Definition: astronomy from *The Penguin Dictionary of Physics*

The study of the universe and its contents. The main branches of the subject are:

1. **Astrometry**, positional measurements of the stars and planets on the CELESTIAL SPHERE;
2. **Celestial mechanics**, relative motions of systems of bodies associated by GRAVITATIONAL FIELDS;
3. **Astrophysics**, the internal structure, properties, and evolution of celestial bodies, and the production and expenditure of energy in such systems and in the universe as a whole. COSMOLOGY, RADIO ASTRONOMY, X-RAY ASTRONOMY, INFRARED ASTRONOMY, and ultraviolet and gamma-ray astronomy are normally considered subsections of astrophysics.

Summary Article: astronomy from *The Columbia Encyclopedia*

branch of science that studies the motions and natures of celestial bodies, such as planets, stars, and galaxies; more generally, the study of matter and energy in the universe at large.

**Ancient Astronomy**

Astronomy is the oldest of the physical sciences. In many early civilizations the regularity of celestial motions was recognized, and attempts were made to keep records and predict future events. The first practical function of astronomy was to provide a basis for the calendar, the units of month and year being determined by astronomical observations. Later, astronomy served in navigation and timekeeping. The Chinese had a working calendar as early as the 13th cent. B.C. About 350 B.C., Shih Shen prepared the earliest known star catalog, containing 800 entries. Ancient Chinese astronomy is best known today for its observations of comets and supernovas. The Babylonians, Assyrians, and Egyptians were also active in astronomy. The earliest astronomers were priests, and no attempt was made to separate astronomy from astrology. In fact, an early motivation for the detailed study of planetary positions was the preparation of horoscopes.

**Greek Innovations**

The highest development of astronomy in the ancient world came with the Greeks in the period from 600 B.C. to A.D. 400. The methods employed by the Greek astronomers were quite distinct from those of earlier civilizations, such as the Babylonian. The Babylonian approach was numerical and best suited for studying the complex lunar motions that were of overwhelming interest to the Mesopotamian peoples. The Greek approach, on the contrary, was geometric and schematic, best suited for complete cosmological models. Thales, an Ionian philosopher of the 6th cent. B.C., is credited with introducing geometrical ideas into astronomy. Pythagoras, about a hundred years later, imagined the universe as a series of concentric spheres in which each of the seven “wanderers” (the sun, the moon, and the five known planets) were embedded. Eudoxus developed the idea of rotating spheres by introducing extra spheres for each of the planets to account for the observed complexities of their motions. This was the beginning of the Greek aim of providing a theory that would account for
all observed phenomena. Aristotle (384–322 B.C.) summarized much of the Greek work before him and remained an absolute authority until late in the Middle Ages. Although his belief that the earth does not move retarded astronomical progress, he gave the correct explanation of lunar eclipses and a sound argument for the spherical shape of the earth.

**The Alexandrian School and the Ptolemaic System**

The apex of Greek astronomy was reached in the Hellenistic period by the Alexandrian school. Aristarchus (c.310–c.230 B.C.) determined the sizes and distances of the moon and sun relative to the earth and advocated a heliocentric (sun-centered) cosmology. Although there were errors in his assumptions, his approach was truly scientific; his work was the first serious attempt to make a scale model of the universe. The first accurate measurement of the actual (as opposed to relative) size of the earth was made by Eratosthenes (284–192 B.C.). His method was based on the angular difference in the sun's position at the high noon of the summer solstice in two cities whose distance apart was known.

The greatest astronomer of antiquity was Hipparchus (190–120 B.C.). He developed trigonometry and used it to determine astronomical distances from the observed angular positions of celestial bodies. He recognized that astronomy requires accurate and systematic observations extended over long time periods. He therefore made great use of old observations, comparing them to his own. Many of his observations, particularly of the planets, were intended for future astronomers. He devised a geocentric system of cycles and epicycles (a compounding of circular motions) to account for the movements of the sun and moon.

Ptolemy (A.D. 85–165) applied the scheme of epicycles to the planets as well. The resulting Ptolemaic system was a geometrical representation of the solar system that predicted the motions of the planets with considerable accuracy. Among his other achievements was an accurate measurement of the distance to the moon by a parallax technique. His 13-volume treatise, the *Almagest*, summarized much of ancient astronomical knowledge and, in many translations, was the definitive authority for the next 14 centuries.

**Development of Modern Astronomy**

**The Copernican Revolution**

After the fall of Rome, European astronomy was largely dormant, but significant work was carried out by the Muslims and the Hindus. It was by way of Arabic translations that Greek astronomy reached medieval Europe. One of the great landmarks of the revival of learning in Europe was the publication (1543) by Nicolaus Copernicus (1473–1543) of his *De revolutionibus orbium coelestium* (On the Revolutions of the Celestial Spheres). According to the Copernican system, the earth rotates on its axis and, with all the other planets, revolves around the sun. The assertion that the earth is not the center of the universe was to have profound philosophical and religious consequences. Copernicus's principal claim for his new system was that it made calculations easier. He retained the uniform circular motion of the Ptolemaic system, but by placing the sun at the center, he was able to reduce the number of epicycles. Copernicus also determined the sidereal periods (time for one revolution around the sun) of the planets and their distance from the sun relative to the sun-earth distance (see astronomical unit).

**Brahe and Kepler**

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The great astronomer Tycho Brahe (1546–1601) was principally an observer; a conservative in matters of theory, he rejected the notion that the earth moves. Under the patronage of King Frederick II, Tycho established Uraniborg, a superb observatory on the Danish island of Hveen. Over a period of 20 years (1576–97), he and his assistants compiled the most accurate and complete astronomical observations to that time. At his death his records passed to Johannes Kepler (1571–1630), who had been his last assistant. Kepler spent nearly a decade trying to fit Tycho's observations, particularly of Mars, into an improved system of heliocentric circular motion. At last, he conceived the idea that the orbit of Mars was an ellipse with the sun at one focus. This led him to the three laws of planetary motion that bear his name (see Kepler's laws).

**Galileo's Telescope**

Galileo Galilei (1564–1642) made fundamental discoveries in both astronomy and physics; he is perhaps best described as the founder of modern science. Galileo was the first to make astronomical use of the telescope. His discoveries of the four largest moons of Jupiter and the phases of Venus were persuasive evidence for the Copernican cosmology. His discoveries of craters on the moon and blemishes on the sun (sunspots) discredited the ancient belief in the perfection of the heavens. These findings were announced in *The Sidereal Messenger*, a small book published in 1610. *Galileo's Dialogue on the Two Chief Systems of the World* (1632) was an eloquent argument for the Copernican system over the Ptolemaic. However, Galileo was called before the Inquisition and forced to renounce publicly all doctrines considered contrary to Scripture.

**Astrophysical Discoveries**

Isaac Newton (1642–1727), possibly the greatest scientific genius of all time, succeeded in uniting the sciences of astronomy and physics. His laws of motion and theory of universal gravitation provided a physical, dynamic basis for the merely descriptive laws of Kepler. Until well into the 19th cent., all progress in astronomy was essentially an extension of Newton's work. Edmond Halley's prediction that the comet of 1682 would return in 1758 was refined by A. C. Clairault, who included the perturbing effects of Jupiter and Saturn on the orbit to calculate the nearly exact date of the return of the comet. In 1781, William Herschel accidentally discovered a new planet, eventually named Uranus. Discrepancies between the observed and theoretical orbits of Uranus indicated the existence of a still more distant planet that was affecting Uranus's motion. J. C. Adams and U. J. J. Le Verrier independently calculated the position where the new planet, Neptune, was actually discovered (1846). Similar calculations for a large “Planet X” led in 1930 to the discovery of Pluto, now classed as a dwarf planet.

By the early 19th cent., the science of celestial mechanics had reached a highly developed state at the hands of Leonhard Euler, J. L. Lagrange, P. S. Laplace, and others. Powerful new mathematical techniques allowed solution of most of the remaining problems in classical gravitational theory as applied to the solar system. In 1801, Giuseppe Piazzi discovered Ceres, the first of many asteroids. When Ceres was lost to view, C. F. Gauss applied the advanced gravitational techniques to compute the position where the asteroid was subsequently rediscovered. In 1838, F. W. Bessel made the first measurement of the distance to a star; using the method of parallax with the earth's orbit as a baseline, he determined the distance of the star 61 Cygni to be 60 trillion mi (about 10 light-years), a figure later shown to be 40% too large.

**Modern Techniques, Discoveries, and Theories**

Astronomy was revolutionized in the second half of the 19th cent. by the introduction of techniques
based on photography and spectroscopy. Interest shifted from determining the positions and
distances of stars to studying their physical composition (see stellar structure and stellar evolution).
The dark lines in the solar spectrum that had been observed by W. H. Wollaston and Joseph von
Fraunhofer were interpreted in an elementary fashion by G. R. Kirchhoff on the basis of classical
physics, although a complete explanation came only with the quantum theory. Between 1911 and 1913,
Ejnar Hertzsprung and H. N. Russell studied the relation between the colors and luminosities of typical
stars (see Hertzsprung-Russell diagram). With the construction of ever more powerful telescopes (see
observatory), the boundaries of the known universe constantly increased. E. P. Hubble's study of the
distant galaxies led him to conclude that the universe is expanding (see Hubble’s law). Using Cepheid
variables as distance indicators, Harlow Shapley determined the size and shape of our galaxy, the Milky
Way. During World War II Walter Baade defined two “populations” of stars, and suggested that an
examination of these different types might trace the spiral shape of our own galaxy (see stellar
populations). In 1951 a Yerkes Observatory group led by William W. Morgan detected evidence of two
spiral arms in the Milky Way galaxy.

Various rival theories of the origin and overall structure of the universe, e.g., the big bang and steady
state theories, have been formulated (see cosmology). Albert Einstein's theory of relativity plays a
central role in all modern cosmological theories. In 1963, the moon passed in front of the radio source
3C-273, allowing Cyril Hazard to calculate the exact position of the source. With this information,
Maarten Schmidt photographed the object’s spectrum using the 200-in. (5-m) reflector on Palomar Mt.,
then the world's largest telescope. He interpreted the result as coming from an object, now known as a
quasar, at an extreme distance and receding from us at a substantial fraction of the speed of light. In
1967 Antony Hewish and Jocelyn Bell Burnell discovered a radio source a few hundred light years away
featuring regular pulses at intervals of about 1 second with an accuracy of repetition of one-millionth of
a second. This was the first discovered pulsar, a rapidly spinning neutron star emitting lighthouse-type
beams of energy, the end result of the death of a star in a supernova explosion.

The discovery by Karl Jansky in 1931 that radio signals were emitted by celestial bodies initiated the
science of radio astronomy. Most recently, the frontiers of astronomy have been expanded by space
exploration. Perturbations and interference from the earth's atmosphere make space-based
observations necessary for infrared, ultraviolet, gamma-ray, and X-ray astronomy. The Surveyor and
Apollo spacecraft of the late 1960s and early 1970s helped launch the new field of astrogeology. A
series of interplanetary probes, such as Mariner 2 (1962) and 5 (1967) to Venus, Mariner 4 (1965) and
6 (1969) to Mars, and Voyager 1 (1979) and 2 (1979), provided a wealth of data about Jupiter, Saturn,
Uranus, and Neptune; more recently, the Magellan probe to Venus (1990) and the Galileo probe to
Jupiter (1995) have continued this line of research (see satellite, artificial; space probe). The Hubble
Space Telescope, launched in 1990, has made possible visual observations of a quality far exceeding
those of earthbound instruments.

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