12

GALILEO GALILEI

1564 - 1642

Galileo Galilei, the great Italian scientist who was probably more responsible for the development of the scientific method than any other individual, was born in 1564, in the city of Pisa. As a young man, he studied at the University of Pisa, but dropped out for financial reasons. Nevertheless, he was able, in 1589, to obtain a teaching position at that university. A few years later, he joined the faculty of the University of Padua and remained there until 1610. It was during this period that the bulk of his scientific discoveries were made.

Galileo's first important contributions were made in mechanics. Aristotle had taught that heavy objects fall at a more rapid rate than light objects, and generations of scholars had accepted this assertion on the Greek philosopher's authority. Galileo, however, decided to test it, and through a series of experiments, he soon found that Aristotle had been incorrect. The fact is that heavy and light objects fall at the same velocity except to the extent that they are retarded by the friction of the air. (Incidently, the tradition that Galileo performed these experiments by dropping objects from the Leaning Tower of Pisa seems to be without foundation.)

Having learned this, Galileo took the next step. He carefully measured the distance that objects fall in a given period of time and found that the distance traversed by a falling object is proportional to the square of the number of seconds it has been falling. This discovery (which implies a uniform rate of acceleration) is significant in itself. Even more important, Galileo was able to summarize the results of a series of experiments by a mathematical formula. The extensive use of mathematical formulas and mathematical methods is an important characteristic of modern science.

Another of Galileo's major contributions was his discovery of the law of inertia. Previously, people had believed that a moving object would naturally tend to slow down and stop unless some force were exerted to keep it moving. But Galileo's experiments indicated that the common belief was erroneous. If retarding forces, such as friction, could be eliminated, a moving object would naturally tend to continue moving indefinitely. This important principle, which Newton restated clearly and incorporated into his own system as the first law of motion, is one of the vital principles of physics.

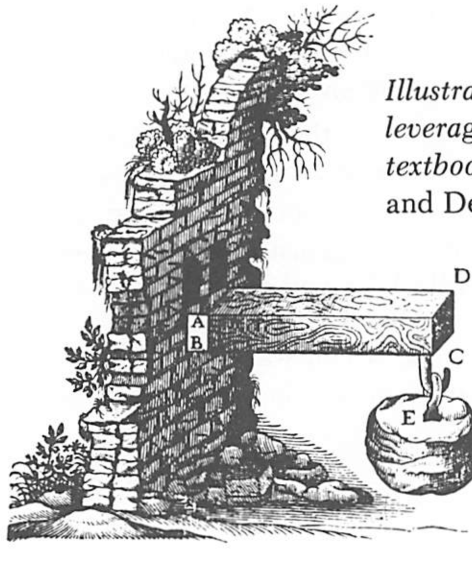
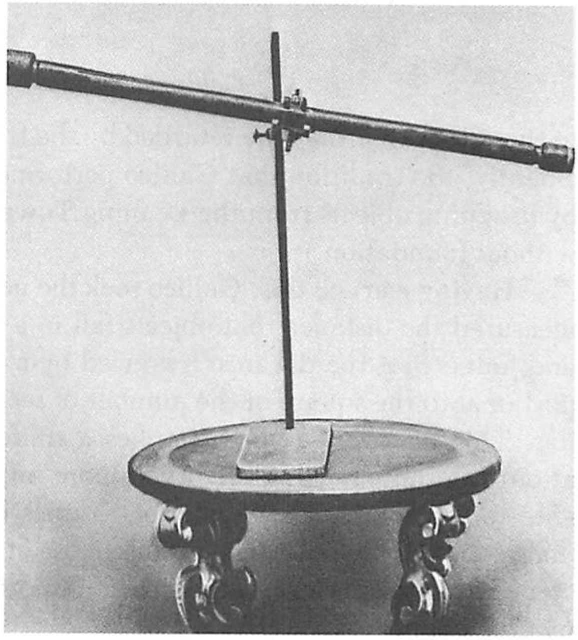


Illustration of Galilean law of leverage from Galileo's physics textbook Mathematical Discourses and Demonstrations.



Galileo's telescope.

Galileo's most celebrated discoveries were in the field of astronomy. Astronomical theory in the early 1600s was in a state of great ferment, with an important dispute going on between the followers of the heliocentric theory of Copernicus and the adherents of the earlier geocentric theory. As early as 1604, Galileo had announced his belief that Copernicus was correct, but at that time he had no method of proving it. In 1609, however, Galileo heard of the invention of the telescope in Holland. Although he had only the barest description of the device, Galileo's genius was such that he was soon able to construct a vastly superior telescope himself. With this new tool, he turned his observational talents to the heavens, and in a single year made a whole series of major discoveries.

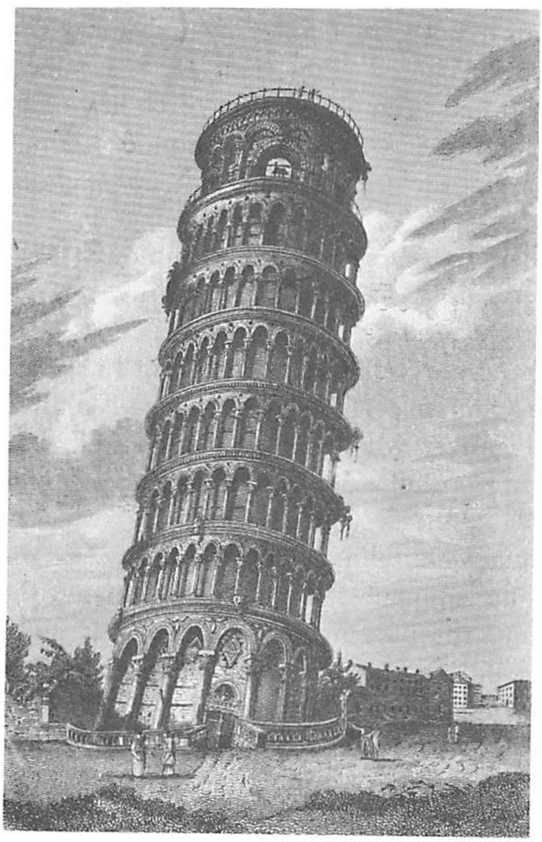
He looked at the moon and saw that it was not a smooth sphere, but had numerous craters and high mountains on it. Celestial objects, he concluded, were not smooth and perfect after all, but had the same sort of irregularities that one observed on earth. He looked at the Milky Way and saw that it was not a milky, nebulous body after all, but was composed of an enormous number of individual stars, which were so far away that the naked eye tended to blur them together. He looked at the planets and saw that four moons revolved around Jupiter. Here was clear evidence that an astronomical body could revolve about a planet other than Earth. He looked at the sun and observed sunspots. (Actually, other persons had observed sunspots before him, but Galileo publicized his observations more effectively and brought sunspots to the attention of the scientific world.) He observed that the planet Venus had phases quite similar to the phases of the moon. This became a significant piece of evidence corroborating the Copernican theory that the earth and all the other planets revolve around the sun.

The invention of the telescope and the series of discoveries that resulted from it made Galileo famous. However, by supporting the theory of Copernicus he aroused opposition in important Church circles, and in 1616 he was ordered to refrain from teaching the Copernican hypothesis. Galileo chafed under this restriction for several years. When the Pope died, in 1623, he was succeeded by a man who had been an admirer of Galileo. The following year the new Pope, Urban VIII, hinted (though somewhat ambiguously) that the prohibition would no longer be in force.

Galileo spent the next six years composing his most famous work, the *Dialogue Concerning the Two Chief World Systems.* This book was a masterly exposition of the evidence in favor of the Copernican theory, and the book was published in 1632 *with* the imprimatur of the Church censors. Nevertheless, Church authorities responded in anger when the book appeared, and Galileo was soon brought to trial before the Inquisition in Rome on charges of having violated the 1616 prohibition.

It seems clear that many churchmen were unhappy with the decision to prosecute the eminent scientist. Even under the Church law of the time, the case against Galileo was questionable, and he was given a comparatively light sentence. He was not, in fact, confined to jail at all, but merely to house arrest in his own comfortable villa in Arcetri. Theoretically, he was to have no visitors, but that provision of the sentence was not enforced. His only other punishment was the requirement that he publicly recant his view that the earth moved around the sun. This the sixty-nine-year-old scientist did in open court. (There is a famous and probably apocryphal story that after he finished making his retraction, Galileo looked down to the earth and whispered softly, "It still moves.") In Arcetri he continued to write on mechanics. He died there, in 1642.

Galileo's enormous contribution to the advancement of science has long been recognized. His importance rests in part on his scientific discoveries such as the law of inertia, his invention of the telescope, his astronomical observations, and his genius in proving the Copernican hypothesis. Of greater importance,



The Leaning Tower of Pisa, from which Galileo supposedly demonstrated the laws of falling bodies.

however, is his role in the development of the methodology of science. Most previous natural philosophers, taking their cues from Aristotle, had made qualitative observations and categorized phenomena; but Galileo measured phenomena and made quantitative observations. This emphasis on careful quantitative measurements has since become a basic feature of scientific research.

Galileo is probably more responsible than any other man for the empirical attitude of scientific research. It was he who first insisted upon the necessity of performing experiments. He rejected the notion that scientific questions could be decided by reliance upon authority, whether it be the pronouncements of the Church or the assertions of Aristotle. He also rejected reliance on complex deductive schemes that were not based on a firm foundation of experiment. Medieval scholastics had discussed at great length what *should* happen and *why* things happen, but Galileo insisted upon performing experiments to determine what actually *did* happen. His scientific outlook was distinctly nonmystical; in this respect, he was even more modern than some of his successors, such as Newton.

Galileo, it might be noted, was a deeply religious man. Despite his trial and conviction, he did not reject either religion or the church, but only the attempt of Church authorities to stifle investigation of scientific matters. Later generations have quite rightly admired Galileo as a symbol of revolt against dogmatism, and against authoritarian attempts to stifle freedom of thought. Of greater importance, however, is the role he played in founding modern scientific method.