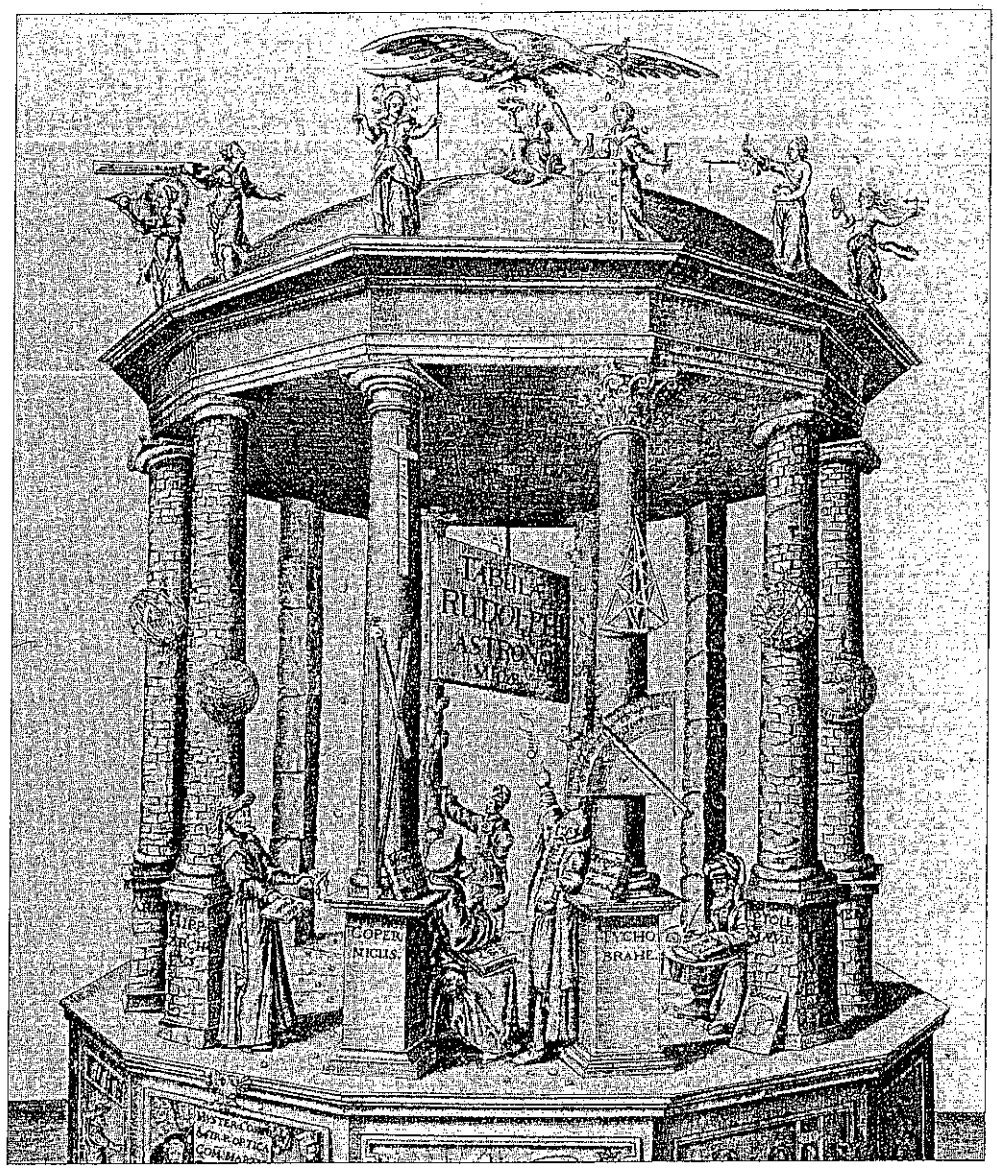
CHAPTER 2

The Scientific Revolution



JOHANNES KEPLER's vision of the "House of Astronomy" from his book *Tabulae Rudolphinae*, 1627. Each pillar bears the name of such important contributors to the new science as Ptolemy, Copernicus, and Tycho Brahe. Astronomical instruments of the time hang from the pillars. *(Fotomas Index)*

The Scientific Revolution of the sixteenth and seventeenth centuries replaced the medieval view of the universe with a new cosmology and produced a new way of investigating nature. It overthrew the medieval conception of nature as a hierarchical order ascending toward a realm of perfection. Rejecting reliance on authority, the thinkers of the Scientific Revolution affirmed the individual's ability to know the natural world through the method of mathematical reasoning, the direct observation of nature, and carefully controlled experiments.

The medieval view of the universe had blended the theories of Aristotle and Ptolemy, two ancient Greek thinkers, with Christian teachings. In that view, a stationary earth stood in the center of the universe just above hell. Revolving around the earth were seven planets: the moon, Mercury, Venus, the sun, Mars, Jupiter, and Saturn. Because people believed that earth did not move, it was not considered a planet. Each planet was attached to a transparent sphere that turned around the earth. Encompassing the universe was a sphere of fixed stars; beyond the stars lay three heavenly spheres, the outermost of which was the abode of God. An earth-centered universe accorded with the Christian idea that God had created the universe for men and women and that salvation was the aim of life.

Also agreeable to the medieval Christian view was Aristotle's division of the universe into a lower, earthly realm and a higher realm beyond the moon. Two sets of laws operated in the universe, one on earth and the other in the celestial realm. Earthly objects were composed of four elements: earth, water, fire, and air; celestial objects were composed of the divine ether—a substance too pure, too clear, too fine, too spiritual to be found on earth. Celestial objects naturally moved in perfectly circular orbits around the earth; earthly objects, composed mainly of the heavy elements of earth and water, naturally fell downward, whereas objects made of the lighter elements of air and fire naturally flew upward toward the sky.

The destruction of the medieval world picture began with the publication in 1543 of *On the Revolutions of the Heavenly Spheres,* by Nicolaus Copernicus, a Polish mathematician, astronomer, and clergyman. In Copernicus's system, the sun was in the center of the universe, and the earth was another planet that moved around the sun. Most thinkers of the time, committed to the Aristotelian-Ptolemaic system and to the biblical statements that seemed to support it, rejected Copernicus's conclusions.

The work of Galileo Galilei, an Italian mathematician, astronomer, and physicist, was decisive in the shattering of the medieval cosmos and the shaping of the modern scientific outlook. Galileo advanced the modern view that knowledge of nature derives from direct observation and from mathematics. For Galileo, the universe was a "grand book which . . . is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without

which it is humanly impossible to understand a single word of it." Galileo also pioneered experimental physics, advanced the modern idea that nature is uniform throughout the universe, and attacked reliance on scholastic authority rather than on experimentation in resolving scientific controversies.

Johannes Kepler (1571–1630), a contemporary of Galileo, discovered three laws of planetary motion that greatly advanced astronomical knowledge. Kepler showed that the path of a planet was an ellipse, not a circle as Ptolemy (and Copernicus) had believed, and that planets do not move at uniform speed but accelerate as they near the sun. He devised formulas to calculate accurately both a planet's speed at each point in its orbit around the sun and a planet's location at a particular time. Kepler's laws provided further evidence that Copernicus had been right, for they made sense only in a sun-centered universe, but Kepler could not explain why planets stayed in their orbits rather than flying off into space or crashing into the sun. The resolution of that question was left to Sir Isaac Newton.

Newton's great achievement was integrating the findings of Copernicus, Galileo, and Kepler into a single theoretical system. In *Principia Mathematica* (1687), he formulated the mechanical laws of motion and attraction that govern celestial and terrestrial objects.

The creation of a new model of the universe was one great achievement of the Scientific Revolution; another accomplishment was the formulation of the scientific method. The scientific method encompasses two approaches to knowledge, which usually complement each other: the empirical (inductive) and the rational (deductive). Although all sciences use both approaches, the inductive method is generally more applicable in such descriptive sciences as biology, anatomy, and geology, which rely on the accumulation of data. In the inductive approach, general principles are derived from analyzing external experiences—observations and the results of experiments. In the deductive approach, used in mathematics and theoretical physics, truths are derived in successive steps from indubitable axioms. Whereas the inductive method builds its concepts from an analysis of sense experience, the deductive approach constructs its ideas from self-evident principles that are conceived by the mind itself without external experience. The deductive and inductive approaches to knowledge, and their interplay, have been a constantly recurring feature in Western intellectual history since the rationalism of Plato and the empiricism of Aristotle. The success of the scientific method in modern times arose from the skillful synchronization of induction and deduction by such giants as Leonardo, Copernicus, Kepler, Galileo, and Newton.

The Scientific Revolution was instrumental in shaping the modern outlook. It destroyed the medieval conception of the universe and established the scientific method as the means for investigating nature and acquiring knowledge, even in areas having little to do with the