Biographical Encyclopedia of Astronomers

Archimedes

Born Syracuse, (Sicily, Italy), 287 BCE

Died Syracuse, (Sicily, Italy), 212 BCE

Archimedes is widely regarded as the greatest mathematician of Antiquity and one of the greatest mathematicians of all time. He lived in Syracuse on the island of Sicily and was a protégé of its kings Hieron and Gelon. Archimedes was killed by a soldier during the Second Punic War between Rome and Carthage. Episodes in the life of Archimedes have become legendary, the information coming in large part from Plutarch's account in his description of the conquest of Syracuse by Rome in his Life of Marcellus

The contributions of Archimedes to astronomy are less well known. There was a lost work on optics, *On Catoptrica,* some of which is transmitted in a commentary by Theon of Alexandria on Ptolemy's *Almagest*. Cicero, who was treasurer of Sicily in 75 BCE, wrote that spheres built by Archimedes were brought to Rome by Marcellus and that one of these was a planetarium, a mechanical model showing the motions of the Sun, the Moon, and the planets. It is believed that Archimedes wrote a paper on the construction of his planetarium, *On Sphere Making*, as is mentioned by Pappus. Since lost works of Archimedes were rediscovered as late as 1900, it is not inconceivable that these works may eventually be found.

The surviving astronomical work of Archimedes is contained in his *The Sand Reckoner*, and the rest of this article is concerned with this work. Apart from its inherent contributions, *The Sand Reckoner* might be the best introduction to classical science

Archimedes set himself the task not just of calculating a number greater than the number of grains of sand not just on a beach, or on the entire surface of the Earth, or even the Earth filled with sand, but the task of calculating a number that would be greater than the number of sand grains that could fill the entire Universe. To do this, he required, among other things, the circumference of the Earth in stadia, and the distance between the center of the Earth and the center of the Sun in Earth radii. He viewed the Universe as a sphere with the Earth at its center; the Sun revolved around the Earth in a circle. The ratio of the diameter of the Universe to the diameter of the Sun's orbit around the Earth is less than the ratio of the diameter of the Sun's orbit around the Earth to the diameter of the Earth.

Archimedes used known estimates on the circumference of the Earth. By this time, Eratosthenes had given his celebrated estimate of the Earth's circumference, arriving at a value very close to the correct 40,000 km. Archimedes' upper bound of 3 million stades is therefore consistent with his strategy of giving an estimate at least 10 times larger than the currently accepted figure

Archimedes' estimate of the distance between the Earth and the Sun is more interesting; this appears to be one of the earliest attempts to determine this distance. His method was to use contemporary estimates for the size of the Moon relative to the Earth (relatively easy) and the size of the Sun relative to the Moon (very difficult). Since the Sun and Moon have the same angular diameter for a terrestrial observer, as seen during solar eclipses, it follows that the

distances of the Sun and Moon from the Earth are proportional to their size. The distance to the Sun is then computed once the angular size of the Sun, as seen on Earth, has been estimated, a measurement which Archimedes himself carried out experimentally

The measurement was done by observing the Sun at sunrise, using a horizontal ruler on a vertical stand, and a cylinder placed on the ruler. The ruler is directed toward the Sun, and the eye is placed at the end of the ruler opposite the Sun. The cylinder blocks the Sun from the eye and is moved away from the eye until a small part of the Sun can be seen. The resulting angle between the sides of the cylinder and the eye, imagined to be a point at the end of the ruler, is a lower bound on the angular size of the Sun. The cylinder placed where it just blocks out the Sun will produce an angle that provides an upper bound on the angular size of the Sun

Archimedes used the simplest estimate on the size of the Moon, namely that it is smaller than the Earth. This is obvious from observations of lunar eclipses. Archimedes then used Aristarchus's estimate that the Sun is between 18 and 20 times the size of the Moon. Since Archimedes only required a safe upper bound, he overestimated this to 30 Moon diameters. Archimedes' final assumption was that the Sun's diameter was no larger than 30 Earth diameters.

Archimedes also took into account solar parallax, in other words, the fact that his estimate of the distance to the Sun was taken from a measurement on the surface of the Earth, while the actual distance that he was interested in is from the center of the Earth. Apparently, this is the first known example of solar parallax being taken into account

Archimedes then concluded that the estimate of 0.36° would be a safe underestimate for the angular size of the Sun. Given the previous assumption that the diameter of the Sun is no larger than 30 times the

diameter of the Earth, this meant that the orbit of the Sun was less than 30,000 Earth diameters. This led to the final estimate that the distance from the center of the Earth to the center of the Sun was less than 10,000 times the radius of the Earth.

Ilan Vardi

Selected References

Archimedes (1953). The Works of Archimedes, edited by Sir Thomas L. Heath. New York: Dover. (Unabridged reissue of the 1897 edition.) (The foremost English translation of Archimedes's works, edited in modern notation. Heath decided that, due to the high standard of Archimedes's works, he would present the paper in modern notation so as to most clearly communicate the ideas of Archimedes. More faithful literal translations of his works are harder to find in English, though available in French, e.g., the books of Mugler.)

(1970–1972). Archimède, edited by Charles Mugler. 4 vols. Paris: Les Belles Lettres. (Translation is based on the edited Greek texts of J. L. Heiberg.)

(1972-1975). Archimedis opera omnia, edited by J. L. Heiberg, with additional corrections by E. S. Stamatis. 4 vols. Stuttgart: B. G. Teubner. (Reprint of the 1910-1915 Leipzig edition.)

Blass, F. (1883). "Der Vater des Archimedes." Astronomische Nachrichten 104: 255-256.

Dijksterhuis, E. J. (1987). Archimedes, translated by C. Dikshoorn, with a new bibliographic essay by Wilbur R. Knorr. Princeton, New Jersey: Princeton University Press. (An excellent account of the life of Archimedes as well as an explanation of his major results.)

Heath, Sir Thomas L. (1913). Aristarchus of Samos, the Ancient Copernicus. Oxford: Clarendon Press. (Reprint, New York: Dover, 1981.)

Paulos, J. A. (1989). Innumeracy. New York: Hill and Wang. Plutarch. (1917). Plutarch's Lives. Vol. 5, translated by Bernadotte Perrin. Loeb Classical Library, no. 87. Cambridge: Massachusetts: Harvard University Press.

Shapiro, Alan E. (1975). "Archimedes's Measurement of the Sun's Apparent Diameter." Journal for the History of Astronomy 6: 75–83.

Vardi, Ilan (1998). "Archimedes' Cattle Problem." American Mathematical Monthly 105: 305–319

(December 2000). "Archimede Faces the Innumerable." Pour la science: 40-43.