Newton, Sir Isaac

Sir Isaac Newton, the culminating figure in the scientific revolution of the 17th century, was born on Jan. 4, 1643 (N.S.; Dec. 25, 1642, O.S.), in the manor house of Woolsthorpe, near Grantham, Lincolnshire, England. Perhaps the greatest scientific genius of all time, Newton made fundamental contributions to every major area of scientific and mathematical concern to his generation.

Newton came from a family of modest yeoman farmers. His father died several months before he was born. Three years later his mother remarried and moved to a nearby village, leaving Isaac in the care of his maternal grandmother. Upon the death of his stepfather in 1656, Newton's mother removed him from grammar school in Grantham in hopes of training him to manage her now much-enlarged estate, but even then Newton's interests ran more toward books and mathematical diversions. His family decided that he should be prepared for the university, and he entered Trinity College, Cambridge, in June 1661.

Even though instruction at Cambridge was still dominated by the philosophy of Aristotle, some freedom of study was permitted in the student's third year. Newton immersed himself in the new mechanical philosophy of Descartes, Gassendi, and Boyle; in the new algebra and analytical geometry of Vieta, Descartes, and Wallis; and in the mechanics and Copernican astronomy of Galileo. At this stage Newton showed no great talent. His scientific genius emerged suddenly when the plague closed the University in the summer of 1665 and he had to return to Lincolnshire. There, within 18 months he began revolutionary advances in mathematics, optics, physics, and astronomy.

Calculus

During the plague years Newton laid the foundation for elementary differential and integral CALCULUS, several years before its independent discovery by the German philosopher and mathematician LEIBNIZ. The "method of fluxions," as he termed it, was based on his crucial insight that the integration of a function (or finding the area under its curve) is merely the inverse procedure to differentiating it (or finding the slope of the curve at any point). Taking differentiation as the basic operation, Newton produced simple analytical methods that unified a host of disparate techniques previously developed on a piecemeal basis to deal with such problems as finding areas, tangents, the lengths of curves, and their maxima and minima. Even though Newton could not fully justify his methods--rigorous logical foundations for the calculus were not developed until the 19th century--he receives the credit for developing a powerful tool of problem solving and analysis in pure mathematics and physics. Isaac Barrow, a Fellow of Trinity College and Lucasian Professor of Mathematics in the University, was so impressed by Newton's achievement that when he resigned his chair in 1669 to devote himself to theology, he recommended that the 27-year-old Newton take his place.

Optics

Newton's initial lectures as Lucasian Professor dealt with optics, including his remarkable discoveries made during the plague years. He had reached the revolutionary conclusion that white light is not a simple, homogeneous entity, as natural philosophers since Aristotle had believed. When he passed a thin beam of sunlight through a glass prism, he noted the oblong spectrum of colors--red, yellow, green, blue, violet--that formed on the wall opposite. Newton showed that the spectrum was too long to be explained by the accepted theory of the bending (or refraction) of light by dense media. The old theory said that all rays of white light striking the prism at the same angle would be equally refracted. Newton argued that white light is really a mixture of many different types of rays, that the different types of rays are refracted at slightly different angles, and that each different type of ray is responsible for producing a given spectral color. A so-called crucial experiment confirmed the theory. Newton selected out of the spectrum a narrow band of light of one color. He sent it through a second prism and observed that no further elongation occurred. All the selected rays of one color were refracted at the same angle.

These discoveries led Newton to the logical, but erroneous, conclusion that telescopes using refracting lenses could never overcome the distortions of chromatic dispersion. He therefore proposed and constructed a reflecting telescope, the first of its kind, and the prototype of the largest modern optical telescopes. In 1671 he donated an improved version to the Royal Society of London, the foremost scientific society of the day. As a consequence, he was elected a fellow of the society in 1672. Later that year Newton published his first scientific paper in the Philosophical Transactions of the society. It dealt with the new theory of light and color and is one of the earliest examples of the short research paper.

Newton's paper was well received, but two leading natural philosophers, Robert HOOKE and Christian HUYGENS, rejected Newton's naive claim that his theory was simply derived with certainty from experiments. In particular they objected to what they took to be Newton's attempt to prove by experiment alone that light consists in the motion of small particles, or corpuscles, rather than in the transmission of waves or pulses, as they both believed. Although Newton's subsequent denial of the use of hypotheses was not convincing, his ideas about scientific method won universal assent, along with his corpuscular theory, which reigned until the wave theory was revived in the early 19th century.

The debate soured Newton's relations with Hooke. Newton withdrew from public scientific discussion for about a decade after 1675, devoting himself to chemical and alchemical researches. He delayed the publication of a full account of his optical researches until after the death of Hooke in 1703. Newton's Opticks appeared the following year. It dealt with the theory of light and color and with Newton's investigations of the colors of thin sheets, of "Newton's rings," and of the phenomenon of diffraction of light. To explain some of his observations he had to graft elements of a wave theory of light onto his basically corpuscular theory.

Gravitation

Newton's greatest achievement was his work in physics and celestial mechanics, which culminated in the theory of universal gravitation. Even though Newton also began this research in the plague years, the story that he discovered universal gravitation in 1666 while watching an apple fall from a tree in his garden is a myth. By 1666, Newton had formulated early versions of his three LAWS OF MOTION. He had also discovered the law stating the centrifugal force (or force away from the center) of a body moving uniformly in a circular path. However, he still believed that the earth's gravity and the motions of the planets might be caused by the action of whirlpools, or vortices, of small corpuscles, as Descartes had claimed. Moreover, although he knew the law of centrifugal force, he did not have a correct understanding of the mechanics of circular motion. He thought of circular motion as the result of a balance between two forces--one centrifugal, the other centripetal (toward the center)--rather than as the result of one force, a centripetal force, which constantly deflects the body away from its inertial path in a straight line.

Newton's great insight of 1666 was to imagine that the Earth's gravity extended to the Moon, counterbalancing its centrifugal force. From his law of centrifugal force and Kepler's third law of planetary motion, Newton deduced that the centrifugal (and hence centripetal) force of the Moon or of any planet must decrease as the inverse square of its distance from the center of its motion. For example, if the distance is doubled, the force becomes one-fourth as much; if distance is trebled, the force becomes one-ninth as much. This theory agreed with Newton's data to within about 11%.

In 1679, Newton returned to his study of celestial mechanics when his adversary Hooke drew him into a discussion of the problem of orbital motion. Hooke is credited with suggesting to Newton that circular motion arises from the centripetal deflection of inertially moving bodies. Hooke further conjectured that since the planets move in ellipses with the Sun at one focus (Kepler's first law), the centripetal force drawing them to the Sun should vary as the inverse square of their distances from it. Hooke could not prove this theory mathematically, although he boasted that he could. Not to be shown up by his rival, Newton applied his mathematical talents to proving Hooke's conjecture. He showed that if a body obeys Kepler's second law (which states that the line joining a planet to the sun sweeps out equal areas in equal times), then the body is being acted upon by a centripetal force. This discovery revealed for the first time the physical significance of Kepler's second law. Given this discovery, Newton succeeded in showing that a body moving in an elliptical path and attracted to one focus must indeed be drawn by a force that varies as the inverse square of the distance. Later even these results were set aside by Newton.

In 1684 the young astronomer Edmond Halley, tired of Hooke's fruitless boasting, asked Newton whether he could prove Hooke's conjecture and to his surprise was told that Newton had solved the problem a full 5 years before but had now mislaid the paper. At Halley's constant urging Newton reproduced the proofs and expanded them into a paper on the laws of motion and problems of orbital mechanics. Finally Halley persuaded Newton to compose a full-length treatment of his new physics and its application to astronomy. After 18 months of sustained effort, Newton published (1687) the Philosophiae naturalis principia mathematica (The Mathematical Principles of Natural Philosophy), or Principia, as it is universally known.

By common consent the Principia is the greatest scientific book ever written. Within the framework of an infinite, homogeneous, three-dimensional, empty space and a uniformly and eternally flowing "absolute" time, Newton fully analyzed the motion of bodies in resisting and nonresisting media under the action of centripetal forces. The results were applied to orbiting bodies, projectiles, pendula, and free-fall near the Earth. He further demonstrated that the planets were attracted toward the Sun by a force varying as the inverse square of the distance and generalized that all heavenly bodies mutually attract one another. By further generalization, he reached his law of universal gravitation: every piece of matter attracts every other piece with a force proportional to the product of their masses and inversely proportional to the square of the distance between them.

Given the law of gravitation and the laws of motion, Newton could explain a wide range of hitherto disparate phenomena such as the eccentric orbits of comets, the causes of the tides and their major variations, the precession of the Earth's axis, and the perturbation of the motion of the Moon by the gravity of the Sun. Newton's one general law of nature and one system of mechanics reduced to order most of the known problems of astronomy and terrestrial physics. The work of Galileo, Copernicus, and Kepler was united and transformed into one coherent scientific theory. The new Copernican world-picture finally had a firm physical basis.

Because Newton repeatedly used the term "attraction" in the Principia, mechanical philosophers attacked him for reintroducing into science the idea that mere matter could act at a distance upon other matter. Newton replied that he had only intended to show the existence of gravitational attraction and to discover its mathematical law, not to inquire into its cause. He no more than his critics believed that brute matter could act at a distance. Having rejected the Cartesian vortices, he reverted in the early 1700s to the idea that some sort of material medium, or ether, caused gravity. But Newton's ether was no longer a Cartesian-type ether acting solely by impacts among particles. The ether had to be extremely rare so it would not obstruct the motions of the planets, and yet very elastic or springy so it could push large masses toward one another. Newton postulated that the new ether consisted of particles endowed with very powerful short-range repulsive forces. His unreconciled ideas on forces and ether deeply influenced later natural philosophers in the 18th century when they turned to the phenomena of chemistry, electricity and magnetism, and physiology.

With the publication of the Principia, Newton was recognized as the leading natural philosopher of the age, but his creative career was effectively over. After suffering a nervous breakdown in 1693, he retired from research to seek a government position in London. In

1696 he became Warden of the Royal Mint and in 1699 its Master, an extremely lucrative position. He oversaw the great English recoinage of the 1690s and pursued counterfeiters with ferocity. In 1703 he was elected president of the Royal Society and was reelected each year until his death. He was knighted (1708) by Queen Anne, the first scientist to be so honored for his work.

Newton died in London on Mar. 31, 1727, (N.S.; Mar. 20, O.S.), having singlehandedly completed the scientific revolution and molded much of the content and the image of modern science.
