Italian astronomer and physicist associated with many of the important advances in science in the late Middle Ages. He made major investigations in mechanics, including experiments on acceleration, friction, inertia, and falling bodies. He improved the telescope and pioneered its use for astronomical observation, discovering mountains on the moon, many new stars, the four satellites of Jupiter, and the composition of the Milky Way. He also supported the theories of Copernicus concerning the motion of the planets.

**Definition:** **Galileo Galilei 1564-1642**, from *Dictionary of Energy*

Italian physicist and astronomer whose work founded the modern scientific method of deducing laws to explain the results of observation and experiment. In physics, Galileo discovered the properties of the pendulum, invented the thermometer, and formulated the laws that govern the motion of falling bodies. In astronomy, Galileo was the first to use the telescope to make observations of the Moon, Sun, planets, and stars.

Galileo was born in Pisa on 15 February 1564. His full name was Galileo Galilei, his father being Vincenzo Galilei (c.1520-1591), a musician and mathematician. Galileo received his early education from a private tutor at Pisa until 1575, when his family moved to Florence. He then studied at a monastery until 1581, when he returned to Pisa to study medicine at the university. Galileo was attracted to mathematics rather than medicine, however, and also began to take an interest in physics. In about 1583 he discovered that a pendulum always swings to and fro in the same period of time regardless of the amplitude (length) of the swing. He is said to have made this discovery by using his pulse to time the swing of a lamp in Pisa Cathedral.

Galileo remained at Pisa until 1585, when he left without taking a degree and returned home to Florence. There he studied the works of Euclid and Archimedes, and in 1586 extended Archimedes’ work in hydrostatics by inventing an improved version of the hydrostatic balance for measuring specific gravity. At this time, Galileo’s father was investigating the ratios of the tensions and lengths of vibrating strings that produce consonant intervals in music, and this work may well have demonstrated to Galileo that the validity of a mathematical formula could be tested by practical experiment.

In 1589 Galileo became professor of mathematics at the University of Pisa. He attacked the theories of Aristotle that then prevailed in physics, allegedly demonstrating that unequal weights fall at the same speed by dropping two cannon balls of different weights from the Leaning Tower of Pisa to show that they hit the ground together. Galileo also published his first ideas on motion in *De motu/On Motion* (1590).

Galileo remained in Pisa until 1592, when he became professor of mathematics at Padua. He flourished at Padua, and refined his ideas on motion over the next 17 years. He deduced the law of falling bodies in 1604 and came to an understanding of the nature of acceleration. In 1609 he was diverted from his work in physics by reports of the telescope, which had been invented in Holland the year before. Galileo immediately constructed his own telescopes and set about observing the heavens, publishing his findings in *Sidereus nuncius/The Starry Messenger* (1610). The book was a sensation throughout Europe and brought Galileo immediate fame. It resulted in a lifetime appointment to the University of Padua, but Galileo rejected the post and later in 1610 became mathematician and philosopher to the Grand Duke of Tuscany, under whose patronage he continued his scientific work at Florence.

In 1612 Galileo returned to hydrostatics and published a study of the behaviour of bodies in water, in which he championed Archimedes against Aristotle. In the following year he performed the same service for Nicolaus Copernicus, publicly espousing the heliocentric system. This viewpoint aroused the opposition of the church, which declared it to be heretical and in 1616 Galileo was instructed to abandon the Copernican theory. Galileo continued his studies in astronomy and mechanics without publicly supporting Copernicus although he was personally convinced. In 1624 Urban VIII became pope and Galileo obtained permission to present the arguments for the rival heliocentric and geocentric systems in an impartial way. The result, *Dialogue Concerning The Two Chief World Systems*, was published in 1632, but it was scarcely impartial. Galileo used the evidence of his telescope observations and experiments on motion to favour Copernicus, and immediately fell foul of the church again. The book was banned and Galileo was taken to Rome to face trial on a charge of heresy in April 1633. Forced to abjure his belief that the Earth moves around the Sun, Galileo is reputed to have muttered ‘Eppur si muove’ (‘Yet it does move’).
Galileo was sentenced to life imprisonment, but the sentence was commuted to house arrest and he was confined to his villa at Arcetri near Florence for the rest of his life. He continued to work on physics, and summed up his life’s work in *Discourses and Mathematical Discoveries Concerning Two New Sciences*. The manuscript of this book was smuggled out of Italy and published in Holland in 1638. By this time Galileo was blind, but he still continued his scientific studies. In these last years, he designed a pendulum clock. Galileo died in Arcetri on 8 January 1642.

Galileo made several fundamental contributions to mechanics. He rejected the impetus theory that a force or push is required to sustain motion, and identified motion in a horizontal plane and rotation as being ‘neutral’ motions that are neither natural nor forced. Galileo realized that gravity not only causes a body to fall, but that it also determines the motion of rising bodies and furthermore that gravity extends to the centre of the Earth. He found that the distance travelled by a falling body is proportional to the square of the time of descent. Galileo then showed that the motion of a projectile is made up of two components: one component consists of uniform motion in a horizontal direction and the other component is vertical motion under acceleration or deceleration due to gravity. This explanation was used by Galileo to refute objections to Copernicus based on the argument that birds and clouds would not be carried along with a turning or moving Earth. He explained that a horizontal component of motion provided by the Earth always exists to keep such objects in position even though they are not attached to the ground.

Galileo came to an understanding of uniform velocity and uniform acceleration by measuring the time it takes for bodies to move various distances. In an era without clocks, it was difficult to measure time accurately and Galileo may have used his pulse or a water clock - but not, ironically, the pendulum - to do so. He had the brilliant idea of slowing vertical motion by measuring the movement of balls rolling down inclined planes, realizing that the vertical component of this motion is a uniform acceleration due to gravity while the horizontal component is a uniform velocity. Even so, this work was arduous and it took Galileo many years to arrive at the correct expression of the law of falling bodies. This was presented in the *Two New Sciences*, together with his derivation that the square of the period of a pendulum varies with its length (and is independent of the mass of the pendulum bob). Galileo also deduced by combining horizontal and vertical motion that the trajectory of a projectile is a parabola. He furthermore realized that the law of falling bodies is perfectly obeyed only in a vacuum, and that air resistance always causes a uniform terminal velocity to be reached.

The other new science of Galileo’s masterwork was engineering, particularly the science of structures. His main contribution was to point out that the dimensions of a structure are important to its stability: a small structure will stand whereas a larger structure of the same relative dimensions may collapse. Using the laws of levers, Galileo went on to examine the strengths of the materials necessary to support structures.

Galileo’s other achievements include the invention of the thermometer in 1593. This device consisted of a bulb of air that expanded or contracted as the temperature changed, causing the level of a column of water to rise or fall. Galileo’s thermometer was very inaccurate because it neglected the effect of atmospheric pressure, but it is historically important as one of the first measuring instruments in science.

Galileo’s astronomical discoveries were a tribute to both his scientific curiosity and his ability to devise new techniques with instruments. Within two years of first building a telescope he had compiled fairly accurate tables of the orbits of four of Jupiter’s satellites and proposed that their frequent eclipses could serve as a means of determining longitude on land and at sea. His observations on sunspots are noteworthy for their accuracy and for the deductions he drew from them regarding the rotation of the Sun and the orbit of the Earth. He believed, however - following both Greek and medieval tradition - that orbits must be circular, not elliptical, in order to maintain the fabric of the cosmos in a state of perfection. This prejudice prevented him from deriving a full formulation of the law of inertia, which he himself discovered although it is usually attributed to the contemporary French mathematician René Descartes. Lacking the theory of Newtonian gravity, he hoped to explain the paths of the planets in terms of circular inertial orbits around the Sun.

Galileo was a pugnacious and sarcastic man, especially when confronted with those who could not or would not admit the validity of his observations and arguments. This characteristic symbolizes his position in the history of science, for with Galileo the idea that experiment and observation can be used to prove the validity of a proposed mathematical description of a phenomenon really became a working method in science. Although he built on the views and work of Archimedes and Copernicus, in his achievements Galileo can be considered to have founded not only classical mechanics and observational astronomy, but the method of modern science overall. In mechanics Isaac Newton developed Galileo’s work into a full understanding of inertia, which Galileo had not quite grasped, and arrived at the basic laws of motion underlying Galileo’s discoveries.

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