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(*b*. London, England, 29 October 1656[?]; *d*. Greenwich, England, 14 January 1743)

astronomy, geophysics.

Halley was the eldest son of Edmond Halley, a prosperous landowner, salter, and sopmaker of the City of London. There is doubt about when he was born, and the date given is that accepted by Halley himself. Although his father suffered some loss of property in the Great Fire of London in 1666, he remained a rich man and spent liberally on his son's education, arranging for him to be tutored at home before sending him to St. Paul's School and then, at the age of seventeen, to Queen's College, Oxford. Young Halley showed an early interest in astronomy and took to Oxford a valuable collection of astronomical instruments purchased by his father. Halley's mother died in 1672, the year before he went to Oxford; and after his father's disastrous second marriage ten years later, financial support became rather more restricted. Nevertheless, everything points to Halley's having private means, for although he married Mary Tooke, daughter of an auditor of the Exchequer, in 1682 and thus accepted wider financial liabilities, he was able to pay for the publication of Newton's *Principia* four years later. Halley and his wife had three children: Katherine and Margaret, born probably in 1688, and a son, Edmond, born in 1698. The daughters survived their father but young Edmond, a naval surgeon, predeceased his father by one year; Halley's wife died five years earlier, in 1736. Halley seems to have enjoyed life and to have possessed a lively sense of humor; religiously he was a freethinker and did not consider that the Bible should be taken literally throughout. Indeed, when he was thirty-five, he was considered for the Savilian professorship of astronomy at Oxford, but the appointment went to David Gregory.

A man of great natural diplomacy, at twenty-two Halley dedicated a planisphere of the southern hemisphere stars to Charles II and obtained a royal mandamus for his M.A. degree at Oxford, although he had not resided there for the statutory period. A year later, with the blessing of the Royal Society, of which he had been elected a fellow in 1678, Halley visited Johannes Hevelius at Danzig and, in spite of a forty-five-year difference in age, was able to pacify the older astronomer, who had received severe criticisms about his use of open instead of telescopic sights for the measurement of celestial positions. Again, when Newton was writing the *Principia*, it was Halley who contributed important editorial aid and persuaded him to continue, despite an argument with Robert Hooke about priority. In 1698, when Peter the Great visited Deptford to study British shipbuilding, Halley was his frequent guest, discussing with him all manner of scientific questions; perhaps it was this kind of success that led Queen Anne, in 1702 and 1703, to send him on diplomatic missions to Europe to advise on the fortification of seaports, a subject on which he had already shown himself adept by providing intelligence reports on French port fortifications while surveying the English channel in 1701.

Halley's interests were wide, even for a seventeenthcentury savant. He showed a lively concern with archaeology, publishing in 1691 a paper on the date and place of Julius Caesar's first landing in Britain, using evidence from an eclipse of the moon and critically analyzing other accounts; in 1695 he published one on the ancient Syrian city of Palmyra, the ruins of which had been described by English merchants a few years previously. The latter paper aroused considerable interest and stimulated British antiquaries in the eighteenth century to make an exhaustive study. When he was elected to assist the honorary secretaries of the Royal Society in 1685—a paid post that obliged him to resign his fellowship—he was able to broaden his interests further by an extensive correspondence. Halley held this post for fourteen years, during which time he discussed microscope observations by letter with Anton van Leeuwenhoek and, with others, matters that ranged from medical abnormalities and general biology to questions of geology, geography, physics, and engineering, as well as his own more familiar subjects of astronomy and mathematics.

When he became deputy controller of the mint at Chester in 1696, during the country's recoinage, Halley retained his Royal Society office and reported everything of archaeological and scientific interest in the area. From 1685 to 1693 he also edited the *Philosophical Transactions of the Royal Society* with outstanding competence at a formative time in the journal's development. Halley was also fortunate in possessing great practical sense as well as intellectual ability, and he carried out many experiments in diving, designing a diving bell and a diver's helmet that were much in advance of anything available. Reports on the colors of sunlight that he observed at various depths were sent to Newton, who incorporated them in his *Opticks*. Halley also formed a public company for exploiting the bell and helmet by using them for salvaging wrecks; its shares were quoted between 1692 and 1696.

Halley's best-known scientific achievement was a scheme for computing the motion of comets and establishing their periodicity in elliptical orbits. Although he took a particular interest in the bright naked-eye comet of 1680, it was only in 1695, after the publication of Newton's *Principia*, that he was able to begin an intensive study of the movements of comets. The difficulty in determining cometary paths arose because a comet could be seen for only a short time and, in consequence, it was possible to fit a series of curves through the observed positions. A straight line had been favored for a long time, but by the mid-seventeenth century it was generally accepted that the path must be an ellipse, a parabola, or a hyperbola. Newton preferred the parabola, but Halley decided to consider in detail the possibility of an ellipse.

Utilizing this hypothesis that cometary paths are nearly parabolic, he made a host of computations that led him to consider that the bright comets of 1531, 1607, and 1682 were the same object, making a periodic appearance approximately every seventy-five years. Later he also identified this object with the bright comets of 1305, 1380, and 1456. Halley next set about calculating its return and, allowing for perturbations by the planet Jupiter, announced that it should reappear in December 1758. The comet was in fact observed on 25 December 1758, arriving some days later than Halley's calculations had indicated, but in that part of the sky he had predicted. He also believed that the bright comet of 1680 was periodic, taking 575 years to complete an orbit, but in this he was mistaken. Halley's cometary views were published in 1705 in the *Philosophical Transactions*, and separately at Oxford in the same year in Latin and at London in English with the title *A Synopsis of the Astronomy of Comets*. Although this work aroused the interest of astronomers, it was not until the 1682 comet reappeared as predicted in 1758 that the whole intellectual world of western Europe took notice. By then Halley had been dead fifteen years; but his hope that posterity would acknowledge that this return "was first discovered by an Englishman" was not misplaced, and the object was named "Halley's comet." This successful prediction acted as a strong independent confirmation of Newtonian gravitation, and it is often said, but without direct evidence, to have helped dissipate the superstitious dread attached to cometary appearances.

Halley's astronomical contributions were not confined to comets, and he made notable advances in the determination of the distance of the sun, in positional and navigational astronomy, and in general stellar astronomy. Determination of the distance of the sun from the earth was crucial, since a correct evaluation was necessary before the size of the planetary system or the distances of the stars could be determined as direct values. Halley proposed evaluating the distance by observing the transit of Venus across the sun, an idea first sketched by James Gregory in 1663. Halley first assessed the practicability of the idea when he observed and timed a transit of Mercury in 1677. By recording the local time at which Mercury appeared to enter the sun's disk and the time at which it left, and then comparing his results with those made at an observing station in a different latitude, the distance of Mercury was obtained. Using Johann Kepler's third law of planetary motion, the distance from the earth to the sun could be found.

Halley appreciated that greater precision could be obtained by observing a transit of Venus, since it lies nearly twice as close to the earth as Mercury and thus the same percentage of error in timing would result in smaller errors in distance determination. Transits of Venus are rare, and the next were to occur in 1761 and 1769, by which time he would doubtless be dead. Nevertheless, Halley worked out methods of observation and subsequent calculation in considerable detail, publishing his results in the *Philosophical Transactions* for 1691, 1694, and, most fully, 1716. Joseph Delisle, who planned to organize expeditions to observe the 1761 transit, came to London in 1724 and discussed the subject with him; and it was Delisle's arrangements for European observations that at last stimulated British astronomers to take action in June 1760, twelve months before the transit. Delisle had devised a method that was a slight modification of what Halley had proposed and, in June 1761, a total of sixty-two observing stations were in operation. For the 1769 transit a total of sixty-three stations sent in observations and a value of 95 million miles was obtained for the sun's distance, a figure that further analysis subsequently reduced to 93 million. This compares favorably with the present figure of 92.87 million miles, but even 95 million represented a great achievement in the mid-eighteenth century.

Halley began positional astronomy assisting Flamsteed in 1675. He broke this connection when he continued on his own, leaving Oxford in 1676 for the island of St. Helena, off the west coast of Africa at a latitude of sixteen degrees south. Here he cataloged the stars of the southern hemisphere and, incidentally, discovered a star cluster in Centaurus (ω Centauri). He compiled his results in *Catalogus stellarum Australium*..., which was published late in 1678 at London; a French translation by Augustin Royer appeared at Paris early in 1679. In addition Halley drew up a planisphere, a copy of which was presented in 1678 to the king. The Royal Society received both catalog and planisphere, and it was primarily on the strength of these that he was elected a fellow.

Halley's other positional work was carried out at Greenwich after he was appointed astronomer royal in 1720, succeeding John Flamsteed. Here he found no instruments, since those used by Flamsteed had been removed, but he immediately obtained financial aid from the government. He established the first transit instrument to be put to regular use and ordered a large mural quadrant that was set up in 1724. He then observed the planets and, in particular, studied the motion of the moon. Halley's observing program for the latter was as bold as it was ambitious, for although he was aged sixty-four when appointed astronomer royal, he set about planning observations to cover a complete saros of eighteen years, after which the relative positions of the sun and moon would be repeated with respect to the nodes of the lunar orbit. He adopted this program because he was convinced, correctly, that once the moon's orbit was really known precisely, the problem of determining longitude at sea would be solved.

Flamsteed had made excellent measurements of star positions and some of the moon, so Halley concentrated on completing a set of lunar observations and, surprisingly enough, was able to finish his self-imposed task. By 1731 he was already in a position to publish a method of using lunar observations for determining longitude at sea that gave an error of no more than sixty-nine miles at the equator, a result that showed a real improvement over previous methods and augured well for even greater precision. Halley's observations were later criticized for their lack of precision; but even if they were not all they might have been, he certainly established the viability of the "method of lunars" as a solution of the longitude problem. It is worth noting, too, that while Halley was astronomer royal he was visited by John Harrison, who explained his ideas for an accurate timepiece. On Halley's personal recommendation, the instrument maker George Graham lent Harrison money to enable him to make a clock for submission to the Board of Longitude and thus develop what ultimately was to prove another successful solution.

Halley's achievements in stellar astronomy were of considerable significance, although they were not as fully appreciated in his day as might have been expected. In 1715 he published a paper on novae, listing those previously observed, making comments, and drawing parallels with long-period variables such as o Ceti (Mira), which is sometimes visible to the naked eye and sometimes invisible. In the same year Halley also made known his thoughts on nebulae. A few had been detected with the naked eye but the number had increased after the telescope came into use astronomically. Without a telescope they often looked like stars; with a telescope they were clearly seen to be something different. Halley boldly suggested that they were composed of material spread over vast expanses of space, "perhaps not less than our whole Solar System," and were visible because each shone with its own light, which was due not to any central star but to the "lucid Medium's" behavior. In this explanation Halley anticipated some aspects of the later work of William Herschel and William Huggins.

Halley also studied the question of the size of the universe and the number of stars it contained. The problem was much discussed just then, even by Newton, although he had also stated that the universe was infinite—otherwise gravity would attract all matter to the center. Halley's approach was an observational one, and in 1720 he concluded that since every increase in telescopic power had shown the existence of stars fainter than any hitherto observed, it seemed likely that the universe was to be taken as "actually infinite." There was a physical argument, too, for Halley considered the effects of gravitation on material spread out in a finite part of an infinite space and came to a conclusion similar to Newton's.

One contemporary criticism (revived a few years later by Jean de Chésaux and again in 1823 by H. W. M. Olbers) stated that if the number of stars were infinite, the sky should be bright, not dark, at night: Halley believed that he had resolved this paradox. He calculated that if all the stars were as distant from each other as the nearest (to earth) was from the sun, then, in spite of an increase in numbers, they would occupy ever smaller areas of the sky, so that, at very large distances, their diminished brightness would render them too dim to observe. As a corollary, he pointed out that even when observed with the largest telescopes some stars were so dim that it was to be expected that there were others whose light did not reach us.

There was a fallacy in Halley's argument, for he seems to have confused linear and angular dimensions: star disks do become smaller with greater distance, but the solid angle subtended by the heavens does not. Nevertheless, it was a carefully reasoned attempt to analyze an important problem that was to exercise astronomers for many generations. In a subsequent paper Halley discussed the number of stars to be expected in a given volume of space, assuming a given separation between them, and the way in which their brightness would diminish with distance. In this he anticipated what John Herschel was to discover and express precisely a century later: that stars of magnitude six were 100 times dimmer than those of magnitude one. Again Halley worked out figures that led him to conclude that the most distant stars would still be too dim to be detectable; but whatever the faults in all this work, his methods of attack were new and paved the way for later investigators.

Halley's most notable achievement in stellar astronomy was his discovery of stellar motion. From earliest times the stars had been regarded as fixed, and there seemed no reason to question this assumption. In 1710 Halley, who took a great interest in early astronomy, settled down to examine Ptolemy's writings and paid particular attention to his star catalog. It soon became evident that there were discrepancies, even allowing for precession and observational errors; and Halley rightly decided that the differences between Ptolemy's catalog and those compiled some 1,500 years later were so gross that the only rational explanation was to assume that the stars possessed individual motions. Halley was able to detect such proper motion only in the case of three bright stars—Arcturus, Procyon, and Sirius—but he correctly deduced that others which were dimmer, and could therefore be expected to be further away, possessed motions too small to be detected. It was not until a century and a half later that the study of proper motions could really be extended, but this was due to insufficient instrumental accuracy and not to disregard of Halley's opinion. The limitations of precise measurement in Halley's time also prevented the successful determination of even one stellar distance. Claims to have achieved this were made nonetheless, notably in 1714 by Jacques Cassini, who believed he had obtained an annual parallax for Sirius. In 1720 Halley analyzed this claim, showed that it could not be upheld, and made suggestions for observations which he thought might be successful.

Halley's interest in early astronomy was coupled with an equally great interest in early mathematics; and when he was appointed Savilian professor of geometry at Oxford in 1704, Henry Aldrich, dean of Christ Church, suggested to him that he prepare a translation of the *Conics* of Apollonius. Aldrich made a similar proposal to David Gregory, who held the Savilian chair of astronomy; Halley and Gregory worked on the subject together until the latter's death in 1708, after which Halley carried on alone. Two Latin editions of books V-VII (from Arabic) existed, but since these lacked book VIII Halley used Greek lemmas by Pappus to aid him in his reconstruction of the whole work. The *Conics* had attracted other mathematicians, but Halley aimed at and prepared a definitive edition. He also translated Apollonius' *Sectio rationis* (and restored his *Sectio spatii*) and tracts by Serenus of Antinoeia, publishing these in 1706 and 1710. Oxford University recognized the scholarly achievement by conferring a Doctor of Civil Laws degree, and it is worth noting that his *Conics*, although partially supplanted by J. L. Heiberg's translation of books I-IV (Leipzig, 1891–1893), is still used for the remaining books (V-VII). Halley followed up this work on early mathematics by translating the *Sphaerica* of Menelaus of Alexandria, an elegant translation that has won praise even today; it was published posthumously in 1758.

Halley's mathematical interests were not purely historical: between 1687 and 1720 he published seven papers on pure mathematics, ranging from higher geometry and construction and delimitation of the roots of equations to the computation of logarithms and trigonometric functions. He also published papers in which he applied mathematics to the calculation of trajectories in gunnery and the computation of the focal length of thick lenses. Halley was also one of the pioneers of social statistics, demonstrating in 1693 how mortality tables could be used as a basis for the calculation of annuities, a suggestion that was later pursued by Abraham de Moivre.

Halley was not only an astronomer and mathematician; he was also the founder of scientific geophysics. His first major essay in this field was an important paper on trade winds and monsoons (1686) in which he specified solar heating as their cause, although he was aware that this was not a complete explanation and urged others to pursue the matter. To aid them he produced a meteorological chart of the winds, the first provision of data in such a form, in which he depicted the winds by short broken lines, each dash having a thick front and a pointed tail to indicate direction. He also studied tidal phenomena, in 1684 analyzing information received at the Royal Society about tides at Tonkin; his work on tides culminated in his survey of the English Channel in 1701.

Halley's most significant geophysical contribution was his theory of terrestrial magnetism, on which he published two important papers (1683, 1692); in both he developed his own theory, the second paper providing a physical basis for the proposals made in the first. Halley's suggestion was that the earth possessed four magnetic poles, one pair situated at the ends of the axis of an outer magnetic shell and the other at the extremities of the axis of an inner magnetic core. The shell and core had slightly different periods of diurnal rotation to account for observed variations. He also postulated that the space between core and shell was filled with an effluvium—a favorite theoretical device of the seventeenth century—and in 1716 used it as a basis for his suggestion that the aurora was a luminous effluvium that escaped from the earth and that its motion was governed by the terrestrial magnetic field.

Between 1698 and 1700 Halley was commissioned as a naval captain and, in spite of a mutiny on board, took the small ship *Paramore* across the Atlantic, reaching as far as fifty-two degrees south latitude and the same latitude north. He charted magnetic variation in the hope of using it as a means of determining longitude at sea; but although it proved unsatisfactory for this purpose, his chart, published in different editions in 1701, 1702, and 1703, was significant because it was the first to adopt isogonic lines (called "Halleyan lines" by contemporaries) to connect points of equal magnetic variation.

Halley's scientific attitude toward terrestrial physics led him to take an independent and novel approach to the question of the age of the earth. From investigations he made in 1693 on the rate of evaporation of water, he concluded that the salinity of lakes and oceans must gradually be increasing and suggested that if the rate of increase could be determined, it should be possible to obtain factual evidence about the earth's age. From approximate results Halley suggested that the figure derived from biblical genealogies was too low and that an alternative view, that the earth was eternal, was also incorrect. He further suggested a physical explanation for the Flood, postulating a very close approach of a comet to the earth. Although not now accepted, this was an interesting scientific explanation for a biblical event. These views did not commend him to some powerful ecclesiastics of his day.

Throughout much of his life Halley had to suffer the active disapproval of John Flamsteed, the first astronomer royal, who first encouraged and then turned against him. In 1712, at Newton's request, Halley prepared an edition of Flamsteed's observations using materials deposited at the Royal Society. Their publication as *Historia coelestis*... infuriated Flamsteed.

Halley was also involved in the Newton-Leibniz controversy to the extent of lending his name to the report of the supposed committee of the Royal Society which in effect sanctioned Newton's own version of the affair.

Recognition came to Halley early in life, with his M.A. and election to the Royal Society; but after that there was a long pause due, to a great extent, to Flamsteed. Nevertheless, he obtained the Savilian chair of geometry at Oxford in 1704, was appointed astronomer royal in 1720, and was elected a foreign member of the Académie des Sciences at Paris in 1729. At his death in 1743 Halley seems to have been widely mourned, for he was a friendly as well as a famous man and always ready to offer support to young astronomers.

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Colin A. Ronan