Celebrating Newton

The legacy and legend of Isaac Newton live on 300 years after the publication of his masterpiece, the Principia

By STEFI WEISBURD

Then ye who now on heavenly nectar fare,
Come celebrate with me in song the name
Of Newton, to the Muses dear; for he
Unlocked the hidden treasures of Truth:
So richly through his mind had Phoebus cast
The radiance of his own divinity.
Nearer the gods no mortal may approach

— Edmund Halley's preface to Newton's *Principia*

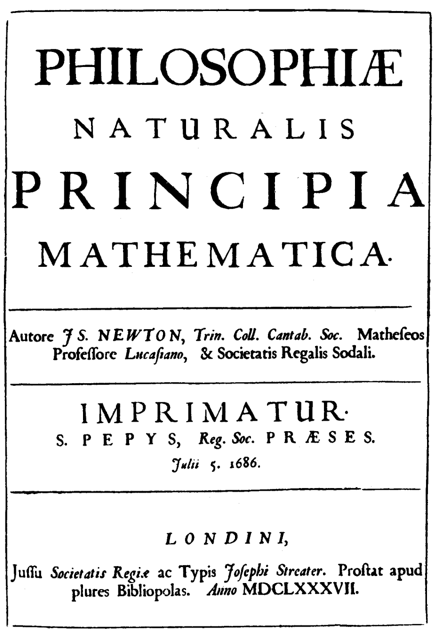
Science is a search for the essence of everything, for the fundamental laws that govern the universe. If there is one person whose work embodies the spirit and remarkable products of this pursuit, it is Isaac Newton. His *Philosophiae Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy), commonly known as the *Principia*, may well be the most important document in the history of science.

In many ways, the *Principia* is a blueprint for modern physical science. With it, Newton created a mathematical framework for physics and conceived basic laws of motion and of universal gravitation that unify a diverse array of phenomena both in the heavens and on earth. The revolutionary power of the *Principia* and other Newtonian works is felt to this day: His celestial mechanics guide the paths of satellites and spacecraft, his reflecting telescope is enabling astronomers to study recently discovered supernovas, his numerical methods are used in computers and his mathematics and approach to solving many physical problems remain as vital today as in his time.

And the *Principia* has influenced not only science but Western culture in general. Newton's ideas fostered the development of social sciences, they played center stage during the Age of Reason and they inspired the French and American authors of new governments. "The Newtonian revolution . . . remains one of the most profound revolutions in the history of human thought," writes I. Bernard Cohen in *Revolution in Science* (1985, The Belknap Press of the Harvard University Press).

This year marks the 300th anniversary of the *Principia's* publication. While Einstein's relativity theories and quantum mechanics have shown the limits of Newton's work (applicable only to the macroscopic, slowly moving physical world), scientists today are as much in awe of Newton's accomplishments as Edmund Halley and others were while Newton lived. To celebrate his genius, scientists and historians are gathering at a number of commemorative symposia planned for this year in Washington, D.C., Tel Aviv, Oxford, Holland and elsewhere. In addition, the Smithsonian's National Museum of American History in Washington, D.C., is hosting a special exhibit on Newton and the *Principia*. And in Britain, four commemorative stamps have been issued in Newton's honor.

These activities, says physicist Frank A. Wilczek at the Institute for Theoretical Physics in Santa Barbara, Calif., are "not only a celebration of Newton, but a celebration of [his] whole scientific world view and method that has led to such enormous insights" long after his death.


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.
Autore J. S. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.
IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.
LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

Smithsonian Institution Libraries

The frontispiece of Newton's Principia.

Historians are fond of saying that Newton was the culmination of the 17th-century scientific revolution. Newton's predecessors, such as Galileo, Kepler and Hooke, were moving away from the Aristotelian world view, in which the behavior of objects is dictated by the "qualities" they possess; Aristotelians believed, for example, that a stone falls because its "nature" necessitates that it move toward the center of the universe, or that planets travel in circular orbits because the circle is a heavenly form.

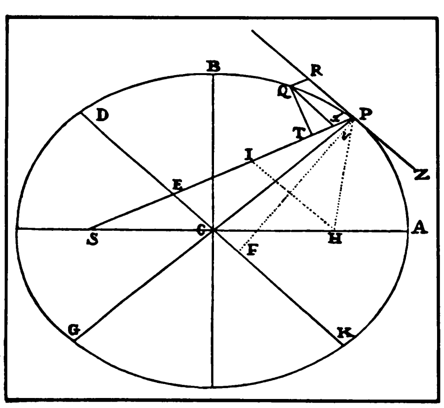
In contrast, the emerging view during the scientific revolution was more clearly rooted in the underlying forces or laws that can be expressed mathematically. Newton acknowledged that he stood "on the shoulders of Giants" who developed this approach. But, writes Paul Theerman, curator of the Smithsonian exhibit, "Newton was no mere disciple; his genius eclipsed that of any scientist of his era."

In its depth, scope and approach, the *Principia* contains an understanding of the workings of the universe that goes far beyond that of previous works. Moreover, Newton showed that many of the existing ideas were incorrect – Descartes had the notion, for example, that the planets move not in a vacuum but in a sea of material that swirls in huge vortices.

In addition to Newton's three laws of motion and universal law of gravitation, the *Principia*, which he wrote in only 18 months, contains work on hydrostatics, the motion of solids in resisting media and the propagation of sound waves. Newton's crowning achievement, however, was the application of his abstract mathematical laws to the real universe; he explained the orbits of planets, the irregular motion of the moon, the paths of comets and the ebb and flow of the tides. He predicted that the earth is flattened at the poles, an idea that was confirmed by a French expedition to Lapland in 1736. Based on Newton's work, Halley made his famous prediction that the comet of 1682 (Halley's comet) would return to view in 1758.

Courtesy: Smithsonian Inst.

"Like most classics in science, Newton's *Principia* is more honored than read," says Cohen, a science historian at Harvard University. But among those scientists who have studied the work firsthand, there is tremendous admiration not only of Newton's results, but also of how he arrived at them. They say that Newton's proofs, which are largely geometric constructs peppered with concepts of calculus, are extremely clever. Nobel-prize-winning astrophysicist Subrahmanyan Chandrasekhar of the University of Chicago says he compared his own proofs of Newton's propositions with those of Newton's and was "astonished at the originality, the careful arrangement, elegance and astonishing lightness" of Newton's proofs. "Every time I looked at what Newton did, I felt like a schoolboy admonished by his master," says Chandrasekhar, who along with Cohen and others recently attended a Washington-area symposium on Newton sponsored by the University of Maryland and the Smithsonian Institution.


Principia

Johannes Kepler had discovered that planets move in elliptical orbits. Newton showed that the force of attraction between a planet P, traveling in an ellipse, and a sun S, located at one focus of the ellipse, varies as the square of the distance between the two. In this way he proved that a central gravitational force from the sun governs the paths of the planets.

Scientists and historians are also taken with the intellectual range of Newton's achievements. He made important contributions to pure and applied mathematics. He studied chemistry and heat and designed scientific instruments. In his book the *Opticks*, he showed that white light is composed of rays of different colors that pass through a prism at different angles. Although he considered his optics experiments a failure in that he was unable to develop a mathematical basis for them, says Cohen, the *Opticks* ensured a premier place in science for experimentation and greatly influenced the later study of electricity, magnetism and chemistry by Benjamin Franklin and others.

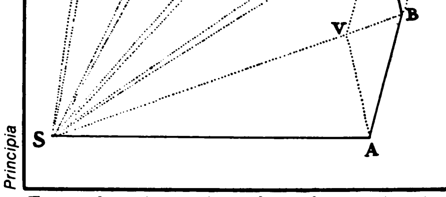
Like many scientists of his day, Newton was also fascinated by alchemy. According to Richard S. Westfall, a historian at Indiana University and author of *Never at Rest: A Biography of Isaac Newton* (1983, Cambridge University Press), Newton left behind about a million words on the subject. He also had an intense, but private, interest in religious studies, says Westfall, and was among the first scientists to grapple with the unavoidable problems associated with the rise of modern science in a society centered in Christianity.

"It is remarkable how modern Newton's point of view was," says Wilczek. For example, Newton struggled with the question of whether light was a particle or a wave. He had the insight to suspect that light and matter were unified in some way, says Wilczek, and because matter was thought to consist of particles, he ultimately embraced the particle theory – even though he had evidence for the periodicity of light and even though his own observations of light were the basis of the wave theory that prevailed for the next two centuries until the advent of quantum mechanics.

Today, says Wilczek, "we know that matter has wave-like properties and light has particle-like properties, and they are capable of being described in the same language." If Newton's questioning about the nature of light had been pursued, he adds, "we probably would have had quantum mechanics long before we in fact did."

Newton, according to Wilczek, anticipated or struggled with what are now three major themes of contemporary physics. By showing that gravitational attraction applied equally well to an apple falling toward earth as to the moon orbiting our planet, Newton expressed the idea of uniformity, in which the same physical laws and building blocks occur everywhere in the universe. However, says Wilczek, Newton did not believe in this idea absolutely, as he did not want to limit the power of God to make the rules different in different areas.

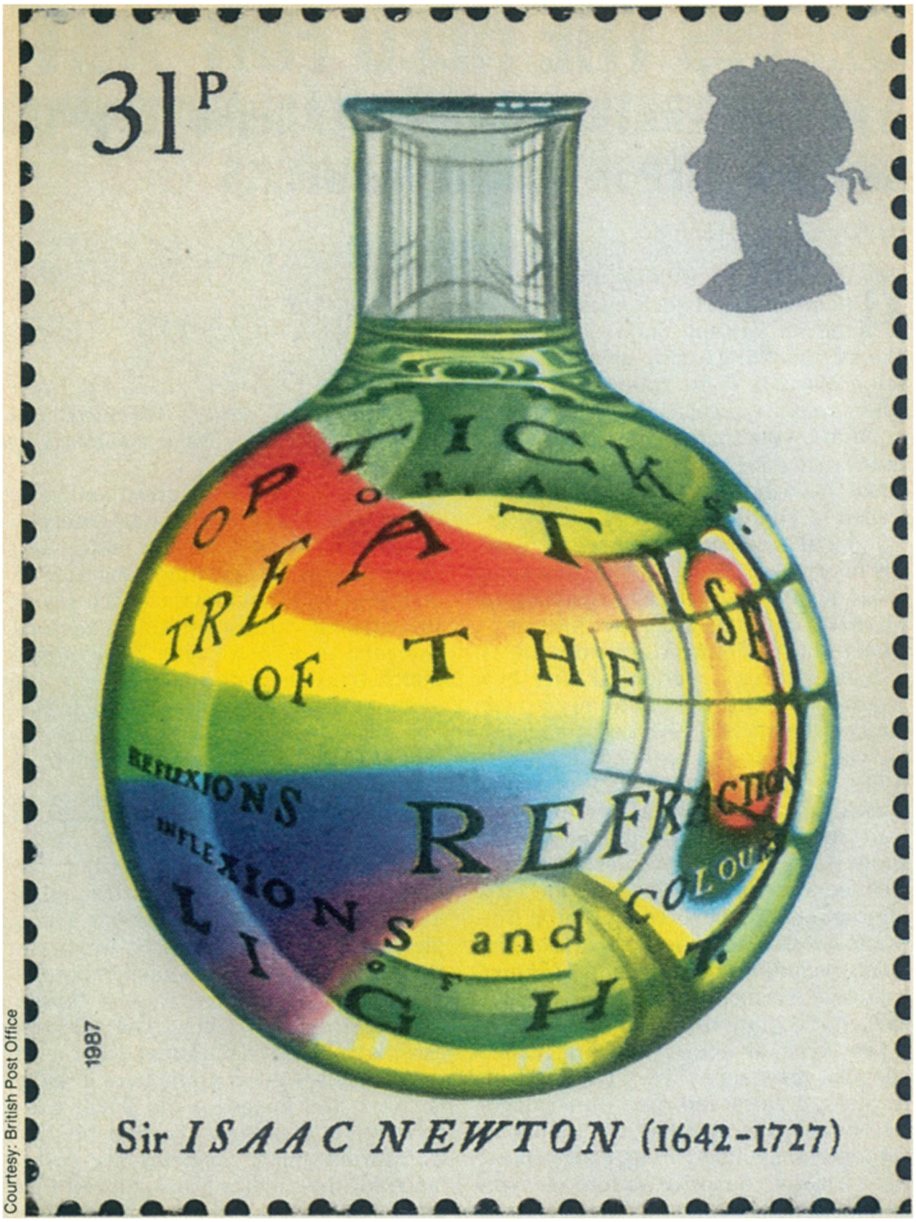
Wilczek says Newton also anticipated the concept of transformations, which holds that particles can be created and destroyed. In Newton's time and years after, scientists believed that observed changes in matter were due to rearrangements of immutable particles. But be-


Principia

From the viewpoint of modern scientists, for whom calculus is second nature, Newton's proofs are surprising because they are largely geometrical. In Book I, Proposition 1 of the Principia, *Newton begins a line of reasoning that shows that a body, continually drawn to some center of force (S), will move along a curve and that a line drawn from the center of the body will sweep through equal areas in equal times.*

cause light could be made to disappear (by being absorbed in a black cloth, for example), Newton may have suspected that the constituents of matter too could be created and destroyed, says Wilczek.

A third idea of modern physics is that the material content of the universe, and not only the motion and behavior of matter, is governed by the physical laws. Newton's thinking on this point, says Wilczek, was complicated by his theology. In the end, while he envisioned a clocklike universe, running by a set of laws, he seems to have left the initial conditions, such as the material makeup of the universe, up to God.



Courtesy: British Post Office

This stamp commemorates another great work of Newton's, the Opticks *(published in 1704), which pioneered the study of light and colors and validated the experimental approach to science. While in his epitaph on Newton, Alexander Pope was apparently inspired by the* Principia, *his words are equally appropriate to the* Opticks*: "Nature and Nature's laws lay hid in the night: God said, 'Let Newton be!' and all was light."*

What makes a man of such genius? A powerful combination of talent and character, says Wilczek. "Newton had a fantastic dedication," he says; he was the kind of person who "would sit with a problem, missing meals without even noticing."

But while his tenacity and strong personality may have helped direct his scientific genius, it did not make him a pleasant person to deal with. "Newton was an intense and solitary man" who abhorred criticism, says Theerman. He had heated run-ins with Robert Hooke over optics, with John Flamsteed, England's Astronomer Royal, over the control of astronomical data, and with the German mathematician Gottfried Wilhelm Leibniz over which of them invented calculus (historians say the two men invented calculus independently of one another).

His behavior in these disputes was reportedly driven by an obsessive and irrational rage. After an early entanglement with Hooke and the Royal Society he retreated from public life and broke off all intellectual correspondence. If it weren't for Halley in 1684 coaxing Newton out of his shell and urging him to write his solutions to some problems in orbital dynamics, the *Principia* might never have been written.

Newton also suffered a number of nervous breakdowns. During one episode in 1693, he sent his friend John Locke a wildly written letter accusing Locke of trying to entangle him with women (Newton never married). Some psychologically oriented scholars have attributed Newton's behavior to his childhood, particularly to the death of his father before his birth and to the child's long separation from his mother after she remarried. Others have suggested that he was poisoned by mercury and other toxic chemicals during his extensive alchemical experiments.

In spite of his temperament Newton was revered in his time. The publication of the *Principia* brought him instant fame internationally, especially in London society. Westfall notes that shortly after the *Principia*'s publication, the English government called on Newton as one of the 10 leading intellectuals of the time to solve the country's economic crisis. Newton was elected Cambridge University's representative in Parliament, and later, president of the Royal Society. He was made Warden, and then Master, of the Mint, where he oversaw the recoining of English currency and became the scourge of London counterfeiters. According to Chandrasekhar, people would stand for hours hoping for a glimpse of the carriage taking Newton to his work at the mint. In 1705, he became the first scientist to be knighted.

This adoration continued long after his death in 1727. During the 18th century it was fashionable for the social elite to familiarize themselves with Newton's ideas and to own fine editions of his works. In schools, Latin and English versions of the *Principia* were standard fare for students through the 19th century. Newton, notes Theerman, "became a potent symbol of the progress and popularity of science" and rational thought, inspiring writers, artists and social thinkers of the last two centuries.

Today scientists remain unwavering in their appreciation of and wonder at Newton's accomplishments. Chandrasekhar says that while he can imagine how other important scientists throughout history might have thought and felt, he "cannot imagine being Newton." To try, he says, would be akin "to someone climbing a little hill and asking what it must be like to be on the top of Mt. Everest." □