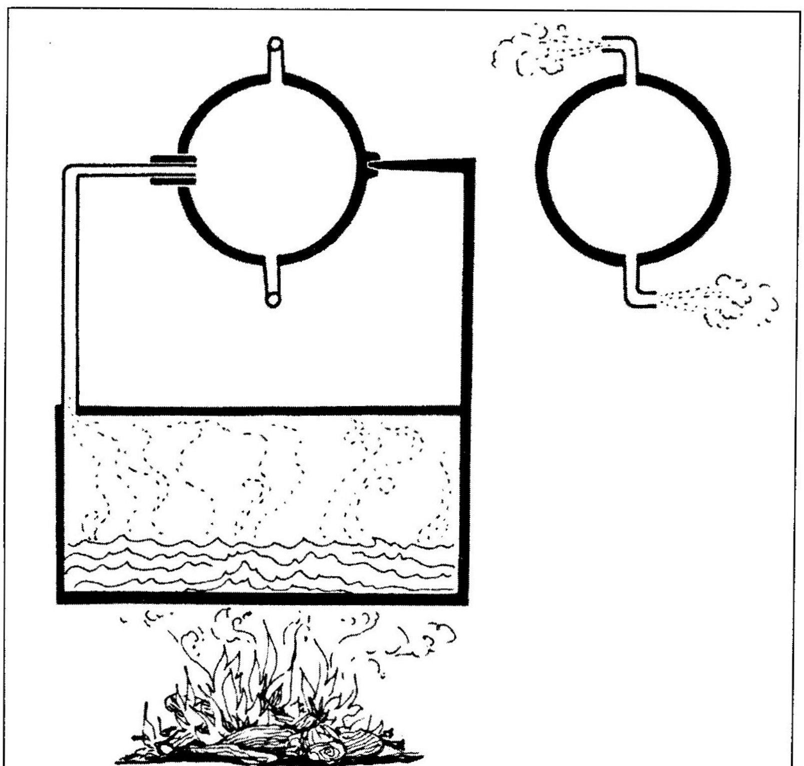
HERO OF ALEXANDRIA
Greek mathematician and engineer

Hero invented, improved, or at least preserved the designs for a variety of devices, including a surveying instrument, a catapult, a coin-operated water dispenser, and automata. His most famous invention was the aeolipile, a forerunner of the steam engine.

Born: Before 62 C.E.; Alexandria, Egypt
Died: c. 100 C.E.; Alexandria, Egypt
Also known as: Heron of Alexandria
Primary fields: Mathematics; mechanical engineering; military technology and weaponry
Primary inventions: Aeolipile; coin-operated water dispenser

EARLY LIFE

Virtually no biographical information survives concerning Hero of Alexandria, but some details of his childhood can be reasonably surmised. Given his profession and judging from his voluminous writings, he probably came from at least a moderately wealthy family and received a first-class education. Alexandria, founded by Alexander the Great in 331 B.C.E., had become a thriving center for trade and scholarship under the Ptolemaic dynasty that ruled Egypt from 323 to 30 B.C.E. Though the Romans ruled Egypt in Hero's time, the city of Alexandria remained important both commercially and culturally. The young Hero would presumably have had access to the vast holdings of the Library of Alexandria and may well have attended the lectures of that institution's eminent scholars. In the form of its lighthouse, a hundred-meter-tall structure on the island of Pharos, Alexandria also offered a vivid daily reminder of the wonders that science and technology could achieve. Probably, but not certainly, of Greek descent, Hero was heir to a centuries-old tradition of intellectual curiosity and engineering innovation. In Alexandria, he would have been exposed to an incredibly diverse population of Greeks, Jews, native Egyptians, Romans, and other peoples from the Near East, Africa, and Europe. Perhaps only Rome itself could have offered a more fertile environment for a would-be inventor.



A representation of the aeolipile, an ancient steam engine. (The Granger Collection, New York)

LIFE'S WORK

What is known of Hero's work comes almost entirely from his writings. He wrote four works on aspects of mensuration, the science of measuring lengths, areas, and volumes. These works are his *Geometrica*, *Stereometrica*, *De mensuris*, and *Metrica*. Another work on geometry is his *Definitiones*. The works that discuss the construction of devices are the *Pneumatica*, about the use of compressed air, liquids, and steam; *De automatis*, describing the construction of two miniature automatic theaters; *Dioptra*, on a new surveying instrument; *Catoptrica*, which only survives in Latin translation, on mirrors; *Mechanica*, three books surviving only in Arabic translation, on the theory and practice of moving weights; and the *Belopoeica*, on catapults. Only fragments survive of his

Cheiroballistra, which describes another catapult-type weapon. Hero also wrote a volume on water clocks, a commentary on Euclid's *Elements*, and the *Baroulkos*, on a special lifting machine, but these works have not survived. Two later works, the *Geodaesia* and *Liber Geoponicus*, are collections of extracts from his writings.

In his writings, Hero describes a large number of useful, entertaining, and instructive devices, but it is seldom clear which devices he himself invented. In some cases, he merely describes earlier inventions, perhaps with minor improvements of his own. The *Belopoeica*, for example, only describes earlier types of catapults, not contemporary designs. Furthermore, it is sometimes uncertain whether a described device was ever actually built or could have really functioned. Some historians have gone so far as to deny that Hero was an inventor at all, asserting that he merely collected, organized, and published the designs of earlier innovators. However, his nickname, *mechanicus* (machine man), and the practical advice scattered throughout his writings suggest that he was more than just a compiler of information.

Hero was probably an adult by 62 C.E., since his *Dioptra* describes a lunar eclipse that occurred on March 13 of that year. It is unclear when Hero died, but a series of tantalizing references in late first and early second century sources may reflect his activities. Suetonius, the imperial biographer, mentions that the emperor Nero showed off a new kind of water organ in 68 C.E. This instrument, Paul Keyser has suggested, may have been the work of Hero, who describes a hydraulic organ in the *Pneumatica*. Pliny the Elder, who died in the eruption of Vesuvius in 79 C.E., reports in his encyclopedic *Naturalis Historia* (c. 77 C.E.) that a new type of wine press had recently been invented. This too may be the work of Hero, since he describes an innovative screw press design in his *Mechanica*. In his biography of Vespasian, Suetonius reports that the emperor rewarded an unnamed engineer for inventing a device designed to move heavy columns. If, as has been suggested, this is a reference to Hero, who shows considerable interest in such devices, then he was still active in the 70's. It is also likely that Hero invented the *cheiroballistra*, the small, torsion-powered arrow shooter he describes in the work of the same name. This weapon seems to appear on Trajan's Column and thus probably saw use in Rome's wars with Dacia in the first decade of the second century.

Hero invented (or at least recorded the designs for) dozens of devices. Among the most important are the aeolipile, the dioptra, various automata, automatic doors, a coin-operated water fountain, a variety of trick containers for water and wine, a wind-powered organ, a machine

THE AEOLIPILE

Among the many inventions of Hero of Alexandria, none have exerted the same amount of fascination as his so-called aeolipile, or "wind ball," which some historians have described as the first steam engine and earliest jet turbine. Hero briefly explains the construction of this device in his *Pneumatica*. The device is quite simple, consisting of two metal chambers, three tubes, and a rod. The first chamber is a hollow hemisphere or covered cauldron and is meant to be filled with water. When this vessel is heated, the water gradually turns to steam and escapes through a tube or pipe leading to a hollow sphere. This pipe and a rod also attached to the cauldron hold up the sphere and are connected to it in such a way that the sphere can pivot around the axis they form. The steam, after entering the sphere, is allowed to escape through two additional L-shaped tubes set opposite one another along its circumference equidistant from the "poles" formed by the rod and tube connecting the sphere and the hemisphere. The exhaust ends of the L-shaped pipes point in opposite directions so that the force of the escaping steam causes the sphere to rotate around its axis. The classicist J. G. Landels, an expert in ancient science and engineering, reported that his own model of the aeolipile reached speeds of 1,500 revolutions per minute.

There continues to be some dispute over the precise significance of Hero's steam engine. Some scholars have essentially dismissed the device as no more than a toy without any practical application. Others have suggested that Hero intended the aeolipile not to do work but to demonstrate fundamental physical principles. This position seems reasonable given that the introduction to the *Pneumatica* explores the nature of air, water, and vacuum in general. Nevertheless, it is remarkable that this device, mentioned in no other ancient text, receives no special comment or explanation from Hero amid the other, more banal inventions described in this work. Another recurring debate concerning the aeolipile asks why Hero or some other ancient inventor did not adapt it for useful work, precipitating an ancient industrial revolution. The answer seems to be that the lack of proper fuel, construction materials, and tools impeded further development. Some have also suggested that the slave-based Roman economy did not place a sufficient premium on labor-saving machines to promote further development of the device.

for cutting female screws, a fire pump, self-regulating oil lamps, and the syringe. The dioptra was a forerunner of the theodolite, used by surveyors to measure horizontal and vertical angles. Hero's dioptra lacked the theodolite's telescope but could be used to excavate a straight tunnel through a hill or mountain from both ends simultaneously or estimate the distance to an inaccessible or dangerous spot such as an enemy's fortifications. The automata Hero describes include a miniature theater that would produce a multiact Greek tragedy complete with sound effects. His automatic doors opened a temple when a worshiper lit a fire on an external altar. The doors would close again when the fire was extinguished. Hero's coin-operated fountain worked in much the same way as the tank of a modern flush toilet. A coin fell through a slot onto a plate attached to a lever. The coin's weight depressed its end of the lever, lifting a plug attached to the other end and allowing water to flow out. Once the coin slipped off the plate, the plug returned to its initial position, stopping the flow of water. The *Pneumatica* describes a number of trick vessels in which one could pour wine and water and then, depending on which air holes were open or blocked, pour out either wine, water, or a mixture. Hero's windmill-powered organ is the only known application of wind power (aside from sailing) to survive from classical antiquity.

Impact

The mere fact that Hero's writings survived him suggests that later Greek and Roman thinkers considered his work to be important. Writing materials and scribes were expensive, so the preservation of Hero's work constituted a significant investment. A lack of sources makes it difficult to assess Hero's impact in antiquity, but Pappus of Alexandria, an early fourth century scholar, suggests that Hero had many followers. To this day, Hero's books remain a vital source for the study of ancient mathematics, engineering, surveying, and natural philosophy because so few other works on these subjects survive.

The impact of Hero's ideas and inventions in later periods is somewhat easier to gauge and seems to have been considerable. Scholars in the Islamic world preserved some of his writings, demonstrating their continued importance. Hero's wind-powered organ may have inspired Islamic engineers to develop the windmill. Many in both the Islamic world and the Byzantine Empire were inspired, directly or indirectly, by the wonderful automata described in the *Pneumatica* and sought to emulate them. Hero was not forgotten in medieval Europe, but interest in him increased dramatically in the Renaissance. In Italy and elsewhere, demand for automata grew. Humanist scholars also took an interest in Hero, particularly his ideas about the vacuum, and translated the *Pneumatica* into Latin, Italian, and German. Leonardo da Vinci, Francis Bacon, and Robert Boyle were all familiar with his writings. Hero's aeolipile even contributed to early efforts to design functional steam engines.

—*David B. Hollander*

Further Reading

Hall, Marie B., ed. *The Pneumatics of Hero of Alexandria: A Facsimile of the 1851 Woodcroft Edition*. 2d ed. London: Macdonald, 1971. Provides an illustrated translation of Hero's most famous work, which includes descriptions of automata, trick containers for liquids, lamps, musical instruments, a fire engine, and the aeolipile.

Keyser, Paul. "Suetonius Nero 41.2 and the Date of Heron Mechanicus of Alexandria." *Classical Philology* 83, no. 3 (1988): 218-220. Suggests that Hero invented the new type of water organ displayed by Nero at Rome in 68 C.E. and discusses the improvements Hero made in organ design.

Lewis, M. J. T. *Surveying Instruments of Greece and Rome*. New York: Cambridge University Press, 2001. Explores the instruments, methods, and texts relating to surveying in the Greco-Roman world. Includes a translation of most of Hero's *Dioptra* and ample illustrations.

Marsden, E. W. *Greek and Roman Artillery: Technical Treatises*. New York: Oxford University Press, 1971. Contains the original text, translations, and notes on five ancient artillery manuals, including Hero's *Belopoeica* and *Cheiroballistra*. Includes photographs of a full-scale model of the cheiroballistra.

Murphy, Susan. "Heron of Alexandria's *On Automaton-Making*." *History of Technology* 17 (1995): 1-44. Provides an annotated and illustrated translation of Hero's *Automatopoieca*, which describes the construction of miniature, automated displays. An introduction discusses the text's context and transmission.

Tuplin, C. J., and T. E. Rihll, eds. *Science and Mathematics in Ancient Greek Culture*. New York: Oxford University Press, 2002. Includes two chapters on Hero's work. J. J. Coulton's essay looks at the dioptra, while S. Cuomo's considers the content and purpose of the *Belopoeica*.

Tybjerg, Karin. "Wonder-Making and Philosophical Wonder in Hero of Alexandria." *Studies in History and Philosophy of Science* 34 (2003): 443-446. Discusses Hero's view of the field of mechanics in relation to philosophy, examining how his inventions could both amaze audiences and illustrate theories about the natural world.

See also: Archimedes; Giovanni Branca; Ctesibius of Alexandria; Leonardo da Vinci.

HEINRICH HERTZ

German physicist and electronic engineer

Hertz invented the first radio transmitter and receiver and used them to discover radio waves and confirm that they are electromagnetic waves that travel at the speed of light. He also discovered the photoelectric effect, in which light produces electricity.

Born: February 22, 1857; Hamburg (now in Germany)
Died: January 1, 1894; Bonn, Germany
Also known as: Heinrich Rudolf Hertz (full name)
Primary fields: Electronics and electrical engineering; physics
Primary inventions: Radio transmitter and receiver

EARLY LIFE

Heinrich Rudolf Hertz (HIN-rihk REW-dahlf HURTZ) was born on February 22, 1857, in Hamburg (now in Germany). His father, Gustav Ferdinand Hertz, was Jewish but converted to Christianity and raised his family as Lutherans. He was well known as a lawyer and became a senator in 1887. Heinrich's mother, Anna Elisabeth, was the daughter of a Frankfurt physician, Dr. Pfefferkorn. When Heinrich graduated from the Johanneum Gymnasium (secondary school) in 1875, he was first in his class, having studied Greek, Arabic, and Sanskrit. He was the eldest of four sons and one daughter.

After working for an engineering company in Frankfurt for a year, Hertz left in April of 1876 to enroll in engineering at the Dresden Technical Institute, but he left in September to fulfill a year of mandatory military service with the First Railway Guards Regiment in Berlin. He soon decided that his real interest was in science, and in 1877 he enrolled in physics at the University of Munich. A year later, he transferred to the prestigious Physical Institute at the University of Berlin, where he studied under Gustav Kirchhoff and Hermann von Helmholtz, two of the foremost physicists of the day.

Under the guidance of Helmholtz, Hertz won first prize for his electrical research entitled "Experiments to Determine an Upper Limit to the Kinetic Energy of an Electric Current." In 1880, he obtained his Ph.D. with a thesis on electromagnetic induction in rotating spheres, graduating magna cum laude. He then continued in Berlin for three years as the assistant of Helmholtz, publishing fifteen papers on both electrical and mechanical topics, which included early studies of contact forces associated with two objects under loading.

LIFE'S WORK

Heinrich Hertz was an unusual physicist in that he was skilled in both experimental and theoretical physics, both of which he employed during his short career. His first university appointment was in 1883 as a lecturer at the University of Kiel. He remained in contact with Helm-

Heinrich Hertz. (Library of Congress)