wore in his mature years.

In 1749, at the age of eighteen, Henry entered Cambridge University,
choosing Peterhouse for his college. He was the twenty-first member of
the Cavendish family to attend the university. His brother followed
two years later. Henry chose the student status known as “fellow com-
moner,” the second highest. It permitted him to do and study pretty
much what he chose, but did not tie him to the pattern of activities
followed by students who wished to make more of their nobility.

Since the memory and the works of Isaac Newton had left deep
imprints on the intellectual culture of the university, Henry absorbed
all the available knowledge of frontier physics and useful mathematics.
His command of these and other fields in his later career indicates that
he used his time reasonably well, with the help of tutors and the univer-
sity staff. The highly competitive Tripos examinations in mathematics
were just gaining prominence at that time, but, unlike the physicist
James Clerk Maxwell at a later date, he did not bother to participate,
though he probably would have done well. It is unlikely that his studies
extended very far beyond the major areas of science that were cur-
rently of interest. He did not bother to obtain an academic degree,
since he had neither the need nor the desire to become a member of the
academic profession. He left the university in 1753 to start his main
career as a dedicated scientist in the privacy of his home.

Once Henry settled back home in London, his father began to take
him along fairly regularly as an invited guest at semi-social dinner
meetings of members of the Royal Society. These gatherings, held at
private homes, inns, or private clubs, gave the young man an excellent
opportunity to mingle personally with some very productive scientists.
It gave him, too, an opportunity to become exposed to many more
diverse areas of scientific investigation than would otherwise have been
the case. As a result he became something in the nature of a scientist-
generalist, who was well aware of developments across a wide scientific
map. An important result of this form of association with the members
of the Society was his election as a Fellow on 1 May 1760, when he
was twenty-nine.

In the meantime Henry dedicated his attention to personal research,
with serious publication beginning in the mid-1760s. In starting, Henry
obtained reasonably adequate financial support through his father to
furnish a suitable laboratory in one of the structures associated with
their home in London, and to acquire the services of good instrument
makers. Eventually, however, he fell heir to an enormous fortune
bequeathed to his father by a first cousin, Elizabeth Cavendish (1701–
1779), in the early 1780s. She had married the son of a wealthy mer-
chant and died after him without issue. Apparently she admired Charles’s
and Henry’s dedication to scientific research. Henry was reputed to
have become by far the richest scientist of the times.
Among other things, Henry’s altered financial status permitted him to acquire an elegant new home in London and to rent a country estate near London. His first choice was a mansion at Hampstead, a small community north of London, which he occupied between 1782 and 1785. In the meantime, however, he found a more satisfactory alternative, also a rental, at Clapham Common just south of London. He retained it until his death.

The home at Clapham was extensively modified for experimental research and was the place where some of Henry’s most significant work was carried out. The basic features of his life changed little, however. Culturally he remained closely tied to London and the various institutions that served his interests there.

A word or two must be said about the status of the field of chemistry at this time. There was general agreement among scientifically oriented chemists that it needed to be turned into a far more exact branch of science, sloughing off much of the encrustation of traditions and mysticism that it had accumulated over the millennia through technological trial and error carried out with almost no knowledge of guiding principles. Superimposed on this was the quasi-mystical work of generations of alchemists who hoped to achieve the transmutation of elements even though they did not know what the elements were. The Greeks had proposed that the basic elements of chemistry were earth, water, air, and fire, but this offered little comfort to the scientifically oriented chemist. A key to undo the gridlock in basic understanding was needed.

At the turn of the century, a prominent German chemist, Georg Stahl (1660–1734), had proposed, in association with colleagues, that the key to the riddle lay in gaining understanding of an ingredient of nature he called phlogiston. The chemical community was prepared to go along with the concept in what might be called “a pooling of ignorance.” The only trouble was that neither he nor anyone else knew exactly what phlogiston was. Varying opinions were held on the matter. Stahl associated phlogiston with the flame of a fire, and suggested that it might be an oily by-product found in many forms of combustion. Others thought it was the heat that was generated in some chemical reactions and by frictional forces in mechanical processes. Cavendish rejected the latter view, since he believed it much more reasonable to accept Newton’s opinion that the degree to which bodies displayed heat was tied to the level of motion of their ultimate constituents, whatever they might be. Eventually he proposed that phlogiston, if it indeed existed, was hydrogen, the most basic substance he knew from his study of gases. In other words, he decided that hydrogen was elemental.

Antoine Laurent Lavoisier (1743–1794), the great French chemist, eventually (1784) rejected the concept of phlogiston. He was looking
intently for another key. Nevertheless, the concept of phlogiston became so prevalent that it dominated the vocabulary used by many chemists. Examples of their terminology, with present-day counterparts, are as follows:

- Factitious air: any gas emitted by a body
- Fixed air: carbon dioxide
- Inflammable air: hydrogen
- Dephlogisticated air: oxygen
- Phlogisticated air: nitrogen
- Nitrous air: nitric oxide (NO)

Cavendish’s research career can be divided into four major periods. His starting research in chemistry was relatively conventional, focused upon the chemical reactions and properties of some arsenic compounds and of tartaric acid, found as a solid deposit in wine vats. Research on such relatively complex compounds was obviously not aimed at seeking out solutions to the most fundamental issues of the day. He quickly changed, however, to the study of the chemistry of gases, as if deeply inspired from within, and effectively opened the field. Here he brought about the start of a major revolution in chemical thinking.

In this early work on gases, initiated in about 1766, Cavendish discovered that many gases, including hydrogen and carbon dioxide, are distinct from ambient air, and he made comparisons of their chemical and physical properties with that of ordinary air. He found that carbon dioxide is soluble to a degree in water, can quench the ability of ordinary air to sustain combustion, is commonly generated in fermentation and putrefaction, and is produced in respiration. As noted earlier, he was inclined to associate phlogiston with hydrogen, produced by the interaction of some metals with acids.

In the second period, which began toward the end of the 1760s and continued into the 1770s, he all but dropped his personal involvement in chemical research and focused on electrical phenomena.

The topic of electricity was receiving much attention everywhere as a result of the stimulus provided in the mid-1740s by the invention and evolution in Holland and Germany of the Leyden jar for storing substantial amounts of electric charge. It was in essence a large electrical condenser. Benjamin Franklin’s various experiments and theories in the mid-1740s and early 1750s, including the two-fluid theory of electricity, also provoked much attention among physicists.

During this period of Cavendish’s rising professional maturity, he perfected an experimental style based upon creating instruments precisely designed for the observations at hand, making exacting measurements, and carrying out detailed analysis that included the search for
all possible errors in measurement. Perhaps above all, he learned to think like the ideal physicist: Select for careful observation the simplest of physical systems whose properties are apt to reveal the underlying laws that govern more general cases, a tradition firmly established by Galileo. This is exemplified by his switch, while engaged in chemical studies, from the examination of relatively complex compounds to that of much simpler gases.

Benjamin Franklin, who was active in the Royal Society at the time, was much impressed with the precise working methods Cavendish developed. They served together on several of the Society’s advisory boards that attempted to resolve disputes on scientific issues. For example, he and Cavendish were members of a committee that provided advice on the best way to protect magazines that store gunpowder from being struck by lightning.

In the third period (1778–86), Henry returned to the chemistry of gases, continuing to avoid relatively complex systems. He was apparently encouraged to do so because others were adding to the work on gases he had undertaken a decade earlier. It was during this phase of his work that he opened the doorway to modern chemistry through which Lavoisier would gallop to earn the much-used title “The Father of Modern Chemistry.”

The central topic that drew Cavendish’s attention during a fourth period that started in the second half of the 1790s was the measurement of the gravitational constant that governs the attraction of two masses in accordance with Newton’s law of gravitation. His careful methods of observation permitted him to obtain by far the best available value of the period. Associated with this work was the most accurate determination of the mean density of the mass of the earth, or, as it was often popularly expressed, “the weight of the earth.” As mentioned in note 1, Russell McCormmach has made the experiment the subject of a special essay.

Beyond this he continued to keep up with the numerous, almost limitless, areas of science that interested him, offering suggestions and providing support to investigators when opportunities arose. He frequently suggested appropriate research programs to individuals of scientific bent who were undertaking extensive land or sea voyages. His concerns ranged from the large to the small. For example, he became much involved in determining the freezing point of mercury in order

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2 Considering Franklin’s connections to Cavendish in the 1760s, it is surprising that Cavendish was never elected a member of the American Philosophical Society. For a discussion of the subject, see appendix 1.
to check on reports of temperatures attained in arctic and subarctic regions with mercury thermometers. When a younger colleague, Charles Blagden, made an ocean voyage to America during the early stages of the Revolutionary War, Cavendish provided him with the means to measure the temperatures of ocean waters, including that of the Gulf Stream, along the way.

In returning to the study of gases in the 1770s, he helped the chemical community achieve entirely new levels of understanding. Fortunately, two contemporary chemists, namely Joseph Black (1728–1799), a Scot, and Joseph Priestley (1733–1804), had begun carrying out closely related research on gases in the mid-1770s, although with somewhat less emphasis on the type of precision and the sharp search for goals that Cavendish would ultimately achieve. In fact, their activities probably influenced Cavendish to return to chemistry. They provided a form of professional comradeship and inspiration for new research.

Black, a close friend of James Watt, had been well educated in chemistry during his university years and was a superb chemist. He was, however, compelled to become a physician to earn an adequate living. One of his major achievements was to focus on the properties of carbon dioxide produced in various ways, such as during the calcinations of limestone. He also discovered the latent heats involved in the freezing of water and the condensation of steam, discoveries of the first magnitude that bothered Cavendish at first since they did not seem to fit his views of the behavior of phlogiston.

Priestley did many quantitative experiments with carbon dioxide gas more or less in parallel with Black, obtaining large quantities from a local brewery. In fact, he began the marketing of carbonated water. He also obtained pure oxygen through the decomposition of red mercury oxide, and observed not only that it greatly stimulates combustion, producing brilliant flames, but that its addition to so-called “spent air,” which has lost its ability to burn a candle or to sustain life, restores these properties. The gaseous emanations from growing plants have a similar restorative effect. Actually, the prolific chemist, Carl Wilhelm Scheele (1742–1786), who carried out most of his work in Sweden, had anticipated Priestley’s work on oxygen, having found as early as 1772 that ordinary air contains two major constituents, one of which sustains combustion.

About 1782, Cavendish formed a close scientific association with Charles Blagden. Blagden, whom he had first met in 1775, had spent the period between 1775 and 1778 as a military physician in North America. He was some seventeen years younger than Cavendish, had obtained a degree in medicine at the University of Edinburgh (1765–69), and had studied chemistry under Black. He was not as capable or
brilliant an investigator as Cavendish, but was pleased to be of considerable service to the master scientist, carrying messages both at home and abroad, performing useful tasks, and giving practical advice on important issues. He also paved the way for Cavendish to make a number of journeys, particularly throughout the British Isles, to visit scientific laboratories and industrial centers. In all of this he was meticulously sensitive regarding Cavendish’s perfectionism in carrying out experiments. The arrangement endured for nearly a decade, but Blagden’s personal career eventually led him to drift off to other pursuits.

Meanwhile, Cavendish not only improved his research on the gases present in the atmosphere, but made analyses of the ratios of the main constituents of ambient air derived from many sources and different times, finding them essentially identical. Ballooning was just becoming popular at this time, so he had enthusiastic aeronauts provide him with samples from various altitudes to include in the study.

His greatest discovery with gases at this time (1781), however, was that water is a compound formed from hydrogen and oxygen, revising the opinion held for millennia that it is a basic chemical element. In an experiment in which he exploded a mixture of air and hydrogen, the English chemist John Warltire found that the weight of the residual gases was less than that of the original mixture. He attributed the loss to the weight of the emitted heat of the reaction. Cavendish concluded that some substantial error was involved, since he did not believe that heat possesses sufficient weight on the scale of interest. On repeating the experiment in 1781, in keeping with his meticulous style of research, Cavendish found that the weights involved did balance if he included the weight of a thin film of liquid produced in the reaction—a film that had been ignored in all previous work on the combustion of hydrogen and oxygen. Careful examination demonstrated that the liquid was pure water. In keeping with the views of phlogiston that he held at the time, according to which hydrogen might be that hypothetical substance, he was inclined to think at first that oxygen might be a form of water that does not contain phlogiston. At least at the moment, this seemed to fit together rather well.

It would be left to Lavoisier to make full use of the profound discovery that emerged from the experiment. While Cavendish informed a number of colleagues of his observations by correspondence and word of mouth, he did not issue a formal paper until 1784 (“Experiments on Air,” Transactions of the Royal Society of London 74 [1784]: 119–69). Fortunately, archival records supported his priority when the issue later became a matter of dispute. The discovery was so basic to the foundations of chemistry that many individuals, including Lavoisier (see note 5), claimed to be the discoverer.
It is interesting that the decomposition of water by electrolysis occurred just a few decades later, following the invention of the electric battery by Alessandro Volta (1745–1827) in 1800. Volta, incidentally, was inspired by the work of Luigi Galvani (1737–1798), who discovered a link between electrical impulses and nerve conduction in the 1780s. The composition of water could no longer have remained a secret. Lavoisier, however, would have lacked the use of that critical knowledge in the musings that led to his synthesis of the field of chemistry, without Cavendish’s early discovery.

Cavendish also found that he could generate nitric acid by exposing mixtures of air and hydrogen to the electric arcs provided by a Leyden jar. Quantitative analyses in which the ratios of the basic constituents were varied led him to the chemical formula for the composition of the acid. During these experiments he found that a component of ambient air present in a relatively tiny quantity did not enter into the reaction. Experiments carried out a century later by Lord Rayleigh and William Ramsey demonstrated that the inert substance is argon, the first of the rare gases to be discovered. This incidental observation demonstrates the great care with which Cavendish carried out his experiments.

The advancing work on gases was transporting the science of chemistry to a watershed point. Cavendish realized this in principle since he had intentionally labored toward the goal. He admitted, however, that he saw no single, relatively simple, way to clarify all the knowledge he had helped assemble. He was not without ideas. He simply had too many, and was bathed in a form of confusion linked in part to his lingering commitment to the concept of phlogiston. Lavoisier was more than a decade younger than Cavendish, much more a man of the world, presumably more flexible in imagination at that stage, and no less devoted to revolutionizing the field of chemistry.

It should be emphasized that Lavoisier led a far more complicated life than Cavendish, but with a brilliant, quick mind and much energy, he carried the burden well. Although he possessed inherited wealth, Lavoisier sought and obtained a post as tax collector under the royal government in 1768, in order to enhance his income and to become involved in public affairs. This led him not only to serve on various committees concerned with matters of tax policy, but also to enter into the analysis of the financial problems faced by communities within the country. He became involved in detailed studies of local management of agriculture or manufacturing, which were designed to reverse difficult problems. He was known on occasion to lend his own money to a community facing a poor harvest or other financial straits, while it took appropriate steps toward recovery. His successes in these endeavors led him to positions of higher and higher responsibility at the national level.
In the meantime, Lavoisier became a very active member of the Royal Academy of Sciences, contributing many papers on basic and applied science and serving on its committees. He held high standards for the admission of new members to the Academy, and probably made enemies among those he helped to exclude, including some who became powerful figures in the revolutionary governments that lay ahead.

Alongside this, Lavoisier established a chemical research laboratory at the national arsenal, mainly with his own funds. Here he carried out a combination of basic and applied researches, many of the former being replications or variants of important discoveries made by others, such as Black, Priestley, and Cavendish. This aspect of his activities kept him in close touch with the evolving frontier of the field. Early in this phase of his work he began to have significant inner doubts about the existence of phlogiston, which was taken so seriously by others. It was shrouded in a somewhat mystical aura, and no one could quite put a finger on it.

Lavoisier chose to cooperate with the revolutionary government after 1789, when France found itself besieged by foreign armies. He worked through the official committees on which he served as well as through the Academy of Sciences. Once the more radical revolutionaries took power and the country entered into the Terror, however, he became a target.

The distinguished chemist Baron Justus von Liebig (1803–1873), who entered the field of chemistry in the great period of upsurge that followed the work of Cavendish, Lavoisier, and their contemporaries, made the following comment regarding Lavoisier: “He discovered no new body, no new property, no natural phenomenon previously unknown; but all the facts established by him were the necessary consequences of the labors of those who preceded him. His merit, his immortal glory, consists in this—that he infused into the body of science a new spirit; but all the members of that body were already in existence, and rightly joined together.”† He might have added that as a result of his appreciation of his own brilliant mind, Lavoisier was something of a gadfly and opportunist.

Pierre-Simon de Laplace (1749–1827), a great scientist in his own right who had followed Lavoisier’s work in detail, made this memorable statement: “It took a moment for his head to fall. It may take a century to find another as great!”

Lavoisier’s first step, taken in 1784, was to throw the concept of phlogiston, and everything associated with it, overboard. Here he was

†This quotation of von Liebig appears in the article on Lavoisier in the eleventh edition of the Encyclopedia Britannica.
strongly supported by Benjamin Thompson (Count Rumford, 1753–1814), the American-born scientist, inventor, diplomat, adventurer, military officer, spy, and sometimes scoundrel. During his early years in America, Thompson had become so closely linked to the English colonial authorities that he had little choice but to flee to England during the American Revolution, retaining British citizenship. While serving as adviser to Charles Theodore, the elector of Bavaria, for an extended period after the Revolution, he had, among many other duties, the charge of the royal arsenal in Munich, where he found that the temperature of the guns being drilled rose more or less in proportion to the time of drilling. He wrote a definitive treatise on the mechanical theory of heat that, in addition to denigrating the phlogiston theory, opened the doors to the development of a systematic theory of thermodynamics. Eventually he was to marry Lavoisier’s widow, in what turned out to be a catastrophic union.

Next, Lavoisier accepted the principle that substances such as hydrogen, nitrogen, and oxygen are members of a large family of primary chemical elements, each of which is on a par with the others. Moreover, each element has its own characteristic physical and chemical properties, including its ability to combine with others. Lavoisier also introduced new nomenclature for elements and compounds. Cavendish tended to resent this unilateral procedure at first, partly because of the name Lavoisier gave to oxygen (“acid-former”). Cavendish knew there were acidic compounds such as hydrochloric acid that did not contain oxygen. Lavoisier’s prestige had become so great, however, that the international profession rapidly followed his proposals. The German chemists, preferring the vernacular at that time, used equivalent designations such as Wasserstoff and Sauerstoff for hydrogen and oxygen.

To provide a firm base, as well as very broad publicity, for his new views on the scientific basis of the field of chemistry, Lavoisier published a two-volume treatise (fig. 2) entitled Traité Élémentaire de Chimie (présenté dans un ordre nouveau et d’après les découvertes modernes) in 1789.
apparatus, and there is a discussion of natural processes such as fermentation and putrefaction. The treatise provides a great deal of incidental information in a way that is fairly systematic for its time. In fact, the second volume can be regarded as a compendium of basic practical knowledge for the working chemist or serious chemistry student. It was presumably compiled by a committee. There is, however, a somewhat hodge-podge quality to the books when taken as a whole. Most of his references to individuals focus on continental Europeans, although the author does mention Priestley and the research of “les Physiciens Anglois” in connection with caloric processes. The single direct reference to Henry Cavendish that I found in a reasonably careful series of readings centers about the latter’s determination of the composition of nitric acid (1: 235), to which Lavoisier takes exception. With regard to Cavendish’s revolutionary discovery that water is a compound rather than an element, Lavoisier has this to say: “Jusqu’a ces dernier tems on avoit regardé l’eau comme une substance simple, et les anciens n’avoient fait aucune difficulté de la qualifier du nom d’élément: c’étoit sans doute une substance élémentaire pour eux, puisqu’ils n’étoient point parvenus à la décomposer, au moins puisque les décompositions de l’eau qui s’opérent journellement sous les yeux, avoient échappé à les observations: mais on va voir que l’eau n’est plus un élément pour nous. Je ne donnerai point ici l’histoire de cette découverte qui est tré-moderne, et qui même est encore contestée. On peut consulter a cet égard les Mémoires de la Académie des Sciences, année 1781” (1: 87). Apparently he was unwilling to yield priority on this issue in 1789. I found no place where he was prepared to state explicitly that the combined, careful research on elementary gases by the investigators across the English Channel provided the bridge that allowed him to cross into the new world of chemistry. This quality of self-centered overconfidence in actions may have cost him his life since, like the equally brilliant
In the meantime, by 1787, Cavendish had been won over to the underlying themes of Lavoisier’s theory, including the final jettisoning of the concept of phlogiston. He remained somewhat annoyed at the single-handed way his French colleague had introduced an entirely new nomenclature for the basic chemical elements without consulting the chemical community, even though he himself occasionally used it. It would appear that Cavendish’s acceptance of the new viewpoints was influenced both by his own sound judgment, which treasured truth and reason in science, and to a degree by experiments carried out in 1787 by Martin van Marum (1750–1837), a Dutch physician-scientist. Following Cavendish’s lead, van Marum succeeded in decomposing water vapor into hydrogen and oxygen with the use of an electric arc, a procedure that resembled the one Cavendish had used to generate nitric acid, as mentioned above, and anticipated electrolytic decomposition. Incidentally, van Marum discovered ozone in a related set of experiments.

Had Lavoisier’s quick mind not rapidly solved the puzzle the chemical community faced at this climactic moment, it is quite possible that van Marum’s experiment on the decomposition of water would have enlightened Cavendish independently, and he would now be regarded as the true founder of modern chemistry.

Talleyrand, he might, possibly with some loss of face, have escaped the Terror by fleeing to America for a year or two. There he would have been lionized.

Mr. Roy Goodman of the Library of the American Philosophical Society has generously provided me with a photocopy of Lavoisier’s article dealing with the compound nature of water in the issue of the *Mémoires* of the French Academy of Sciences for 1771 mentioned in the previous paragraph. Actually, the volume was published in 1784, three years after Cavendish’s discovery of the compound nature of water. Pertinent paragraphs from it follow:

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**SUR LA FORMATION ET LA DÉCOMPOSITION DE L’EAU**

Une expérience faite par M. Macquer, en 1776 (Voir *Les Mémoires*, pages 468 & 269), & qu’il rapporte dans son *Dictionnaire*, pouvait faire supçonner qu’il se forme de l’eau dans la combustion de l’air inflammable avec l’air commun.

Au mois de Juin 1783, M. Lavoisier qui, d’après des vues fondées sur une théorie déjà confirmée par beaucoup d’expériences, avait préparé un appareil pour faire brûler dans des vaisseaux clos l’air inflammable avec l’air vital, trouva qu’il résultait de cette combustion un liquide qui n’étoit que de l’eau très-pure, & dont le poids étoit sensiblement égal à celui des deux airs employés. Il apprit alors que M. Cavendish avoit retiré de l’eau par la même operation, & peu de temps après, M. Monge, alors à Mezières, avoit, en employant un autre appareil, fait la même expérience plus en grand, & en avoit déduit le même résultat, mais d’une manière plus précise encore, & par conséquent plus certaine. Cette expérience prove que dans la combustion de l’air inflammable & de l’air vital, il se forme une quantité d’eau égal au poids de ces airs considérés dans l’état de pureté, puisque la petite quantité d’air d’autre nature qui subsiste ensuite, complète ce qui peut manquer au poids de l’eau. Rien ne se perd dans cette expérience que la lumière & la chaleur qui s’échappent au travers du vaisseau.

Il étoit naturel de conclure de cette expérience, qu’il seroit possible de décomposer l’eau, & de séparer l’air inflammable de l’air vital.

Lavoisier follows this with accounts of other experiments involving water, such as the production of hydrogen by the interaction of water with iron filings (*limaille de fer*).
It is interesting that some of Cavendish’s contemporaries were unable to make this transition to the new world of chemistry described by Lavoisier, and clung to views that were rapidly becoming antiquated.

The situation leading chemists faced in the late 1780s resembles the one brought about in 1905 by the special theory of relativity. H. A. Lorentz, Henri Poincaré, and Albert Einstein had full knowledge of the space-time transformation bearing Lorentz’s name, which left Maxwell’s equations invariant. But the first two were so steeped in Newtonian physical concepts that they were unable at the critical moment to make the grand leap achieved by the twenty-seven-year-old Einstein, namely, to see that time like space is relative. Einstein had actually wondered since student days whether the speed of light is the same in space-time frameworks that are moving relative to one another with constant velocity. Great shifts in scientific paradigms are apt to sidetrack well-established scientists.

Until he was guillotined in 1794, Lavoisier carried out extensive analytic work in his well-equipped laboratory in the French arsenal. One of his special pursuits was to reduce heavy-metal oxides with hydrogen and to form metal oxides from pure metals with the use of oxygen, thereby identifying the nature of new elements and the composition of well-known minerals.

He became much interested in silica, a common mineral in the lithosphere, but found that it is not easily reduced by hydrogen. He concluded, however, that it is probably the oxide of a very interesting element. The Swedish chemist Joens Jacob Berzelius (1779–1848) carried out the first comprehensive reduction of silica in 1823. This work led to the long unanswered question whether silicon is an insulator or a metal. Berzelius, a brilliant chemist, was incidentally one of the first of the new generation to benefit from, and pursue the consequences of, the revolution in chemistry.

When I was a student in high school in the 1920s, some chemists were still searching for new elements to fill out the few remaining gaps in Dmitry Mendeleev’s periodic chart of the stable elements, devised in 1871. Some, like technetium, were first produced with the use of nuclear accelerators. This effort climaxed in the extensive search for transuranic elements that was carried out during and after World War II by Glenn Seaborg and others.

The revolution in chemical science brought new attention to the field, attracting a great deal of professional and amateur interest. The identification of new elements and the determination of the composition of materials went on at full speed, opening new vistas and producing wonders. The effects are still very much with us as biochemists continue to extend the field in miraculous ways.
Incidentally, the collective productivity of the many amateur chemists who began to appear on the scene was not trivial.\(^6\)

Henry Cavendish’s shift from chemistry to electricity in the late 1760s was not without significant fruit. It should be emphasized that because the links between electric currents and magnetism were not yet known, he confined his study to the properties of electric charges, both static and in motion, derived from Leyden jars. Much was, of course, known about natural magnetism through the systematic study of naturally magnetic materials by William Gilbert (1544–1603), but the association between electric currents and magnetism was not revealed until early in the nineteenth century. Officially, the discovery is attributed to the Dane Hans Christian Oersted (1777–1851), who observed the effect and reported it in 1820; but the Italian scientist Gian Domenico Romagnosi (1761–1835) had discovered it as early as 1802, soon after the invention of the chemical battery permitted studies with continuous electric currents.\(^7\) Romagnosi was primarily a jurist and politician who focused much of his activity in the town of Trento in the Adige. He had, however, a deep interest in natural science. His observation was made too early, and given too little publicity, to be appreciated at the time. Oersted acknowledged his priority in 1830.

The invention of the battery also opened the field of electrochemistry in which the great Michael Faraday (1791–1867) was to take the lead.

From what he learned and discovered about electricity, Cavendish decided that it is a special form of fluid that flows easily in good conductors such as metals and poorly in insulators. The origin of the differences between the two was out of his reach. He also decided that the

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\(^6\) During the war with England, Napoleon forbade the import of many everyday commodities usually supplied by English merchants, with the hope that this would help undermine the British economy. Because sugar from the West Indies was included, the Continent was essentially deprived of this important nutrient and sweetener. A pharmacist and amateur chemist in my maternal grandmother’s ancestral town of Halberstadt, Saxony, observed that the beets being grown in the local area as animal fodder had a sweet taste. Exploration demonstrated that the quantity of sugar in the beets was sufficient to justify extraction in view of wartime scarcity. The local farmers quickly developed a mass production approach and the beet-sugar industry was born. Later in the century one of the participants (Rudolph Spreckels) carried the beet technology to California, where it formed the basis of a great corporation. Doubtless genetic versions of the beets that contained higher levels of sugar than the originals were then available. When I visited Saxony on a tour in 1997, after the fall of the iron curtain, I found that the extensive cultivation of sugar beets had continued unabated.

equilibrium distribution of the fluid in an isolated good conductor would be what we today call equipotential; that is, the body would have no transverse electric fields that would cause motion of the charge.

Since like charges repel, it was natural to ask about the exact dependence of the force upon distance. There was a chance that it varies inversely as the second power of the separation of the charges, as is the case for the attractive force associated with gravitation. Cavendish put this problem to an acid test by an ingenious method that displayed a thorough command of Newtonian physics and mathematics. Newton had demonstrated that the gravitational potential within a hollow, shell-like sphere composed of uniformly thick homogeneous material should be constant because of the special mathematical features of the inverse square law of force. Cavendish measured the potential of the field within such a hollow charged metallic sphere and, finding it to be constant within estimated experimental error, concluded that electric charges interact with a law similar to that of gravity. Apparently Cavendish prepared a manuscript describing this work for publication, but did not release it. It is also possible that the method used was over the heads of most scientists of the day when they learned of it by grapevine. In any case credit for the discovery of the inverse square law of electrostatic attraction and repulsion is commonly given to Charles Augustin de Coulomb (1736–1806), who, in the period from 1785 to 1789, carried out a much more direct investigation involving the actual forces between charged bodies. His method did have the added advantage that it provided numerical values for the force parameters involved. Today the basic unit of electric charge is appropriately designated the Coulomb.

Cavendish followed his research on hollow spheres with studies of the distribution of his electric fluid on bodies having other shapes. These experiments were to elicit special attention from James Clerk Maxwell a century later.

Cavendish also made a series of tests that gave him a semi-quantitative appreciation of what later came to be known as Ohm’s law. He charged a Leyden jar lightly to different levels and used his body as a conduit for the discharge, that is, as a source of relatively constant electrical resistance. In the process, he made estimates of his own physiological response to the pulses that passed through him. The measurements suggested something in the nature of proportionality between the potential of the jar and the current. Georg Simon Ohm (1789–1854) made an extensive quantitative study of electrical resistance around 1827, after the electric battery was invented and continuous currents were available. It provided quantitative confirmation of Cavendish’s surmise. Ohm received the Copley Medal of the Royal Society for this work in 1841. The unit of electrical resistance is named after him.
Cavendish’s final major experiment, a measurement of the gravitational constant, extended over the years 1797 and 1798. As mentioned in note 1, the method he employed was actually developed by John Michell (1724–1793), a leading geologist who died before he was able to complete the experiment. Actually, it was fairly straightforward in principle, but it undoubtedly benefited from the characteristically careful attention Cavendish devoted to detail. As noted earlier, the origin of the experiment, the apparatus used, and the background involved in its execution have been made the subject of an excellent essay by Russell McCormmach, recently published in this journal (see note 1), to which the reader is referred. The apparatus involved a horizontal bar from each end of which a small lead sphere was suspended. The bar in turn was suspended from its center by a torsion fiber to which a small reflecting mirror was attached. Two large lead balls were placed at varying equal distances from the small balls and on opposite sides of the ends of the bar so that their gravitational effect on the small balls acted in tandem insofar as the torsion fiber was twisted. The amount of rotation of the bar about its suspension was measured by determining the movement of a projected beam of light reflected from the mirror attached to the suspension. Both Michell and Coulomb apparently invented independently the technique of using a torsion fiber and attached mirror.

Previous measurements had been made by studying the deviation from the vertical of a line supporting a suspended weight placed alongside a mountain of approximately known mass density. They gave relatively crude results. In contrast, the uncertainties in Cavendish’s measurements lay in the third decimal place. Superior methods have been developed since, but Cavendish broke new ground, as was characteristic of his work. Baron Roland Eötvos (1848–1919), a Hungarian, as well as others, greatly improved on the usefulness of the torsion method in the second half of the nineteenth century. Far more precise measurements have been made since then in connection with tests of the general theory of relativity.

In 1861, the seventh duke of Devonshire, who also bore the name William Cavendish and was a direct descendant of Henry Cavendish’s grandfather, was elected chancellor of Cambridge University. He had been a brilliant student there, having won second place in the Tripos examination and the Smith’s Prize in mathematics, so he had an excellent basis for understanding science and its potentialities for remaking

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the human world. In addition, he was the leading member of the family at a time when its fortune was near its peak. In 1870 he made a decision to endow the university with the most modern laboratory for scientific research that money could provide.

Upon reviewing possible candidates for the position of director, the selection committee finally offered the post to James Clerk Maxwell after Lord Kelvin and Hermann von Helmholtz had turned it down. Maxwell was then just forty years of age and world-famous for his scientific research, not least his brilliant synthesis of the equations describing electromagnetic phenomena, which were just beginning to be understood and used world-wide. Maxwell, who was independently wealthy, had recently decided to retire to his estate in Scotland, resigning from a professorship at the University of London. He had expected to devote most of his time to research of his own choosing, although he had been willing to serve as a member of the committee that selects questions for the Tripos examinations at Cambridge.

Apparently the challenge of the new laboratory, along with his sense of loyalty to the university, caused him to abandon his decision to retire. He served as its first director until his premature death in 1879 at the age of forty-eight. As was the case with every other enterprise in which he became engaged, he threw himself into the design of the laboratory with the utmost zeal. Some research was under way by 1874 in a partially completed building. Although not nearly as wealthy as the duke, Maxwell shared in the cost of equipping the laboratory.

It is not clear why the name Cavendish rather than Devonshire came to be used in dedicating the laboratory (fig. 3), but I am inclined to view this in a straightforward way. Maxwell admired Henry Cavendish and his work enormously. The seventh duke of Devonshire was a Cavendish, deeply committed to the advancement of science, and must have been very proud of Henry’s accomplishments in the previous century. It would have been natural for the two to agree that the laboratory should honor this brilliant bearer of the family name.

I might add that Maxwell assembled all available papers dealing with Henry Cavendish’s research, and published those linked with electrical phenomena.\(^9\) The remainder was published in a general collection at a later date.\(^10\) As a further sign of devotion, he duplicated all of

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Cavendish’s electrical experiments, using more up-to-date equipment and achieving greater sensitivity. He also permitted John Henry Poynting (1852–1914) to begin to repeat Cavendish’s measurement of the gravitational constant in the Cavendish Laboratory, an experiment that was not completed until the 1890s.

There are very few laboratories in the world that can lay claim to a level of scientific productivity that even begins to approach that achieved at the Cavendish during the century in which it served its original purpose. In 1974 it was replaced by an entirely new, more flexible building situated in the suburbs of Cambridge. The very elegant original, bearing with it many of its mementos both tangible and spiritual, was turned over to other purposes.

Acknowledgments

The preparation of this limited biography of Henry Cavendish involved the cooperation of a number of individuals to whom I am deeply indebted. First I wish to thank Dr. Alexander G. Bearn, M.D., the former executive officer of the American Philosophical Society, who provided much guidance during the preparation of early drafts of the text. He was also very helpful in enlisting the support of Dr. Whitfield J. Bell Jr., who graciously collected the material for the tables shown in appendix 1. Then I must offer very special thanks to my Cambridge University friends, emeritus professors Robert W. Cahn, F.R.S., Sir Alan Cottrell, F.R.S., Sir Brian Pippard, F.R.S., and Sir John Meurig Thomas, F.R.S., for their advice. Professor Cahn sent me portions of A History of the University of Cambridge, Volume 4 (1870–1990), by C.N.L. Brooke (Cambridge University Press, 1993), which describes the expansions of the original Cavendish Laboratory as a result of both domestic and international developments. It also gives an account of the entrepreneurial talents of the seventh duke of Devonshire, who funded the original laboratory. Professor Pippard was director of the Cavendish Laboratory from 1971 to 1982, when the new building was constructed. He is deeply steeped not only in the history of the laboratory, but also in the life and times of Henry Cavendish, so he was able to offer detailed suggestions on many items in the text. He also gave me a copy of a special essay, prepared in 1990, in which he reviewed the cross-currents that affected the development of science in Britain during the eighteenth and nineteenth centuries. Dr. Thomas Lassman, then of the Chemical Heritage Foundation in Philadelphia, graciously made a detailed reading of one of the advanced drafts of the manuscript and offered countless valuable suggestions, which I have incorporated in the final text. I owe the British Museum a special debt for providing me with a copy of the sketch of Henry Cavendish shown in figure 1. Similarly, I am indebted to Professor C.W.F. Everitt of Stanford University for permitting me to copy a photograph of the inner court of the original Cavendish Laboratory from his book on James Clerk Maxwell. Rather than include a portrait of Lavoisier, I decided to obtain photocopies of the title pages of the original edition of his two-volume treatise on the new chemistry, published in 1789. Here the curator of printed materials of the American Philosophical Society, Mr. Roy Goodman, was particularly generous in reaching into the Society’s own rich archives, for which I am especially grateful. He also provided me with a photocopy of the paper in the Mémoires of the French Academy of Sciences in which Lavoisier claims to have had knowledge of the compound nature of water prior to Cavendish’s experiments of 1781. Several personal friends and colleagues, such as Professors Charles S. Slichter, Lillian Hoddeson, Robert N. Varney, Robert Weinstock, Norman Hackerman, Frederick Wall, E. L. Goldwasser, and Drs. Robert D. Hill and Marcus Olson made substantial comments. Professor Franco Bassani put me in touch with Professor Sandro

Stringari of the University of Trent, who generously provided me with an important paper regarding the experiments of Gian Domenico Romagnosi (note 7).

I am particularly grateful to our co-executive officer Dr. Mary Maples Dunn for calling my attention to the essay by Russell McCormmach on Cavendish's measurement of the gravitational constant, which appeared in this journal in September 1998 (see note 1). Although I am normally a consistent reader of the Proceedings, this item appears to have slipped by me. Finally, I owe much to my office manager, Mrs. Florence Arwade, as well as to the university librarian, Ms. Patricia E. Mackey. Among many other things, they succeeded in obtaining a complete photocopy of Cavendish's 1798 paper on the measurement of the gravitational constant. They also brought to my attention the availability of the reproduction of Lavoisier's two-volume treatise (note 5).

Appendix I

Foreign Members Elected to the American Philosophical Society between 1770 and 1810

As we have seen, Benjamin Franklin knew Henry Cavendish well in the 1760s as a result of their common interest in the activities of the Royal Society of London, and greatly admired his scientific aptitude. In consequence I was quite surprised at first to learn that Cavendish had never been elected a member of the American Philosophical Society. It then occurred to me that Cavendish achieved his greatest international fame after 1770, by which time Franklin was deeply involved in the politics of the approaching American Revolution and its aftermath. Moreover, Cavendish, because of his eccentricities, probably had very few American friends who might have nominated him.

I started with an inquiry to Dr. Alexander Bearn, who turned for advice to Dr. Whitfield Bell, a former librarian and executive officer of the Society who is deeply steeped in its lore. Dr. Bell very generously provided us with a list of foreign members elected between 1770 and 1810, the year of Cavendish's death. The list has much historical interest in its own right. First and foremost, it spans three important periods of history, namely the American Revolution, the French Revolution, and the rise of Napoleon to the peak of his power as emperor, just prior to the disastrous invasion of Russia in 1812.

Foreign Members of American Philosophical Society
Elected 1770–1810

Those whose names are followed by an asterisk (*) were elected during the American Revolution.

AUSTRIA
Jan Ingenhousz, 1786
Franz Steinsky, 1789

BELGIUM
Baron de Beelen-Bertholff, 1785

ENGLAND
Lieutenant Stephen Adye, 1772
Dr. James Anderson, 1791
William Baker, 1787
Sir Joseph Banks, 1787
Robert Barclay, 1787
Thomas Barnes, 1787
Sir Charles Blagden, 1789
Earl of Crawford, 1785
Erasmus Darwin, 1792
Sir Humphry Davy, 1810
Peter Dolland, 1772
James Ferguson, 1770
Dr. Anthony Fothergill, 1792
Dr. John Fothergill, 1770
Thomas Gibbons, 1775
John Guillemand, 1797
John Haigton, 1810
Dr. William Hawes, 1805
Dr. Thomas Henry, 1786
Sir William Herschel, 1785
Captain Samuel Holland, 1775
John Hunter, 1787
Dr. Edward Jenner, 1804
Sir William Jones, 1801
Dr. Richard Kirwan, 1786
Timothy Lane, 1772
Charles Lennox, 3rd Duke of Richmond, 1787
Dr. John Coakley Lettsom, 1787
Sir Robert Liston, 1800
William Ludlam, 1773
John H. de Magellan, 1784
Nevil Maskelyne, 1771
Colonel John Montresor, 1772
Samuel More, 1774
Edward Nairne, 1770
William Parker, 1785
Thomas Pennant, 1791
Dr. Thomas Percival, 1786
Thomas Pole, 1789
Rev. Dr. Joseph Priestley, 1785
Benjamin Thompson (Count Rumford), 1803
James Six, 1784
Alexander Small, 1773
Sir James Edward Smith, 1796
Charles Stanhope, 3rd Earl, Lord Mahon, 1774
Philip Stanhope, 2nd Earl, Lord Mahon, 1774
William Thornton, 1787
Dr. Benjamin Vaughan, 1786
George Vaux, 1787
Thomas White, 1787
Caleb Whitefoord, 1790
John Whitehurst, 1786

FRANCE
Pierre Adet, 1796
d’Angeviller, Charles C. Labillerderie, comte, 1784
d’Anémours, Charles Le Paulmier, chevalier, 1783*
Marquis de Barbé-Marbois, 1780*
Jacques Barbeu-Dubourg, 1775
J. P. Brisson de Vairville, 1789
Pierre J. G. Cabanis, 1786
Louis Cadet-Gassicourt, 1787
Antoine A. F. Cadet de Vaux, 1787
Jacques A. C. Charles, 1786 (balloonist)
Marquis de Chastellux, 1781*
Marquis de Condorcet, 1775
Dr. Jean F. Coste, 1783*
André F. de Coupigny, 1793
Antoine Court de Gébelin, 1783*
Michael St. Jean de Crévecoeur, 1789
Louis J.M. Daubenton, 1775
Jean B. J. Delambre, 1803
Antoine L.C. Destruitt de Tracy, 1806
Jean Devez, 1796
Louis E. Duhail, 1796
Pierre S. du Pont de Nemours, 1800
Aimé A. J. Feutry, 1786
Thibert Garrier, 1786 (physician to the king’s brother)
René G. Gastelier, 1786
Conrad A. Gérard de Rayneval, 1779*
Benjamin Gloxin, 1791
[Comte] Grauchain [de Semerville], 1786
Jacques M. Le F. de Grandpré, 1796
Guillaume Grivel, 1786
Comte de Guichen, 1785
Marquis de Lafayette, 1781*
Comte de La Forest, 1792
Chevalier de la Luzerne, 1780*
Duc de La Rochefoucauld d’Enville, 1786
François A. F. de La Rochefoucauld-Liancourt, 1796
A. J. F. Larocque, 1796
Comte de Lasteyrie du Saillant, 1807
Antoine Lavoisier, 1775
——— Le Roux, 1775
Jean B. Le Roy, 1773
Julien D. Le Roy, 1786
Philippe Letombe, 1802
Louis Le Veillard, 1786
Pierre J. Macquer, 1775
HENRY CAVENDISH

François A. Michaux, 1809
Médéric Moreau de St. Méry, 1789
Theodore Mozart, 1797
Nicolas Noël, 1786
Comte Louis G. Otto, 1877
A.M.F.J. Palisot de Beauvois, 1792
Guillaume T. F. Raynal, 1775
Philippe Roume de St. Laurent, 1802
Jean F. Rozier, 1775
Jean L. G. Soulavie, 1786
Jean-Baptiste Sue Jr., 1785
Jean-Joseph Sue, 1779*
Charles M. de Talleyrand-Périgord, 1796
Jean-Baptiste Ternant, 1780*
Louis Valentin, 1793
Comte de Vergennes, 1784
Comte de Volney, 1797

GERMANY
Johann F. Blumenbach, 1798
Frederick F. S. de Brahm, 1784
Lorenz Crell, 1786
J. Reinhold Forster, 1793
Friedrich A. von Heinitz, 1789
Alexander von Humboldt, 1804
Baron Hüpsch von Lontzen, 1790
Christian F. Michaelis, 1785
Johann A. Murray, 1791
Rodolph Valltravers, 1792
Franz X. von Zach, 1798
Eberhard A. W. von Zimmerman, 1794

GUATEMALA
Alexander Ramirez, 1801

IRELAND
Sir Edward Newenham, 1787
William Patterson, 1798
Robert Perceval, 1785
Charles Vallancey, 1780*

ITALY
Conte Paolo Andreani, 1792
Conte Luigi Castiglione, 1786
Giuseppe Ceracchi, 1792
Felice Fontana, 1783*
Giambattista Scandella, 1798

NETHERLANDS
Nicholas Burmann, 1791
Adrien G. Camper, 1806
Pieter Camper, 1789
John D. Hahn, 1770

John Luzac, 1791
Joseph Mandrillon, 1785
Martinus van Marum, 1806
Pieter J. Van Berckel, 1784

POLAND
Thaddeus Kosciusko, 1785
Julian U. Niemcewicz, 1798

PORTUGAL
Cypriano Freiré, 1796
Francisco de Borja Gardoquí Stockler, 1806

RUSSIA
Princess Dashkova, 1789
Johann G. Grosche, 1791
Baron von Klingstädt, 1773
Peter S. Pallas, 1791

SCOTLAND
James Anderson, 1794
Dr. James Beattie, 1786
Archibald Cochrane, 9th Earl of Dundonald, 1795
Dr. Andrew Duncan, 1774
David Stuart Erskine, 11th Earl of Buchan, 1794
Dr. William Roxburgh, 1802
Dugald Stewart, 1791
Dr. Charles Stuart, 1789
John Walker, 1790

SPAIN
Pedro Caevallos, 1804
Pedro, Conte de Campomanes, 1784
Casa Irujo, C. M. Martinez de Irujo y Martinez, Marquis de, 1802
Antonio J. Cavanilles, 1804
Joanne B. Cuñat, 1796
José J. de Ferrer, 1801
José M. de Flores, 1789
Valentin de Foronda, 1802
Diego de Gardoquí, 1789
Francisco de Gardoquí, 1789
Manuel Godoy, Prince, 1804
Francisco Peyrolon, 1801
Luis de Urbina, 1796

SWEDEN
Torbern Bergmann, 1773
Gustav von Carleson, 1795
Samuel G. Hermelin, 1785
I quote from a letter by Whitfield Bell that accompanied the list:

Here is the list of men (and one woman!) elected to APS between 1770 and 1810 that you requested. There are more names than I thought there would be.

A few comments on the elections may be in order: The relatively large number of men from Jamaica, Barbados, and Antigua is a reflection, I believe, of Dr. John Morgan’s fund-raising (for the College of Philadelphia) visit there in 1772, and of the close commercial ties between Philadelphia and the islands.

Many of the French men elected in the mid-1780s were proposed by Benjamin Franklin, especially after his return from France in 1785. Other French members, like Talleyrand, were refugees from the French Reign of Terror. Still others were French consuls, chosen, perhaps, as a pro-French sentiment among the members of the Society in the 1790s. John Vaughan used the foreign consuls, as well as his own position of consul for several small countries, to obtain and expedite gifts of the proceedings of the learned societies of the countries. (This practice continued as long as Vaughan was librarian.)

Travelers, including men who came here to judge the opportunities for investment and profit, are numerous; as, for example, Samuel Hermelin, Count Castiglione, Scandella, Niemcewicz, Brissot de Warville, Crevecoeur, La Rochefoucauld, Michaux, Beelen-Bertholf. Perhaps the sculptor Ceracchi might be included because he came here to pursue his trade. (APS owns his bust of Rittenhouse.)

Stephen Adye, judge-advocate of the British Army in America, Colonel John Montresor and Captain Samuel Holland, both engineer and surveyor, appear to be the only British soldiers elected to the Society before the outbreak of the American Revolution. General Thomas Gage had been elected in 1768.

With some allowance of time I could probably provide a descriptive word or two about most of the men. A goodly number are in DNB and Biographie Nouvelle.

Apart from the election of a number of illustrious Frenchmen, the routine election of foreign members essentially ceased during the American Revolution. Among other things, the Society did not meet between 1776 and the spring of 1779 because the British occupied Philadelphia. Franklin was apparently anxious to give special recognition to our French allies. In any event, most members
of the Society were too occupied with the problems of the Revolution to devote much attention to such elections.

Once the Revolution ended, the election of foreign members, not least Englishmen, resumed at full pace as the new nation sought to build up its intellectual ties abroad.

Some of the French elected, such as Charles M. de Talleyrand-Périgord (1796), became notable historical figures. Talleyrand fled the Terror and lived in Philadelphia between 1793 and 1795. On returning to France he became a key adviser to Napoleon during the latter’s rise to power, but fell out of favor around 1808 when, among other things, he objected to the French invasion of Spain. He and Fürst von Metternich played major cooperating roles in shaping the peace of 1815 that ended the first Napoleonic era. It is interesting that Lavoisier was elected as early as 1775, a full decade before he developed the new chemistry. This indicates that he had achieved celebrity status in France and beyond by the time he was thirty years of age. Lafayette was elected during his period of service to the Revolution.

To continue with Whitfield Bell’s letter:

In 1786, 34 persons were elected, including 22 foreigners, most of whom were French, friends or correspondents of Franklin. The same is true of many of the 21 elected in 1787. Most if not all of these foreigners were proposed by Franklin.

The few foreign members elected between 1780 and 1785 were principally French military figures (like Lafayette) or diplomatic figures like Barbé-Marbois.

I note in passing that a good many of the English members elected before 1775 were mechanics, artisans, and amateurs of science, like Dolland, Ferguson, Lane, Ludlam, and Nairne.

Sir Charles Blagden, who had served as understudy and aide to Henry Cavendish in the 1780s, was elected in 1789. Also of special interest is the election of the notorious Tory Benjamin Thompson (Count Rumford) in 1803. His role in creating the Royal Institution may have played a part in this, but he was also an excellent scientist.

The Dutch physician-scientist Martinus van Marum, who following Cavendish’s lead decomposed water with the use of electric arcs generated by Leyden jars, was elected in 1806.