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10-12 minutes

Brahmagupta (c. 598–c. 670) was one of the most significant mathematicians of ancient India. He introduced extremely influential concepts to basic mathematics, including the use of zero in mathematical calculations and the use of mathematics and algebra in describing and predicting astronomical events.

Influenced by the spread of Greek mathematical ideas eastward during the imperial expansion of the ancient Roman empire, Brahmagupta's ideas in turn had an impact on later European developments; they were translated into Arabic from his own Sanskrit language, and thus took their place among the foundation stones of Western mathematics. Brahmagupta's writings contain mathematical and astronomical concepts that are taken for granted today, but they were concepts that he pioneered or refined from ideas he inherited. His estimates of the length of the year were strikingly accurate for their time. Although it is difficult to pinpoint a single inventor of the concept of zero, Brahmagupta is a reasonable candidate for that title. A writer of his own time, Bhaksara II, called him *Ganita Chakra Chudamani*, which means "the gem in the circle of mathematicians."

Headed Ancient Indian Observatory

Brahmagupta was born in c. 598, perhaps in the astronomically significant ancient Indian city of Ujjain—a place near the tropic of cancer that occupies a place in Indian history somewhat comparable to that of Greenwich in England. It was a central reckoning point for ideas of time and space, and it became a major astronomical and mathematical center. The first of his two surviving treatises, according to internal evidence, was written in Bhillamala, now the city of Bhinmal in Rajasthan state. Brahmagupta's first treatise, the *Brahmasphutasiddhanta* (meaning "The Correctly Established Doctrine of Brahma" but often translated as *The Opening of the Universe*), was written in 1628, when he was about 30 years old. His second, the *Khandakhadyaka* (whose title means something like "Edible Bite"), is less well known; it expands on the work of an earlier astronomer, Aryabhata, whose chief contribution was the idea of beginning each day at midnight. It was written in 665, near the end of Brahmagupta's life.

Little else is known of the life of this mathematician and astronomer who flourished 1,400 years ago, other than that he was a devout Hindu who took care not to antagonize his own religious leaders, attacking an idea advanced by thinkers in the competing Jain religion (correctly, as it turned out) that the earth rotated on a central axis. He based his conclusion on the faulty premise that large buildings would fall down if this were true. Brahmagupta did, however, reject ancient Hindu ideas that the earth was flat or bowl-shaped; like ancient Greek thinkers, including Aristotle, he realized that it was a sphere.

Brahmagupta is known mostly through his writings, which cover mathematical and astronomical topics and significantly combine the two. Brahmagupta's descriptions of the motions of the stars and planets were based on mathematical calculations to a degree that earlier astronomers had not achieved. As a result, some of his estimates of celestial cycles remained among the most accurate available for several centuries. He was able, for example, to reliably predict the rising and setting of the planets and trace their trajectories across the sky. While the ancient Greeks and even the Babylonians had dealt superstition a major blow by predicting eclipses, Brahmagupta refined their computational methods and helped to spread an understanding of these phenomena throughout societies where eclipses were still regarded as divine signs.

Brahmagupta's first manuscript, the *Brahmasphutasiddhanta*, was a revision of an older astronomy book, the *Brahmasiddanta* (Doctrine of Brahma). It opened with three chapters on the position and motions of the planets and stars, and on the cycle of daylight and night. Two chapters dealt with lunar and solar eclipses, respectively, and one with the heliacal risings and settings of stars, planets, and moon—the seasonal reappearances (and disappearances) of these celestial bodies as they pass the horizon line before (or, during heliacal setting, after) being hidden by the sun. Brahmagupta goes on to discuss phases of the moon, planetary conjunctions (what appear to be close approaches of planets in the sky), and conjunctions between planets and stars. One chapter in the middle of the book is devoted to a discussion of previous astronomical treatises. At the end of the book he devotes chapters to instruments and units of measure.

Estimated Length of Year

Brahmagupta's first manuscript calculated the length of the solar year at 365 days, 6 hours, 5 minutes, and 19 seconds, among the most accurate of early reckonings and remarkably close to the actual value of 365 days, 5 hours, 48 minutes, and about 45 seconds. In the *Khandakhadyaka* Brahmagupta revised his conclusion and went a small distance in the wrong direction, proposing a length of 365 days, 6 hours, 12 minutes, and 36 seconds. It is thought, however, that he relied on the work of

Aryabhata in arriving at this figure. All were remarkable estimates in an era that had no telescopes or scientific instruments in the modern sense.

After his discussion of astronomy, Brahmagupta then turned to mathematics, discussing what would now be called arithmetic and algebra—his terms were *pati-ganita*, or mathematics of procedures, and *bija-ganita*, or mathematics of equations. These ideas laid the foundation for much of the later development of mathematics in India. Some of Brahmagupta's discussions will sound familiar to the modern student of mathematics. His directions for the multiplication of large numbers involve multiplying one number by each digit of the other in a manner close to what students are taught today, although the numbers are written out in a different configuration. A curious feature of Brahmagupta's treatise is that it is largely written in verse, and his preferred multiplication method, according to the mathematics history website maintained by St. Andrews University in Scotland, is given the name *gomutrika* by Brahmagupta, meaning "like the trajectory of a cow's urine."

Brahmagupta also introduced new methods for solving quadratic equations that would be recognizable to modern students of mathematics. He illustrates such procedures with story problems such as the following (quoted on the St. Andrews University site), which could essentially have come from any modern algebra textbook: "Five hundred drammas were loaned at an unknown rate of interest. The interest on the money for four months was loaned to another at the same rate of interest and amounted in ten months to 78 drammas. Give the rate of interest." Brahmagupta devised formulas for calculating the area (and the lengths of the diagonals) of a cyclic quadrilateral, a four-sided figure whose vertices are points on a circle. His method is still known as Brahmagupta's theorem. Brahmagupta investigated various higher functions of algebra and geometry, in each case building on and refining the mathematical heritage of the ancient world.

Perhaps Brahmagupta's most important innovations, however, pertained to his treatment of the number zero. Several different discoveries converged to form the concept of zero. The circular symbol for the number and the idea of representing orders of magnitude in a number through the use of places arose at different times and places in advance of Brahmagupta's work. Brahmagupta, however, was the first to propose rules for the behavior of zero in common arithmetical equations, relating zero to positive and negative numbers (which he called fortunes and debts). He correctly stated that multiplying any number by zero yields a result of zero, but erred, as did many other ancient mathematicians, in attempting to define division by zero. Nevertheless, Brahmagupta is sometimes referred to as the "Father of Zero."

Brahmagupta's *Khandakhadyaka* refers to a date in the year 665 and is thought to have been written at that time, when Brahmagupta was about 67—an extremely old man by the standards of the time. He died sometime soon after that, perhaps in 670. A line of Indian mathematicians and astronomers working at the Ujjain observatory revered Brahmagupta and extended his ideas over the next decades and centuries.

The real impact of Brahmagupta's discoveries was felt in the Islamic world, where King Khalif Abbasid al-Mansoor (712–775) invited the Ujjain scholar Kanka to lecture on Brahmagupta's applications of mathematics to astronomy. The king ordered Brahmagupta's writings translated into Arabic in 771, and they had a major impact on subsequent writers in the Arab world, including al-Khwarizmi, the "father of algebra." The mathematical thought of medieval and early modern Europe was influenced by Arabic models that had been in existence for centuries. Distant from modern mathematics in time and place, Brahmagupta nevertheless exerted a definite influence on mathematics as the discipline is known today.

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