1776 BROOKHAVEN BULLETIN 1976

Bicentennial Issue

July 9, 1976

Science In Seventy-Six

The events surrounding 1776 had a profound effect on the development of science in the emerging nation. The ties to England which ensured support by the church, crown, established societies and academies were cut. To make things even more difficult, the rampant nationalism meant foregoing the advances being made in Europe to start on a fresh and independent path. It took a long time to re-establish those international connections so necessary to the republic of science.

The modern era of science was barely a century old at the time of the revolution. The influence of Francis Bacon (1561-1626) was everywhere apparent. His "The unassisted hand and the imagination left to itself possess little power" came out as "knowledge is power." He had been inspired by discoveries of, and in, the New World. What new plants, animals, natural features and resources might be found there? Both before and after 1776 his legacy of utility and pragmatism was felt.

In the century before 1776, there was a growing intercourse between natural historians in the colonies and their brethren in England and on the Continent. Large quantities of plant materials, seeds, rock specimens were sent to Europe for classification. In all of Europe, the best preparation for the new experimental philosophy was in the medical schools – Edinburgh, Padua, Leyden – where botany, chemistry, and comparative anatomy were taught. By contrast, the universities were the centers of orthodoxy and scholasticism. It was in the societies of sciences that the new inquiries and discoveries were debated, discussed, and approved.

The Puritans proved to be a positive influence on the pursuit of science in America. Cotton Mather as well as Ben Franklin and David Rittenhouse (who observed the transit of Venus in 1769) were members of the Royal Society of London (1662). The young colony, in sum, was well in tune with all aspects of the Enlightenment and, for better or worse, unencumbered by the older, established, entrenched traditions and philosophies. The mood was set by Franklin in a remark made to his wife about his barely escaping shipwreck off the coast of Falmouth on a voyage to England: "Perhaps I should on this occasion vow to build a chapel to some saint; but . . . if Iwere to vow at all, it should be to build a better lighthouse." He was echoing the view held a century earlier by Hooke in describing the business of the Royal Society as "to improve the knowledge of natural things and useful arts, manufacturers, mechanic practices, engines and inventions by experimentation."

The Declaration of Independence had the effect of reinforcing these practical aspects of the scientific revolution. If, in a democracy, everyone had to earn a living, there was little room for leisured speculation supported by a sympathetic patron. This certainly promoted the business of the practical arts, but suppressed the business, equally important to science, of theorizing. Franklin wanted to be remembered for the invention of the lightning rod, not his much more important theory of electricity as a single fluid. To be independent meant the loss of scientific instruments from Europe, a turning away from education in Europe, the slow painful process of doing everything from scratch. It was as late as 1863 before our own National Academy of Sciences was formed and, characteristically, it was expected to provide advice to the Federal Government (then in crisis during the Civil War).

The events of some 200 years ago have been stamped indelibly on science in the United States. The practical turn of mind, the expectation of ultimate utility, the acceptance of science during crisis remain. We became pragmatists, inventors and artisans, rather than natural philosophers.

—R.C. Anderson

This etching, known as "The Dreams [or Sleep] of Reason" is one in Francisco Goya's *Los Caprichos* series (1796). Goya's own caption for the etching can be translated: "Imagination deserted by reason creates monstrosities. United with reason, imagination gives birth to great marvels and true art."

The State Of The Art Two Hundred Years Ago

Physics

by R.M. Sternheimer

The eighteenth century was above all the Age of Enlightenment; the spirit of this century was one of scientific inquiry. Important advances took place in the field of classical mechanics, both of a particle and of an extended structure; these advances went considerably beyond the theories of Newton, whose *Principia* had been published in 1687. In the field of light and optics, the Newtonian optics were considerably extended and some mistakes or shortcomings in his work were corrected. The field of sound and acoustics and the phenomena involving heat were also considerably extended and quantified.

While the preceding subjects showed a sort of continuous development from the 17th to the 18th century, the sciences of electricity and magnetism were really initiated only in the 18th century, and it was not until the latter half of the 18th century that quantitative measurements of the electric charge on a body and of the forces between charges were made. The foremost physicists (or "natural philosophers," as they were then called) in these fields were Benjamin Franklin (1706-1790), Henry Cavendish (1731-1810), and Charles Augustin Coulomb (1736-1806).

In order to discuss in some detail the contributions to the science of classical mechanics, five scientists must be mentioned. In the early part of the century, Pierre Louis Moreau de Maupertuis (1698-1759) and Jean Le Rond d'Alembert (1717-1783) made substantial contributions. Maupertuis introduced the Principle of Least Action in 1744, which succeeded in combining Newton's law of propagation of light with Snell's law of refraction in one simple extremum law.

In 1760, Leonhard Euler (1707-1783) published a very important treatise on the mechanics of solid, extended bodies. For every solid, Euler defined a center of mass, also called center of gravity. He also defined the moments of inertia of a solid body about a fixed point.

In the latter part of the eighteenth century, the two outstanding physicists in the field of classical mechanics were Joseph Louis Comte de Lagrange (1736-1813) and Marquis Pierre Simon de Laplace (1749-1827). The principal achievement of Lagrange's work was the publication in 1788 of his *Mécanique Analytique* (Analytical Mechanics). Lagrange related all problems of statics to the principle of "virtual work" (or "virtual velocities," as he called them). The elegant method of multipliers was introduced in this work; they are still widely used today and are called Lagrangian multipliers. Lagrange's most celebrated achievement was the deduction of the so-called Lagrangian equations.

The work of Laplace belongs more properly in the realm of mathematics. He was one of the founders of the theory of probability and made many contributions to mathematical and physical astronomy. Laplace's equation (1785) for the potential V in the region outside the distribution of masses is well-known. His *Mécanique Céleste* (Celestial Mechanics) was published over a period of 26 years (1799-1825).

We should also mention that Jean Bernoulli (1667-1748) and his son Daniel Bernoulli (1700-1782) made important contributions to the beginning science of hydrodynamics, to which D'Alembert and Euler also contributed prominently. Alexis Claude Clairaut (1713-1765) and Maupertuis measured the polar flattening of the earth during an expedition to Lapland in northern Sweden (1736-1737). Another French expedition to Peru (1735-1744) confirmed these findings.

The expeditions to Lapland and Peru, led directly to the definition of the meter as one 10-millionth of the meridian of the earth extending from the pole to the equa-

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Medicine

by Eugene P. Cronkite

Two hundred years ago medicine was primitive and pathetically painful. Anesthesia was grog, laudanum, thongs and four strong men. With few exceptions, the medical treatment of the day was to purge with calomel and/or relieve the patient of a few pints of blood until he was so weak he stopped complaining. After all, disease was God's will.

Surgery was primarily amputation for gangrene, crushing and war injuries. The skill of a surgeon was measured by the rapidity of the amputation. The same scalpel was used to incise abscesses and for clean surgery. Little wonder infection almost always followed surgical intervention. The discovery of bacteria was several decades away and germ causation of disease, even further.

The "Father of French surgery," Ambroise Paré, replaced the use of boiling oil and redhot cautery to staunch the flow of blood from amputations with simple ligatures. Gunshot wounds had been routinely treated with boiling oil to drive out the poisons until Paré ran out of oil during one battle and applied simple lotions to the wounds. Much to his surprise, the following day the wounded soldiers treated without boiling oil were comfortable and their wounds healed much better. Through this simple stroke of luck for mankind, Paré made a tremendous advance in the treatment of injuries. Serendipity has played a big role in medical advances.

Sir Charles Blagden (1748-1820) made some remarkable observations on the ability of the body to withstand dry heat. At the age of 26 he described the importance of perspiration for maintaining the constancy of body temperature. The cooling effect of evaporation was proved by covering a vessel of water with a layer of oil, which caused it to boil when placed in a warm atmosphere; otherwise the temperature of the water would not rise above 140°, even though the atmosphere was raised to 260° (Fahrenheit). Blagden also observed the effect of salt in raising the boiling point of water and that the depression of the freezing point of water by inorganic salt is proportional to the amount dissolved.

Stephen Hales (1677-1761), impressed by the demonstration of the circulation of blood by Harvey and aware of pressure relationships in hydraulic systems, decided to avail himself of three mares that were declared unfit for military service. Said horses were cast onto the ground and bound fast to the gate. A glass tube was inserted into the jugular vein and the pressure of venous blood was measured as it varied with respiration and physical straining. Then, to measure the arterial pressure, a brass pipe was connected to the windpipe of a goose and this to a 13-foot long glass tube. The windpipe, being flexible, substituted for rubber tubing not yet available. Hales observed the initial arterial pressure and its progressive decrease with several hemorrhages. He described shock and death when the pressure in the artery fell to two feet. In between his duties as curate of a parish, Hales continued his studies on circulation in live dogs and demonstrated the first pharmacological effect of brandy, warm and cold water, decoction of oak bark, and other drugs of the day on capillary contraction and relaxation. Being trained in Newtonian physics and mathematics, he then made many calculations on the velocity of blood flow and the diameter and number of blood vessels, which are surprisingly close to what is known today.

Alexander Philip Wilson (1770-1851) was an erratic Scottish genius and a highly successful practitioner in London. He extended the studies of Hales, demonstrating the neurological control over blood vessels. He also introduced a form of anesthesia to physiological research by immersing a frog

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Chemistry

by William Rubinson

Just during the period of the American Revolution the ideas and language of chemistry were transformed suddenly and completely from a compound of ancient error, newer error, and a haphazard nomenclature, to a recognizably modern interpretation of chemical facts and the modern systematic chemical nomenclature. It is now commonplace to call this tranformation "The Chemical Revolution," as it was in a book published in 1890: *La révolution chimique: Lavoisier* by Marcelin Berthelot, a man eminently qualified to make such a judgment by virtue of his outstanding work in organic synthesis and physical chemistry, and his classic studies in the history of chemistry.

By an entertaining coincidence the dates of the opening and the culminating events of the two Revolutions, American and Chemical, correspond exactly. In 1775, the year the embattled farmers fired the shot heard 'round the world, Joseph Priestley (1733-1804) reported his experiments showing that "atmospherical air is not an unalterable thing," and thereby exploded the belief accepted as a fact during the whole of the preceding 2100 years, that air is an element. And 1789, the year of George Washington's first inaugural, saw the publication of the chemical treatise *Traité élémentaire de chimie* by Antoine Laurent Lavoisier (1743-1794), a book that, as Partington remarks in his *Short History of Chemistry*, "reads like a rather old edition of a modern textbook," whereas no previous book on chemistry is intelligible to a present-day chemist without special study.

The man who deservedly gets the greatest credit for the Chemical Revolution is Lavoisier.

Lavoisier and his wife. Painting by Jacques Louis David.

The magnitude of what the Chemical Revolution accomplished cannot be appreciated without some knowledge of the pre-revolutionary chemical theory, only the barest sketch of which can be given in this very short article.

Chemistry in the early years of the 18th century was only beginning to free itself from the spirit of alchemy, an art 2000 years old, whose grand aim was the discovery of the Philosopher's Stone, a kind of catalyst that could transmute base metals into gold, and also, perhaps, prolong life. Its underlying ideas were a confused mixture of Greek philosophy and occult Mesopotamian religions. These ideas had come down through the ages with little change. The influential chemists at the turn of the 18th century all believed in alchemy, even the great Robert Boyle (1627-1691), an excellent experimenter and author of *The Sceptical Chymist* (published in 1661, second edition 1680), whose epitaph is said to read "Father of Chemistry and Uncle of the Earl of Cork."

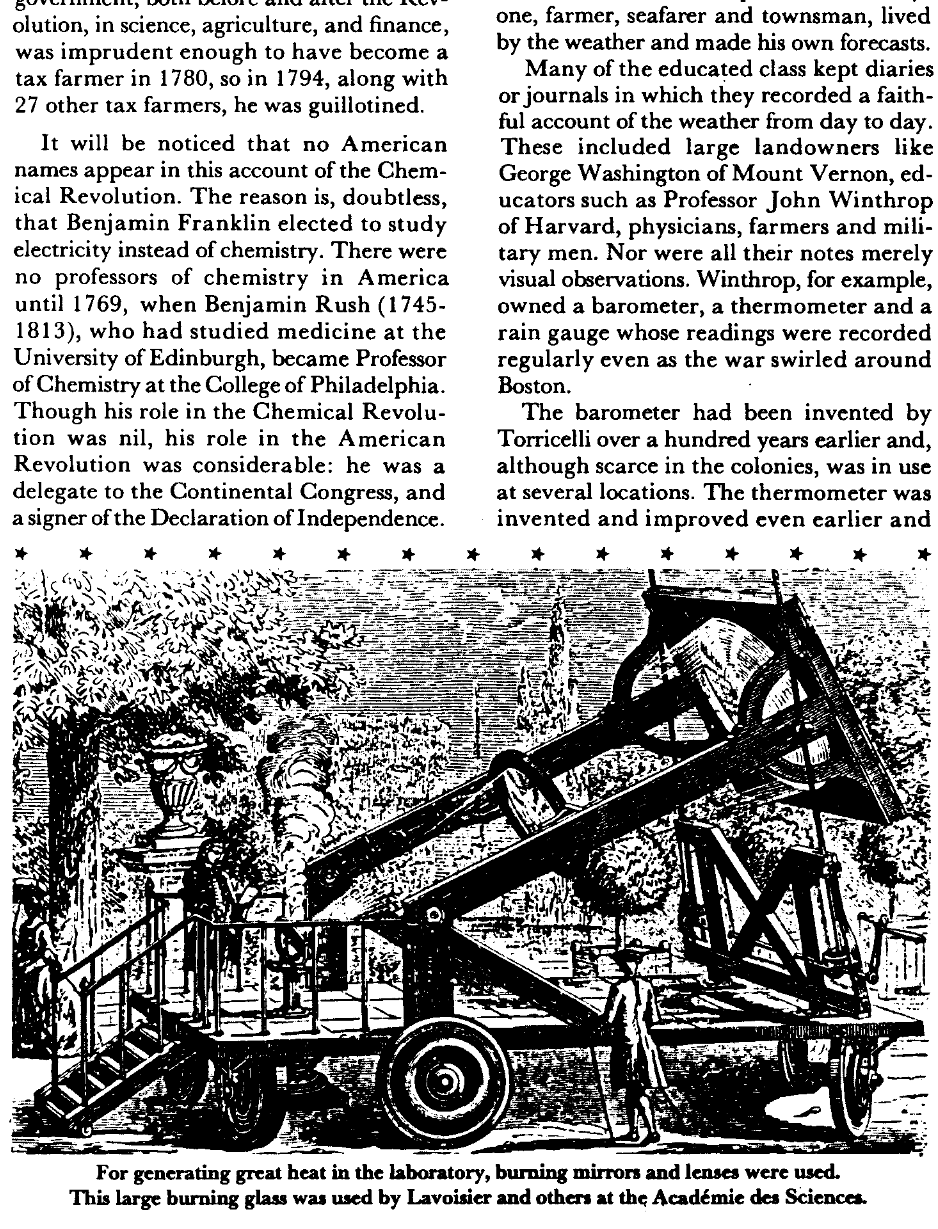
What remained of alchemical theory in the 18th century was the ancient Greek idea that all matter is composed of four elements: earth, water, air, and fire. To this was added a new, curiously inverted theory of combustion, the phlogiston theory, popularized by the German chemist Georg Ernst Stahl (1660-1734).

Phlogiston is effectively "anti-oxygen"; where we say that a body burning in air consumes oxygen, the phlogistonists said it emits phlogiston. The adoption of the phlogiston theory by the chemists of the time must strike the modern reader as simply perverse. Not only were they blind to the clear implications of their own fine experiments, but the correct interpretation was available to them in all but explicit form in the writings of their 17th century predecessors, Robert Hooke (1635-1703) and John Mayow (1641-1679). For more than half a century, despite a rapidy increasing accumulation of facts obtained by increasingly sophisticated experiments, and during a time when mathematics and mechanics were developing at a stupendous rate, this absurd theory maintained its spell over all chemists. Priestley, the discoverer of oxygen himself, called the gas he had discovered "dephlogisticated air" (here "air" meant "gas"), which in our terms is "anti-anti-oxygen," i.e., an odd way of saying "oxygen." He remained a strong advocate of the phlogiston theory to the time of his death in 1804, long after it had been abandoned by all but a few diehards.

It was Lavoisier who broke the spell of phlogiston, in 1785, when he said that phlogiston was an unnecessary hypothesis. After the publication of his *Traité élémentaire de Chimie* in 1789, phlogiston and the last lingering remnants of Aristotle's theory rapidly disappeared from chemistry. In this book Lavoisier emphasized the necessity for quantitative experiments based on the law of conservation of matter, he explicitly stated the modern experimental definition of "element," he used modern chemical nomenclature, and he gave a list of 33 elements, including heat and light, 23 of which are correct. All this provided a sound, but far from complete, basis for the further development of chemistry. What were lacking were the indispensable fundamentals of chemistry: the laws of constant and multiple proportions, and atomic theory. These were soon forthcoming. The law of constant proportions was stated by Joseph Louis Proust (1754-1826) in 1799, and atomic theory was put forth in 1803 by John Dalton (1766-1844) who, in seeking experimental verification of his theory, discovered the law of multiple proportions.

All this splendid development of chemistry was in the main the work of English and French chemists during a period when their respective countries were at war with each other, first in the war of the American Revolution, and then in the wars of the French Revolution. They carried on their work little influenced by the great political events taking place about them, except for Priestley and Lavoisier, into whose lives the French Revolution intruded drastically. Priestley's house and laboratory in Birmingham were sacked in 1791 by a mob that suspected him of sympathy with the French Revolution, and he felt impelled, in 1794, to follow his sons to America, where he died in 1804. Lavoisier, whose extraordinary career included great services to his government, both before and after the Revolution, in science, agriculture, and finance, was imprudent enough to have become a tax farmer in 1780, so in 1794, along with 27 other tax farmers, he was guillotined.

It will be noticed that no American names appear in this account of the Chemical Revolution. The reason is, doubtless, that Benjamin Franklin elected to study electricity instead of chemistry. There were no professors of chemistry in America until 1769, when Benjamin Rush (1745-1813), who had studied medicine at the University of Edinburgh, became Professor of Chemistry at the College of Philadelphia. Though his role in the Chemical Revolution was nil, his role in the American Revolution was considerable: he was a delegate to the Continental Congress, and a signer of the Declaration of Independence.



For generating great heat in the laboratory, burning mirrors and lenses were used. This large burning glass was used by Lavoisier and others at the Académie des Sciences.

Instrumentation

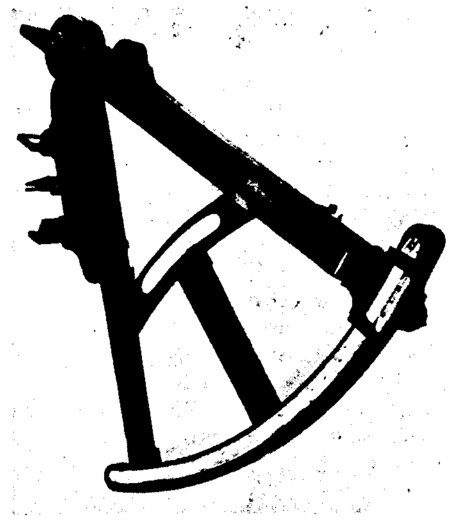
by Robert L. Chase

The status of scientific instrumentation technology at any time reflects both the needs of the community and the techniques available to the instrument designer. By the end of the 18th century, mechanics and optics had reached a fairly high level of sophistication. Electricity, on the other hand, was still in its infancy. Agriculture was still the dominant economic activity, but trade and navigation were becoming increasingly important.

It is not surprising, therefore, that meteorological instrumentation was already highly developed. The barometer had been invented by Torricelli in 1643, alcohol thermometers had been in use since the 1650's and Fahrenheit's calibrated mercury thermometer had arrived in 1714. A variety of hygrometers, rain gauges and wind direction and velocity indicators were in current use.

Instrumentation for navigation was in sufficiently good shape to make ocean voyages reasonably secure. The quadrant (Hadley, 1731), later to be modified into the sextant, made latitude observation, even from the deck of a rolling ship, quite accurate, and with the advent of the first temperature compensated ship's chronometer (Harrison, 1761), longitude could be reckoned to better than half a degree after six weeks at sea.

Optical instruments were being rapidly improved towards the end of the 18th century. Compound microscopes with two-lens eyepieces had been in use since before 1700, but it was not until 1813 that achromatic lenses were introduced. A 48-inch reflecting telescope was in operation in 1789. By the end of the century, accurate dividing engines were used to produce theodolites for



English Hadley quadrant, c. 1780.

land surveying which were nearly as good as those in use today. Newton had split sunlight into its component colors with a glass prism in 1664;however, it was not until 1814 that Fraunhofer added a narrow entrance slit and demonstrated the first dark spectral absorption lines.

Electrical instrumentation before 1800 was relatively primitive. Some work in electrostatics had been done before the 18th century and a number of high voltage electrostatic generators existed. The Leyden jar, the first electrical capacitor, appeared in 1745 and made it possible to store electrostatic energy. However, it took the galvanic pile of Alessandro Volta (1803) to get electricity moving and stimulate a demand for new ways of measuring and using electricity. Until that time, there were really only two electrical instruments – the legs of a freshly killed frog (Galvani, 1786) for detecting low voltages and Abraham Bennett's gold leaf electroscope (1787) for the high voltage range.

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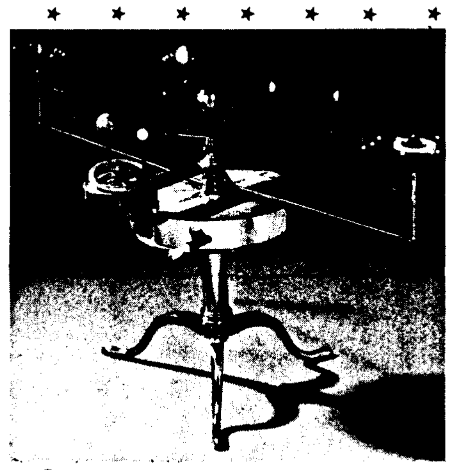
Meteorology

by Gilbert S. Raynor

Three days before putting his signature on the Declaration of Independence, Thomas Jefferson walked into a Philadelphia shop and purchased his first thermometer. A week later, he bought a barometer, further proof that not all his thoughts were on politics and war, even in those critical days. From this simple account, we can infer certain facts about meteorology 200 years ago. The sophisticated science we know today did not exist but meteorological instruments were in use. The public would have to wait nearly another century before the invention of the telegraph would make weather forecasts possible but everyone, farmer, seafarer and townsman, lived by the weather and made his own forecasts.

Many of the educated class kept diaries or journals in which they recorded a faithful account of the weather from day to day. These included large landowners like George Washington of Mount Vernon, educators such as Professor John Winthrop of Harvard, physicians, farmers and military men. Nor were all their notes merely visual observations. Winthrop, for example, owned a barometer, a thermometer and a rain gauge whose readings were recorded regularly even as the war swirled around Boston.

The barometer had been invented by Torricelli over a hundred years earlier and, although scarce in the colonies, was in use at several locations. The thermometer was invented and improved even earlier and



Orrery (a planetarium) by Dudley Adams, late eighteenth century.

apparently was quite widely used by the time of the Revolution. Wind vanes probably topped nearly every barn, and Jefferson a bit later anticipated modern practice by installing a remote indicator inside his home. Thus, the age of quantitative measurement had begun.

So also had the theoretical basis of meteorology. As early as 1696, Hadley formulated a theory of the general circulation of the earth's atmosphere, which was revised by Halley in 1735. Neither was completely correct but, like many modern theories, served as working models for further research. The equations of motion on which modern meteorology is based were formulated by Euler and Lagrange in the 18th century.

Benjamin Franklin, through widespread correspondence, had discovered that storms don't just form and die out in place as previously thought but move. His famous kite experiment in 1752 had identified lightning with that recently discovered scientific curiosity known as electricity. During his several voyages across the Atlantic, he measured ocean temperatures, plotted the course of the Gulf Stream and observed its effect on the weather.

Thus, bits and pieces of data were accumulating, understanding of the complex nature of the atmosphere was increasing slowly and the foundations of meteorology were being laid. It took nearly a century more before new means of communication made fast dissemination of observations and forecasts possible and another half century before the modern theory of fronts and air masses placed seemingly unrelated facts into an orderly framework. However, these advances would not have been possible without the intellectual curiosity of those early natural philosophers who pioneered the slow and difficult journey towards understanding our atmosphere, a journey which is not yet complete.

Engineering

by Ray Tessmer

The origin of the term engineering lies in the Middle Ages. About 200 A.D., a Latin historian referred to an early military battering ram as an *ingenium*, an invention or product of genius. The word "engin" thus came into use to describe "engines of war." Some thousand years elapsed, however, before the man who devised an "engin" was referred to an *ingeniator*, or engineer. Distinction of civil engineering from the work of architects and military engineers was made about 1750 by the Englishman, John Smeaton. He was the first to adopt the title civil engineer.

Engineering in the 18th century was a *practical* art, not yet married to knowledge of natural science. The architect-engineer confined his activities largely to the planning and design of the more permanent, primarily public structures and works required by man. Contact with manufacturing and industry was brought about by the Industrial Revolution in Britain. The 18th century ancestor of the mechanical engineer, however, was the practical millwright – the applicator of water mills, windmills, and the then new technique of steam power. Mining, long an independent, highly specialized practical art, was not to join the engineering family until the 19th century, along with mechanical, chemical and electrical engineering.

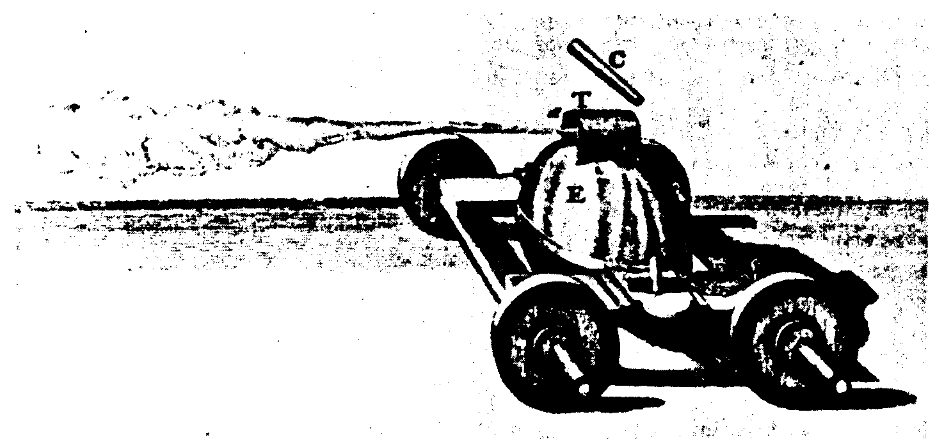
Machinery was needed most for the pumping of water. An English military engineer, Thomas Savery, constructed the first practical steam pump (1698), and it was immediately applied to the problem of mine drainage. Further improvements by Thomas Newcomen and John Smeaton reduced fuel consumption, but these single-acting engines were not well-suited for providing rotary motion and were, thus, mainly used for pumping. Early advances in mechanization also occurred in the spinning and weaving processes with John Kay's fly shuttle (1733) and James Hargreave's "spinning Jenny" (1770), named after his daughter.

Engineering advances were often tied to advances in tools and instruments. Thus, canal and lock construction was dependent on the telescopic sight and level bubble; James Watt's development of a steam engine with separate condenser, on Wilkinson's invention of an accurate boring mill for large diameter holes (1774); and reduction of materials in buildings, on Gauthrey's use of a testing machine to provide information on strength of materials (1770).

When the 13 colonies declared their independence, they had essentially an agrarian-based economy. The British mercantile system had deprived them of an industrial underpinning, technical know-how, and a supporting infrastructure (banking, finance, etc.). The hand tools of local craftsmen were all that were available. Small, localized industries such as iron and copper mining, iron mills and forges, cooperages, sawmills, and grist mills had to be powered by wind, falling water, animals, or man.

Fortunately, three of our founding fathers – Franklin, Jefferson, and Washington – actively furthered scientific inquiry and technical innovation. Most clearly, Benjamin Franklin had shown the way with his pioneering experiments with electricity and his stimulation of institutionalized scientific studies and encouragement of individual inventors. Likewise, Thomas Jefferson's penetrating mind occupied itself with a host of scientific and engineering matters from archaeology to submarines to introduction of the cork oak tree.

The dominant figure on the American scene, George Washington, personally helped give birth and impetus to numerous inventions. He plainly saw that the country needed to build its industrial capabilities if it were to become self-sufficient and competitive with England and France. Toward this end, one of his first priorities as President was to help set up a patent system. His own inventive instincts lay in the direction of agricultural devices, and besides designing several drill plows for planting grain and seed, he granted Eli Whitney's famous patent for the cotton gin in 1794. Some of Washington's less successful promotions included David Bushnell's submarine called the "American Turtle," James Rumsey's paddleboat device, and Jacob Isaack's proposed method for distilling drinking water from seawater. Another famous revolutionary, Paul Revere, built

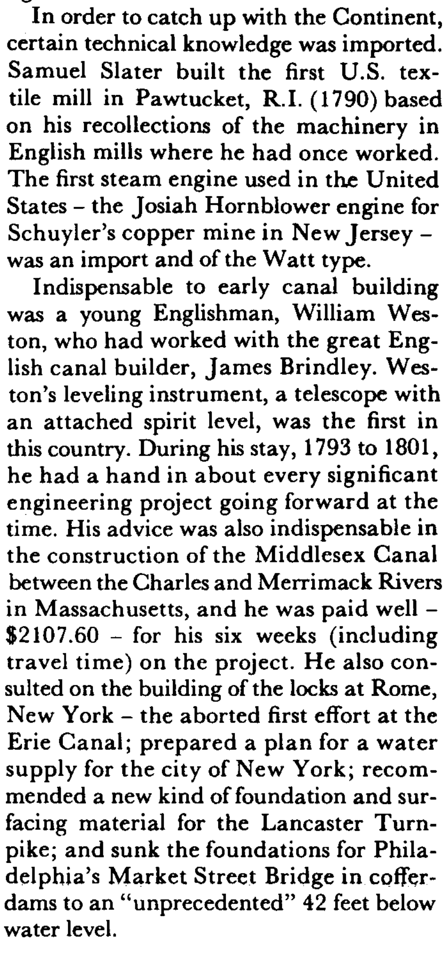


'Jet engine' driven by a jet of steam, and illustrating Newton's third law of motion concerning action and reaction of bodies. From *Mathematical Elements of Natural Philosophy, confirm'd by Experiments*, London, 1747.

the country's first copper sheet mill at the age of 65.

In order to catch up with the Continent, certain technical knowledge was imported. Samuel Slater built the first U.S. textile mill in Pawtucket, R.I. (1790) based on his recollections of the machinery in English mills where he had once worked. The first steam engine used in the United States – the Josiah Hornblower engine for Schuyler's copper mine in New Jersey – was an import and of the Watt type.

Indispensable to early canal building was a young Englishman, William Weston, who had worked with the great English canal builder, James Brindley. Weston's leveling instrument, a telescope with an attached spirit level, was the first in this country. During his stay, 1793 to 1801, he had a hand in about every significant engineering project going forward at the time. His advice was also indispensable in the construction of the Middlesex Canal between the Charles and Merrimack Rivers in Massachusetts, and he was paid well – $2107.60 – for his six weeks (including travel time) on the project. He also consulted on the building of the locks at Rome, New York – the aborted first effort at the Erie Canal; prepared a plan for a water supply for the city of New York; recommended a new kind of foundation and surfacing material for the Lancaster Turnpike; and sunk the foundations for Philadelphia's Market Street Bridge in cofferdams to an "unprecedented" 42 feet below water level.



Benjamin Franklin's discovery of the value of the lightning conductor led to all kinds of extravagances. A member of the Académie des Sciences, went so far as to invent a portable lightning conductor built into an umbrella.

In other areas original technology was developed entirely by Americans. The American system of interchangeable manufacture was a contribution of Eli Whitney, and it resulted from his contract in 1798 to supply the U.S. government with 10,000 muskets. Taking two years to design machinery and construct a plant, he finally convinced Congress that the delay and large expenditure of funds would be rewarded by laying out parts for ten guns in front of them and, by random selection of parts, assembling the ten muskets without a problem.

The inventors and inventions that sprung up at the close of the 18th century helped America to achieve a technological and industrial capability. Backed by the inspiration of Franklin, the curiosity of Jefferson, and above all by the personal support of Washington, the inventive spirit and the great pioneers of technological progress flourished in America.

Mathematics

by Joyce and Charles Goldstein

The latter part of the eighteenth century was an exciting period in terms of political and scientific change. New types of governments were being formed in the new world and the old. Mathematics in the new world was developed for the most part to be applied to various areas of science. In contrast, much of European mathematics was abstract.

In America, significant contributions were made in the fields of astronomy, ballistics, navigation and electricity, to name but a few. For example, Benjamin Banneker, a black mathematician and engineer, helped plan the city of Washington, D.C. He also did work in astronomy and was able to predict a solar eclipse. Benjamin Thompson (Count Rumford) was a loyalist. While working for the British, he invented the Rumford apparatus, a small steel cannon. This led to important discoveries in the field of ballistics. He also made important breakthroughs concerning the nature of heat.

The four major European mathematicians during this period were Euler, Lagrange, Laplace and Legendre.

Leonard Euler did important research in the areas of analysis, algebra, and analytical geometry. A few of Euler's lasting contributions to pure mathematics include the creation of the calculus of variations (with Lagrange), the discovery of fundamental properties of prime numbers, and work on the theory of geodesic curves. In addition, he made numerous discoveries in applied mathematics, including mechanics, hydrodynamics, astronomy and optics.

Joseph Louis Lagrange sought and obtained far-reaching results in both pure and applied mathematics. He helped create the two branches of mathematics known as the calculus of variations and differential equations. He made a significant impact on the fields of number theory, analytical geometry, algebra, mechanics and astronomy.

Pierre Simon Laplace regarded mathematics as a means of attacking problems in physical research. His major contributions were in the fields of integral calculus, differential equations, finite differences, potential theory, probability theory, algebra, astronomy and theoretical physics.

Andrian Marie Legendre, while not as original as Lagrange and Laplace, also made substantial contributions to diverse areas of mathematics. His most important areas of research were geometry, number theory, integral calculus, eliptic integrals and spherical harmonic analysis.

The mathematicians mainly responsible for inventing modern geometry were: Gaspard Monge, Jean Victor Poncelet, and Lazare Nicholas Marguerite Carnot.

The important scientists responsible for the development of mathematical physics include Henry Cavendish, Thomas Young, John Dalton and Jean Baptiste Joseph Fourier.

* * * *

So Science spreads her lighted ray
O'er lands which long in darkness lay;
She visits Fair Columbia
And sets her sons among the stars.
"Long live America!"

Adapted from "Ode on Science" a popular patriotic song by Jezaniah Sumner, 1798. The song conveyed the sentiment of its time, a sentiment which linked science, freedom, and enlightment with the essence of the young republic.

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Biology

by Clifford Cockerham

The eighteenth century produced Karl Linnaeus (1707-78), a man who left an indelible imprint on the field of biology through his greatest work, *Systema Naturae*, a classification of over 4,000 animal species.

Born and raised in Sweden, Linnaeus showed a love of flowers early in his youth, gaining the nickname "the little botanist" by the age of eight. After training as a medical student, he was appointed lecturer in botany at Upsala Academy in 1730. During his tenure he led collecting expeditions which reached as far north as the Arctic Ocean and also sent his students to explore a large part of the known world looking for new plants and animals. In 1753 he produced the *Species Plantarum*, a classification of over 7,000 plants.

Linnaeus established a universal scientific language for the taxonomic classification of animals, plants and even minerals, using standardized two-word Latin names. His terse style and methodical approach to recording observations abolished the use of haphazard descriptions and verbose records. This precise system focused the attention of biologists on classification, particularly by external parts. As a result, the search for new species became the primary goal of most naturalists, to the neglect of both anatomical and physiological studies.

Although Europe could boast of great naturalist writers like Gilbert White (1720-93) and Antoine de Jussieu (1748-1836), the exciting work was in the American colonies.

John Bartram (1699-1777) is credited with being the first American-born botanist. An explorer of virgin forests and a collector of seeds and plants, he gained a wide reputation and was appointed botanist for the American colonies to King George III. His 5-acre botanical garden, which still remains in Philadelphia, started with a tract of land purchased at a sheriff's sale. It became internationally famous for its extensive collection of domestic and foreign plants.

Bartram's cousin, Humphry Marshall (1723-1801), though trained in agriculture and masonry, rose to international recognition as an authority on botany. In 1774 he established another celebrated botanical garden in a town in Pennsylvania now known as Marshalltown.

Jane Colden (1724-66) was the first established woman botanist in America. Her father's correspondence with Linnaeus and collaboration with Bartram introduced her to botany at an early age. Colden mastered the Linnaean system of plant classification and published many articles.

Son of an American Lutheran minister, Gotthilf Muhlenberg (1753-1815) studied for the ministry in Germany and returned to preach in Philadelphia. In 1780 he fled to the countryside to escape the British troops and while in hiding spent his time studying the plant life. At the conclusion of the war, Muhlenberg returned to Philadelphia and began the systematic classification of plants and studied their medical properties. With the help of 28 correspondents, he completed the *Catalogue of Known and Naturalized Plants in North America* in 1809.

During the eighteenth century it became standard practice for exploratory voyages to include a team of naturalists to observe and collect specimens.

Biology's preoccupation with the diversity of life did not set the stage for Charles Darwin (1809-82) through naturalist explorations alone. Popular scientists like George de Buffon (1707-88) and Erasmus Darwin (1731-1802), grandfather of Charles Darwin, wrote on the natural degradation and inevitable evolution of species. Jean Lamarck (1744-1829) made important contributions to biology and the theory of evolution, although his achievements were clouded by hypothesizing the inheritance of acquired characteristics.

Basic biological research in Europe on the question of spontaneous generation, first addressed by Francesco Redi (1611-1697), continued to flounder as conflicting evidence came from all sides.

Joseph Koelreuter (1733-1806), a German botanist was not considered an important biologist by his contemporaries, however his work is now viewed as a foundation of modern genetics. Koelreuter, a pioneer in the experimental hybridization of plants, established that parent plants contribute equally to the physical potential of the off-spring.

Physics (Continued)

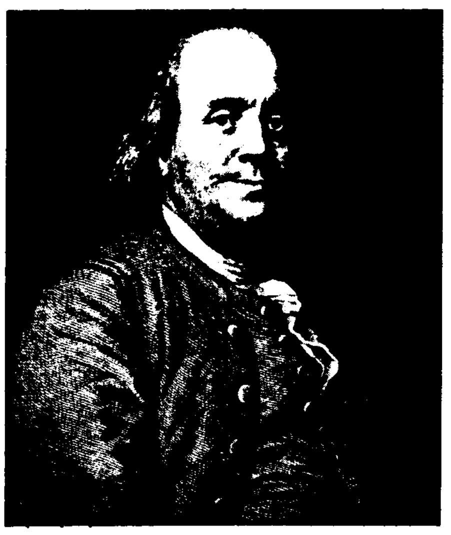
tor. At the suggestion of the French chemist Jean Antoine Claude Chaptal (1756-1832), this definition was adopted by the National Assembly of France in 1791 and 1795. The use of the metric system was made compulsory in all commercial transactions in France by a decree issued on July 4, 1837.

Concerning the developing science of acoustics, Galileo had already introduced the concept of frequency of the vibration of strings in his *Discorsi* in 1638. In 1715, Brook Taylor (1685-1731), who discovered the famous "Taylor series," published the correct formula relating the frequency of a string to its length, tension, and mass per unit length. Daniel Bernoulli was the first to express the form and motion of vibrating strings by means of differential equations. Later, in 1747, D'Alembert stated and integrated the fundamental differential equation of wave motion in terms of two arbitrary functions.

The concept of waves and propagation of vibrations by a movement called "undulatory" had begun to take form in the late 17th century. Christian Huygens (1629-1695) wrote a *Traité de la Lumière* (Treatise on Light) in 1690 which summarized the prevailing views. By the beginning of the 18th century, it was known from the work of Otto von Guericke, Robert Boyle, Denis Papin, and Francis Hauksbee that it is the air which transmits the sound vibrations. In 1738, the velocity of sound in air was measured accurately by Cassini, Maraldi, and Lacaille as 1106 feet/second.

In 1760, Joseph Black (1728-1789) pointed out the distinction between temperature and "quantity of heat." According to Black, heat must be considered as a fluid, the "caloric," which is as indestructible as matter. He was the first to define the specific heat of a substance. Black also introduced the concept of latent heat when he showed that the melting of a fixed mass of ice requires a constant quantity of heat. In 1798, Count Rumford and Sir Humphrey Davy (1778-1829) showed that heat is subject to the general law of conservation of energy. It should be noted that Count Rumford (1753-1814) was originally Benjamin Thompson. He was born in Woburn, Mass., but emigrated to Europe during the Revolution.

The well-known Leyden jar was originally constructed by Pieter van Musschenbroek (1692-1761), Professor of Physics at Leyden, in January 1746. Independent ex-



Benjamin Franklin

periments of the same type had also been carried out somewhat earlier by Ewald von Kleist, a Pomeranian parson, in October 1745. By that time, the existence of an electrical substance or "fluid" was taken for granted, and the propagation of the "electrical virtue" and its accumulation in the Leyden jar had become well-known phenomena. The word "charge" was invented by Franklin, although he used it merely as a special term for electrical "atmosphere," and these concepts did not become clarified until Coulomb introduced quantitative considerations.

Benjamin Franklin (1706-1790) made his first discovery, "the wonderful effect of pointed bodies both in drawing off and throwing off the electrical fire," in 1747. These observations suggested to him the opinion "that the electrical fire was not created by friction, but collected, being really an element diffused among, and attracted by other matter, particularly by water and metals" (*Experiments and Observations on Electricity,* 1750). From an ingenious experiment involving two persons (A and B) standing on wax and "rubbing the [electrical] tube," Franklin deduced that "B is electrised positively, A negatively, or rather B is electrised plus and A minus," i.e., that B has more and A has less than his normal share of electricity.

Franklin then applied his new ideas to the Leyden jar of Musschenbroek, claiming that the top of the bottle is "electrised positively" and the bottom is "electrised negatively" by the same amount (conservation of charge). He then performed an experiment to test this hypothesis. In this way, he evolved the theory of electricity as a single "fluid" (1750).

Franklin as a scientist is chiefly known to laymen for his invention of the lightning conductor. In 1749, having observed the resemblance between lightning and electric sparks, he asked himself if lightning might not be attracted by a pointed conductor. An experiment performed in France in May 1752 by Jean François Dalibard proved this assumption to be correct. In October 1752, Franklin himself carried out his famous kite experiment, as a result of which he was able to develop a lightning rod to "secure houses, churches, ships from lightning . . . by drawing the electrical fire out of a cloud silently, before it could come near enough to strike."

It should be noted that Franklin founded the American Philosophical Society in 1743 in Philadelphia. Moreover, he was the first American to be elected a foreign associate of the Académie Royale des Sciences of Paris in 1773. He was also a Fellow of the Royal Society of London (1756).

Among the scientists in the American colonies besides Franklin, we should mention in particular: Thomas Brattle (1658-1713), David Rittenhouse (1732-1796) and John Winthrop IV (1714-1779). Brattle made several accurate observations of Halley's comet in 1682, which he communicated to Edmund Halley (1656-1742).

David Rittenhouse started out as a clockmaker but subsequently made many scientific observations, including that of the transit of Venus across the sun from his Norristown Observatory in 1769. In 1791, he succeeded Franklin as president of the American Philosophical Society, and in 1795 he became a Fellow of the Royal Society.

John Winthrop IV was elected Hollis Professor of Mathematics and Natural Philosophy at Harvard in 1738. Eight years later, he established there the first laboratory for experimental physics in America and lectured on Newtonian physics. In 1751, he introduced differential and integral calculus into the curriculum, and in 1766 he was elected a Fellow of the Royal Society. He observed the transit of Mercury in 1740, and led a scientific expedition to Newfoundland in 1761 to observe the transit of Venus.

Within his lifetime, Cavendish published only a single memoir (in *Philosophical Transactions,* 1771). His other writings remained unknown until 1879, when James Clerk Maxwell (1831-1879) published them.

The main arguments of his first paper are as follows: (1) It is "likely" that the force between electrified bodies varies as the inverse square, for only on that assumption is it possible to explain the absence of electrical forces inside a hollow sphere, the surface charges of spheres and plane parallel plates, and the phenomenon of electric induction. (2) His theory introduced the "degree of electrification," which corresponds to our electrical potential. The observation was made that when two bodies of different shape are connected by a conducting wire, they do not carry the same charge, although they are electrified "to the same degree" (i.e., at the same potential).

In 1773, while still a military engineer, Coulomb studied the resistance of materials; six years later, he proposed his theory of simple machines and the laws of friction. He was attracted to the problems of electricity and magnetism by a competition (1777) for the best method of constructing a ship's compass. As a result he published a paper which was concerned mainly with the study of the basic magnetic phenomena. Coulomb deduced that "the different magnetic phenomena are not produced by vortices but arise from attractive and repulsive forces of the kind treated by gravitational and celestial physics." Coulomb then showed that the periods of oscillation of a magnetic needle can be used to determine the "momentum of the magnetic force" (torque) by making a series of measurements of the oscillations of magnets suspended by fine wires.

In 1785, Coulomb published his first fundamental paper on electricity, "Construction et usage d'une balance électrique" (construction and use of an electric balance), in which he described his well-known torsion balance for measuring electrical forces to an accuracy of better than one thousandth of a dyne. The book also described his classic experiments on electric *repulsion,* which provided the first rigorous proof of "Coulomb's law." In a second paper, also published in 1785, Coulomb demonstrated the inverse square dependence for the law of *attraction* between opposite charges.

I would like to thank Dr. E.H. Auerbach for several helpful discussions, and for lending me his copy of the book *The Beginnings of Modern Science* edited by René Taton, 1958. The present account was largely adapted from different chapters of this book. Additional sources of information include the *Collier's Encyclopedia* and the *Harper Encyclopedia of Science.*

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Medicine (Continued)

in laudanum until the animal was nearly insensible. Thence the cranium was removed and various substances applied directly to the brain while under direct microscopy circulation in the web of the foot was observed. Infusion of tobacco nearly stopped the circulation, and upon washing of the brain, the circulation returned. Without washing the brain, application of spirit of wine immediately returned the circulation.

Lazaro Spallanzani (1729-1799) described the digestive powers of saliva and gastric juice and performed innovative experiments upon himself. He placed bread in a linen bag and swallowed it. Upon defecation he observed the bag contained no bread thus it had been digested. He performed similar experiments on himself in which he ate cooked and raw tough meat and examined the contents of the bag upon its defecation. These crude and indelicate studies demonstrated some basic facts about digestion.

William Beaumont (1785-1853), an army surgeon in northern Michigan, grasped the unique opportunity to study processes of digestion in a victim of a gunshot wound which had caused a permanent gastric fistula. He observed the influence of psychological factors on circulation in the stomach and the presence of acid, and isolated pepsin in a crude form. Beaumont tied string on bundles of cabbage, cooked meat, raw meat, and salted meat, left it in the patient's stomach for variable periods of time and then removed and examined them.

Aloysio L. Galvani (1736-1798), using dissimilar metals, demonstrated the stimulation of muscular contraction through electrical currents. He also clearly demonstrated the existence of animal electricity by dissecting a nerve and allowing it to touch muscle at two points – one injured and one uninjured – causing a contraction to take place.

François Megendie (1783-1855) developed experimental neurophysiology. By experimentation on animals and study of human disease, he clearly demonstrated the neurological function of diverse spinal nerve routes and discovered that pain and locomotion are mediated through different spinal tests.

Capt. James Cook (1728-1779) performed a series of beautifully conducted experiments on his own men and through comparison of his experience with that of other sea captains, Cook correctly concluded that the administration of certain types of food, such as sauerkraut and fresh vegetables and fruit, would prevent the development of scurvy. He reported his results to the Royal Society of Medicine on 5 March 1776.

John Hunter (1728-1793) was a poorly educated man who was an anatomist and one of the great founders of clinical research. He became interested in venereal disease and took some gonorrheal pus from a patient. With a lancet he punctured his own penis and rubbed in the pus. Unfortunately for Hunter, the patient also had syphilis and Hunter described classical development of chancre, secondary and late syphilis. This observation led Hunter into the grave error of assuming that gonorrhea and syphilis were the same disease, an error that persisted in medicine for a century. He was a man of violent temper and developed severe angina pectoris related to his cardiovascular syphilis. In 1793 while attending a meeting of the board at St. George's Hospital at which he was led into a heated discussion, he dropped dead.

Benjamin Rush (1745-1813) was an American physician. Educated at Princeton and apprenticed to a physician, he later obtained his M.D. degree in Edinburgh. He returned to the colonies, signed the Declaration of Independence and served as Surgeon General to George Washington. His crusades against slavery, war, alcoholism and the death penalty injured his practice so that he became nearly destitute and in desperation requested appointment as Treasurer of the Mint from President Adams, which he received. He died in 1813 from typhus fever. His descriptions of dengue and yellow fever, and his treatise on insanity are classics. He originated the idea that dental infections were the cause of arthritis – a notion that persisted for over 100 years and resulted in the extraction of untold millions of teeth, with little effect on the arthritis.

Earlier English physicians had commented on the fact that urine from diabetic patients tasted sweet. This led Matthew (d. 1784) Dobson to perform a series of studies on a patient with diabetes. He tasted his patient's urine; it was sweet. He collected the urine and let it ferment. He noticed the bubbles and then smelled the vinegar. He tasted it; it was sour. He took eight ounces of blood, let it clot, and tasted the colorless part; it was sweet. He fermented it; it became sour. He took two quarts of urine, evaporated it to dryness and obtained some granular material smelling like brown sugar which tasted sweet and acted like a sugar when treated with vitriolic acid. He concluded that the loss of sugar in the urine was a major cause of the weight loss in diabetes.

Thomas Cadwalader, born in Philadelphia in 1708, was a close friend and associate of Benjamin Franklin, who published his only scientific contribution. Dr. Cadwalader described "the West India dry gripes" and ascribed it to the rum. It was later shown that the colic was due to lead that came from distilling rum through leaden pipes. He also described the development of osteomalacia, or the development of soft bones. Again in ignorance, he ascribed the softness of the bones to a wrong cause.

Sir George Baker (1722-1809) studied colic due to cider rather than rum. He noted that colic was common in Devon and rare in Hereford. He also observed that Devonshire farmers used lead-lined cider presses. He extracted lead from the cider of Devon and found none in the cider made in Hereford and thus first described an aspect of lead poisoning. He was attacked by the farmers of Devonshire as a faithless son. However, to stimulate the sale of Devonshire cider, the lead was removed from the presses and the colic disappeared.

René T.H. Laennec (1781-1826) was the inventor of the stethoscope. His original stethoscope was a roll of paper, and later a cylinder of wood. He described the essential elements of auscultation of the lungs and heart and correlated pathological processes in the lung with the things he could hear. He also correlated murmurs with various autopsy findings and valvular disorders. From his patients he contracted tuberculosis, the disease he so beautifully described in the living patient and at autopsy. He died of tuberculosis at age 45.

Thus one sees that in 1776 the practice of medicine was a rough business, clouded in mysticism and based on faith and what will be, will be. However, man's ingenuity, perspective and intellect were beginning to crack the wall of faith and ignorance. Newtonian principles were beginning to be applied in the life sciences. As the hard sciences continued development they would be applied quickly in biology and medicine. However, in clinical research it would be several decades before quantitative methods would supplant the basic senses of sight, touch, smell, taste and sound. From the excerpts quoted above, it took stout stomachs to apply these senses to satisfy intellectual curiosity and to advance clinical medicine.

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