1.1 HENRY CAVENDISH (1731-1810): HIS CONTRIBUTIONS AND LINKS TO ATMOSPHERIC SCIENCE

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1. INTRODUCTION

Know how to listen, and you will profit even from those who talk badly. — Plutarch (AD 46?–120)

Henry Cavendish (1731–1810) was an unusual man of unusual scientific capabilities. The immense disparity between his important discoveries and the minimal credit he received for them reflects a severe lack of the social skills needed to communicate his work to the rest of the world. Even though he likely suffered from Asperger's syndrome, Cavendish was one of the first to make detailed analyses of our atmosphere and led the way in determining the composition of air. He discovered the chemistry of hydrogen and showed that water is a compound of hydrogen and oxygen. He also performed the first determination of the gravitational constant and of Earth's density and mass by using a specially designed torsional balance.

This review the man and his contributions to chemistry and atmospheric science focuses on techniques for collecting gases above water, as described in *On Fractious Airs* (1766) and in "Experiments on Air" in 1785 *(1-3)*. Cavendish was a pioneer in atmospheric chemistry who deserves to be considered among the fathers of atmospheric chemistry.

2. EARLY YEARS

Henry Cavendish was born the son of Lady Anne Gray and Lord Charles Cavendish on 10 October 1731, in Nice, France. Both parents were descended from the Norman royal house. Lady Anne was the daughter of the Duke of Kent, while Lord Charles was the son of the second Duke of Devonshire. Another son, Frederick, was born in 1733. The family could trace its lineage in England across eight centuries and was very well connected to many British aristocrats. Because of past service to the crown in times of political crisis, the family had attained noble status. The Cavendish family was known for its collections of fine art and literature and for its buildings and architectural contributions to England.

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Lady Anne died, probably from tuberculosis, on 20 September 1733, soon after the birth of her second son. The children were raised by their father and the household staff. Lord Charles was an accomplished scientist and surely influenced his sons. He was elected to the Royal Society in 1727 at age 23 years and received the Copley Medal in 1757 for his work in developing a novel thermometer (*2*).

Young Henry was educated at home until about the age of 11 and then was sent to the Hackney School (which brother Frederick also attended). He entered the school later than the normal age of 7 years for reasons that are unclear, though shyness and difficulties in dealing with strangers dominated his behavior throughout his life. At Hackney he studied science, which was his passion.

In 1749, at the age of 18, Henry entered Peterhouse College, Cambridge University. There he became absorbed in studies of advanced physics and mathematics. His brother Frederick entered the same college two years later. Not needing an academic degree and preferring to pursue science in private, Henry left Cambridge in 1753 to dedicate his life to science in his own laboratory.

Frederick also was interested in science but had an unfortunate accident in his last year at Cambridge. He suffered a fall from a window that caused permanent brain damage, and he required special care for the rest of his life. It has been surmised that this fall occurred while he was attempting to duplicate the "kite-electricity" experiment of Benjamin Franklin (*2*). The brothers were close but not intimate friends because of Henry's personality traits (*2,3*). Frederick's handicap limited his productivity in the rest of his life, though he outlived Henry by two years.

3. CAVENDISH AND HIS ECCENTRICITIES

Henry Cavendish was a rather eccentric individual, extremely shy and reticent in his behavior. Descriptions of his symptoms and social interactions suggest that he suffered from Asperger's syndrome.

Cavendish was obsessed with science and made friends with great difficulty. He had an aversion to women and avoided strangers, often removing himself from social situations. His fear of women extended to refusing to allow housemaids in his sight. He made exceptions for individuals who shared his enthusiasm for science and or whose work in science interested him. He was able to form a relationship with Georgiana, the Duchess of Devonshire (1757–1806), the first wife of the fifth Duke of Devonshire. At 17 years of age, the Lady Georgiana Spencer, great-great-great-great aunt of Princess Diana, was famous throughout Europe because of her marriage to the politically influential Duke of Devonshire (*6*). Lady Georgiana had a fashionable but serious interest in science and surprisingly became a reasonably close friend. Cavendish sought her out on many occasions to describe important new scientific findings. Considering her youth (26 years younger than Cavendish), her notoriety, and his shyness and aversion to women, this friendship was quite remarkable (*2,6*). Not surprisingly, Cavendish never married.

Having inherited a large fortune from a cousin who apparently admired his dedication to science, Cavendish was probably the wealthiest scientist of his time (*2*). He used his fortune to pursue his scientific interests and to establish a library of note in London.

Although Cavendish was very wealthy, he paid no attention to the fashions of the period. He often wore clothes that had long gone out of style and were old and worn. His shyness led him to refuse to sit for portraits. William Alexander was able to sketch the scientist quickly in a dining establishment, without his knowledge. Cavendish would surely have fled if he had realized what was happening, and we would have no likeness of him (*2*).

Cavendish was a very quiet individual who loved being alone. A tall man with a rather soft, squeaky voice, he had difficulty speaking and often hesitated in his responses. When embarrassed or nervous, his speech was even more difficult, especially around women. His preferred to communicate with his servants by writing notes. Lord Brougham said of Cavendish that he "probably uttered fewer words in the course of his life than any man who lived to fourscore year, not at all excepting the monks of La Trappe" (*7*).

Cavendish's single social outlet was his membership in the Royal Society, to which he was elected in 1760 at age 29. The members dined together before weekly meetings. Cavendish seldom missed these meetings and was well respected in the Society for his work and knowledge of chemistry and physics.

Cavendish hated any kind of confrontation and would flee from any potential controversy or argument. If his work led him to a potentially controversial finding, he tended to not publish the results for fear of encountering negative reaction.

Cavendish was connected to Benjamin Franklin but was not made a member of the American Philosophical Society, perhaps an oversight on the part of Franklin, who respected Cavendish's work (*2*), but also perhaps because Cavendish's personality did not endear him to those outside his scientific circles.

4. CONNECTIONS TO ATMOSPHERIC CHEMISTRY

As did many of his contemporaries, Cavendish began his studies in chemistry by examining arsenic compounds and tartaric acid crystals found at the bottoms of wine casks. Such chemistry was popular, though it dealt with complex chemical mixtures that at the time were difficult to unravel. Cavendish made many key findings but published little. He had a strong tendency toward methodical, accurate measurements, not unlike Antoine Lavoisier. His interests soon turned toward studies of air, with which more definitive work could be done. *On Fractious Airs*, published in 1766, had a profound effect on a number of other researchers in the chemistry community. Priestly and Lavoisier performed similar experiments. Cavendish made a number of key studies of gases during the 1760s and early 1770s before turning his attention to electricity. The combination of experience with electricity and the chemistry of gases led to his significant contribution "Experiments on Air" (*1*).

To his credit, Cavendish was among the first to perform key experiments on carbon dioxide (fixed air) and to recognize hydrogen, which he called inflammable air, as a separate chemical compound. Through very precise measurements he found that a constituent in air remained when nitrogen and oxygen were removed. More than a century later, this would be shown to be argon, a finding that led to characterization of the inert gases.

Helped by his wealth, Cavendish was quite inventive in developing instruments for trapping gases and determining their densities. He used these instruments to demonstrate that hydrogen was quite different in density from other constituents of air. He also made some of the first determinations from aloft of the composition of air, showing that samples collected from a balloon had the same ratio of nitrogen to oxygen as those taken at the ground. His methods ranged from collecting gases above water (1766) to using electric sparks to examine the chemistries of components of air (1785) (*1,2*).

Cavendish demonstrated the production of nitric acid from electric spark interactions with nitrogen and oxygen. Similar experiments showed that oxygen and hydrogen combine to form water. A question of credit for this discovery arose when James Watt obtained similar results at about the same time. The problem resulted from Cavendish's failure to publish his findings. His work on heats of solution was probably withheld from publication to avoid competition with Joseph Black. Cavendish's avoidance of conflict often made him reluctant to publish his results, even when they clearly predated similar work of others.

5. INTERESTS IN ELECTRICITY, METEOROLOGY, AND GRAVITY

Cavendish had considerable success in the area of electricity. His unpublished work shows that he had observed key “laws” in electricity whose discovery is credited to Coulomb, Faraday, and Ohm. Cavendish was very interested in meteorology and other sciences as well. He worked to develop and use thermometers. His interest in electricity in the form of lightning led to interactions with Benjamin Franklin. In this area, he worked to protect gunpowder stores from lightning strikes.

Cavendish’s efforts to determine the gravitational constant in collaboration with the geologist John Michell are renowned. The two used a torsional balance and mirror with lead balls to evaluate the small gravitational forces. Their very accurate measurement was not improved for more than a century.

6. THE LEGACY

Cavendish died on 24 February 1810, at the age of 78, alone at his home at Clapham Common. He left his fortune to a favorite cousin, George, rather than funding science. The Cavendish Laboratory at Cambridge was established in 1871 by William Cavendish, the seventh Duke of Devonshire, who was then chancellor of Cambridge University. James Maxwell, the first director, was a great admirer of the work of Henry Cavendish. Had William Cavendish not decided to give the laboratory the family name, it might have been the Devonshire Laboratory (*2*).

7. CONCLUDING REMARKS AND LESSONS LEARNED

“*O wad some Power the giftie gie us to see oursels as ithers see us!*” said Robert Burns in his poem “To a Louse, on Seeing One on a Lady's Bonnet, at Church,” 1786.

Henry Cavendish was clearly a dedicated scientist and a genius who actively pursued experimental science for 60 years. Every area that he addressed, from chemistry to electricity to the physics of small forces, was approached with great care and thoughtfulness. Though his place in the history of science is well established, he often has not been given credit for findings that predated results of others who published more diligently and expressed themselves more fluently (*2*).

Clearly, Henry Cavendish was a significant contributor to atmospheric chemistry and to the chemical revolution of Lavoisier (*2*). However, if he had overcome his eccentricities and published his findings more effectively, he would occupy a far more prominent position in the history of science.

Cavendish’s scientific peers were fewer than they would be today, and his wealth allowed him to develop and finance his work independently, with few restrictions. Today, someone with his limited communication skills would have difficulty making such a contribution. With the current large number of scientists, competition for funding, and proliferation of journals and scientific media, researchers must communicate well to be productive and pass their ideas forward to the future.

Henry Cavendish teaches us that just doing science is not sufficient. We must pass our knowledge to the community if it is to be of benefit. Cavendish was a quiet, solitary man of great intellect who made significant contributions. It is sad that he was not able to communicate all of his triumphs and share that wealth more effectively. We as modern-day scientists must recognize that publishing is as important as doing our research. Communications with our colleagues and interactions with society are key to the advancement of science and the application of new technologies for the betterment of mankind.

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