CHAPTER PREVIEW

The Scientific Revolution
- What was revolutionary in the new attitudes toward the natural world?

The Enlightenment
- How did a new spirit of critical and rational thinking affect ideas about society and human relations?

Enlightened Absolutism
- What impact did new ways of thinking have on monarchical absolutism and those under its rule?

The Growth of Consumerism and the Atlantic World
- How did the growth of consumerism and the Atlantic economy interact with Enlightenment ideas?

The Scientific Revolution

- What was revolutionary in the new attitudes toward the natural world?

A noted historian has said that the scientific revolution, which lasted roughly from 1540 to 1690, was "the real origin both of the modern world and the modern mentality."[1] Through new methods of investigating the physical world, Western society began to come to a new understanding of astronomy, physics, and medicine based on both experimentation and reasoning.

Scientific Thought Through the Early 1500s

The term *science* as we use it today came into use only in the nineteenth century. Prior to the scientific revolution, many different scholars and practitioners were involved in aspects of what came together to form science. One of the most important disciplines was **natural philosophy**, which focused on fundamental questions about the nature of the universe, its purpose, and how it functioned. In the early 1500s natural philosophy was still based primarily on the ideas of Aristotle, the great Greek philosopher of the fourth century B.C.E. Medieval theologians such as Thomas Aquinas brought Aristotelian philosophy into harmony with Christian doctrines. According to the revised Aristotelian view, a motionless earth was fixed at the center of the universe and was encompassed by ten separate concentric crystal spheres in which were embedded the moon, sun, planets, and stars. Beyond the spheres was Heaven, with the throne of God and the souls of the saved. Angels kept the spheres moving in perfect circles.

Aristotle's cosmology made intellectual sense, but it could not account for the observed motions of the stars and planets and, in particular, provided no explanation for the apparent backward motion of the planets (which we now know

The Aristotelian Universe as Imagined in the Sixteenth Century A round earth is at the center, surrounded by spheres of water, air, and fire. Beyond this small nucleus, the moon, the sun, and the five planets were embedded in their own rotating crystal spheres, with the stars sharing the surface of one enormous sphere. Beyond, the heavens were composed of unchanging ether. (Image Select/Art Resource, NY) occurs as planets closer to the sun periodically overtake the earth on their faster orbits). The great second-century Greek scholar Ptolemy offered a theory for this phenomenon. According to Ptolemy, the planets moved in small circles, called epicycles, each of which moved in turn along a larger circle or deferent. Ptolemaic astronomy was less elegant than Aristotle's neat nested circles and required complex calculations, but it provided a surprisingly accurate model for predicting planetary motion.

Aristotle's views, revised by medieval philosophers, also dominated thinking about physics and motion on earth. Aristotle had distinguished sharply between the world of the celestial spheres and that of the earth — the sublunar world. The sublunar realm was made up of four imperfect, changeable elements: air, fire, water, and earth. The spheres, however, consisted of a perfect, incorruptible "quintessence," or fifth essence. Aristotle and his followers also believed that a uniform force moved an object at a constant speed and that the object would stop as soon as that force was removed. Both of these views would be challenged based on new observations and analysis of the physical world.

CHRONOLOGY

ca. 1540–1690	Scientific revolution
ca. 1690–1789	Enlightenment
ca. 1700–1789	Growth of book publishing
1720–1780	Rococo style in art and decoration
1740–1748	War of Austrian Succession
1740–1780	Reign of the empress Maria Theresa
1740–1786	Reign of Frederick the Great of Prussia
ca. 1740–1789	French salons led by elite women
1762–1796	Reign of Catherine the Great of Russia
1765	Philosophes publish *Encyclopedia: The Rational Dictionary of the Sciences, the Arts, and the Crafts*
1780–1790	Reign of Joseph II of Austria
1791	Establishment of the Pale of Settlement
1792	Establishment of mining school in Mexico City as part of reforms

Origins of the Scientific Revolution

Why did Aristotelian teachings give way to new views about the universe? The first important driver of the scientific revolution was the medieval university. By the thirteenth century permanent universities had been established in western Europe. In the fourteenth and fifteenth centuries leading universities established new professorships of mathematics, astronomy, and physics (natural philosophy) within their faculties of philosophy. Although the prestige of the new fields was low, a permanent community of scholars was now focused on investigating scientific problems

Medieval scholarship in the universities was based on the study of ancient texts, whose wisdom was considered authoritative. Contact with Muslims in Spain and Sicily brought awareness of many ancient texts that survived only in Arabic versions, and these were translated into Latin in the twelfth century. In some instances, such as mathematics and astronomy, the translations were accompanied by learned commentaries that went beyond ancient learning. Arabic and Persian mathematicians, for example, invented algebra, the concept of the algorithm, and decimal point notation, while Arabic astronomers improved on measurements recorded in ancient works.

Second, the Renaissance also stimulated scientific progress. Renaissance patrons played a role in funding scientific investigations, as they did art and literature. The goal of exploration in late fifteenth and sixteenth centuries was not only to find wealth and Christian converts, but also to increase Europeans' knowledge about the wider world. In addition, Renaissance artists' turn toward realism and their use of geometry to convey three-dimensional perspective encouraged scholars to practice close observation and to use mathematics to describe the natural world. Furthermore, the Renaissance rise of printing provided a faster and less expensive way to circulate knowledge across Europe.

The navigational problems of long sea voyages in the age of overseas expansion were a third factor in the scientific revolution. To help solve these problems, inventors developed many new scientific instruments, such as the telescope, barometer, thermometer, pendulum clock, microscope, and air pump. Better instruments, which permitted more accurate observations, often led to important new knowledge.

- **natural philosophy** An early modern term for the study of the nature of the universe, its purpose, and how it functioned; it encompassed what we call "science" today.

Finally, recent historical research has focused on the contribution of practices now regarded as far beyond the realm of science. For most of human history, interest in astronomy was inspired by the belief that the changing relationships between planets and stars influenced events on earth. Many of the most celebrated astronomers were also astrologers. Used as a diagnostic tool in medicine, astrology formed a regular part of the curriculum of medical schools. Centuries-old practices of magic and alchemy also remained important traditions for participants in the scientific revolution. The idea that objects possessed hidden or "occult" qualities that allowed them to affect other objects was a particularly important legacy of the magical tradition. Such hidden qualities helped inspire an important new law of physics (see page 530).

Copernican Hypothesis

The first great departure from the medieval understanding of the physical world system was the work of the Polish cleric Nicolaus Copernicus (1473–1543). After studying at the university of Kraków, Copernicus departed for Italy, where he studied astronomy, medicine, and church law at the famed universities of Bologna, Padua, and Ferrara. In the course of his study of astronomy, Copernicus came to believe that Ptolemy's cumbersome and occasionally inaccurate rules detracted from the majesty of a perfect creator. He preferred an ancient Greek idea: that the sun, rather than the earth, was at the center of the universe.

Finishing his university studies and returning to a church position in East Prussia, Copernicus worked on his hypothesis from 1506 to 1530. Without questioning the Aristotelian belief in crystal spheres or the idea that circular motion was divine, Copernicus theorized that the stars and planets, including the earth, revolved around a fixed sun. Fearing the ridicule of other astronomers, Copernicus did not publish his *On the Revolutions of the Heavenly Spheres* until 1543, the year of his death.

The **Copernican hypothesis** presented a revolutionary view of the universe and brought sharp attacks from religious leaders, especially Protestants, who objected to the idea that the earth moved but the sun did not. Protestant leaders John Calvin and Martin Luther condemned Copernicus. Luther noted that the theory was counter to the Bible: "as the Holy Scripture tells us, so did Joshua bid the sun stand still and not the earth."[2] Catholic reaction was milder at first. The Catholic Church had never held to literal interpretations of the Bible, and not until 1616 did it officially declare the Copernican hypothesis false.

Other events were almost as influential in creating doubts about traditional astronomical ideas. In 1572 a new star appeared and shone very brightly for almost two years. The new star, which was actually a distant exploding star, seemed to contradict the idea that the heavenly spheres were unchanging and therefore perfect. In 1577 a new comet suddenly moved through the sky, cutting a straight path across the supposedly impenetrable crystal spheres. It was time, as a sixteenth-century scientific writer put it, for "the radical renovation of astronomy."[3]

Proving Copernicus Right

One astronomer who agreed with Copernicus was the Danish astronomer Tycho Brahe (TEE-koh BRAH-hee; 1546–1601). Brahe established himself as Europe's leading astronomer with his detailed observations of the new star of 1572. Aided by grants from the king of Denmark, Brahe built the most sophisticated observatory of his day.

Upon the king's death, Brahe acquired a new patron in the Holy Roman emperor Rudolph II and built a new observatory in Prague. In return for the emperor's support, he pledged to create new and improved tables of planetary motions, dubbed the *Rudolfine Tables*. For twenty years Brahe observed the stars and planets with his naked eye, compiling much more complete and accurate data than ever before. His limited understanding of mathematics and his sudden death in 1601, however, prevented him from making much sense out of his mass of data.

It was left to Brahe's young assistant, Johannes Kepler (1571–1630), to rework Brahe's mountain of observations. A brilliant mathematician, Kepler was inspired by his belief that the universe was built on mystical mathematical relationships and a musical harmony of the heavenly bodies.

Kepler's examination of his predecessor's findings convinced him that they could not be explained by Ptolemy's astronomy. Abandoning the notion of epicycles and deferents, Kepler developed three revolutionary laws of planetary motion. First, he demonstrated that the orbits of the planets around the sun are elliptical rather than circular. Second, he demonstrated that the planets do not move at a uniform speed in their orbits. When a planet is close to the sun it moves more rapidly, and it slows as it moves farther away from the sun. Finally, Kepler's third law stated that the time a planet takes to make its complete orbit is precisely related to its distance from the sun.

- **Copernican hypothesis** The idea that the sun, not the earth, was the center of the universe.
- **law of inertia** A law formulated by Galileo that states that motion, not rest, is the natural state of an object, and that an object continues in motion forever unless stopped by some external force.

Kepler's contribution was monumental. Whereas Copernicus had speculated, Kepler proved mathematically the precise relations of a sun-centered (solar) system. His work demolished the old system of Aristotle and Ptolemy, and in his third law he came close to formulating the idea of universal gravitation (see page 530). In 1627 he also fulfilled Brahe's pledge by completing the *Rudolfine Tables* begun so many years earlier. These tables were used by astronomers for many years.

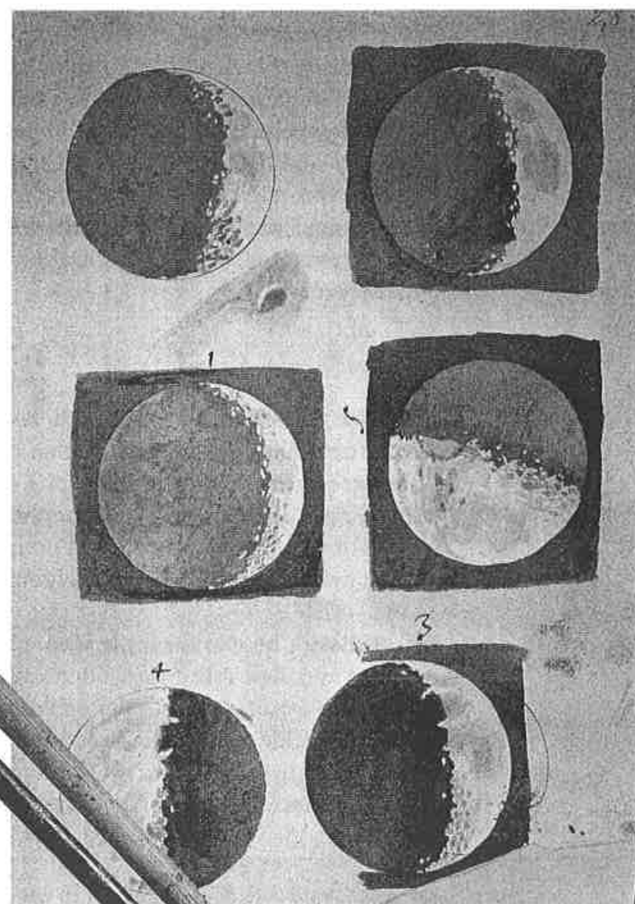
Kepler was not, however, the consummate modern scientist that his achievements suggest. His duties as court mathematician included casting horoscopes, and his own diary was based on astrological principles. He also wrote at length on cosmic harmonies and explained, for example, elliptical motion through ideas about the beautiful music created by the combined motion of the planets. His career exemplifies the complex interweaving of rigorous empirical observations and mystical beliefs in the emerging science of his day.

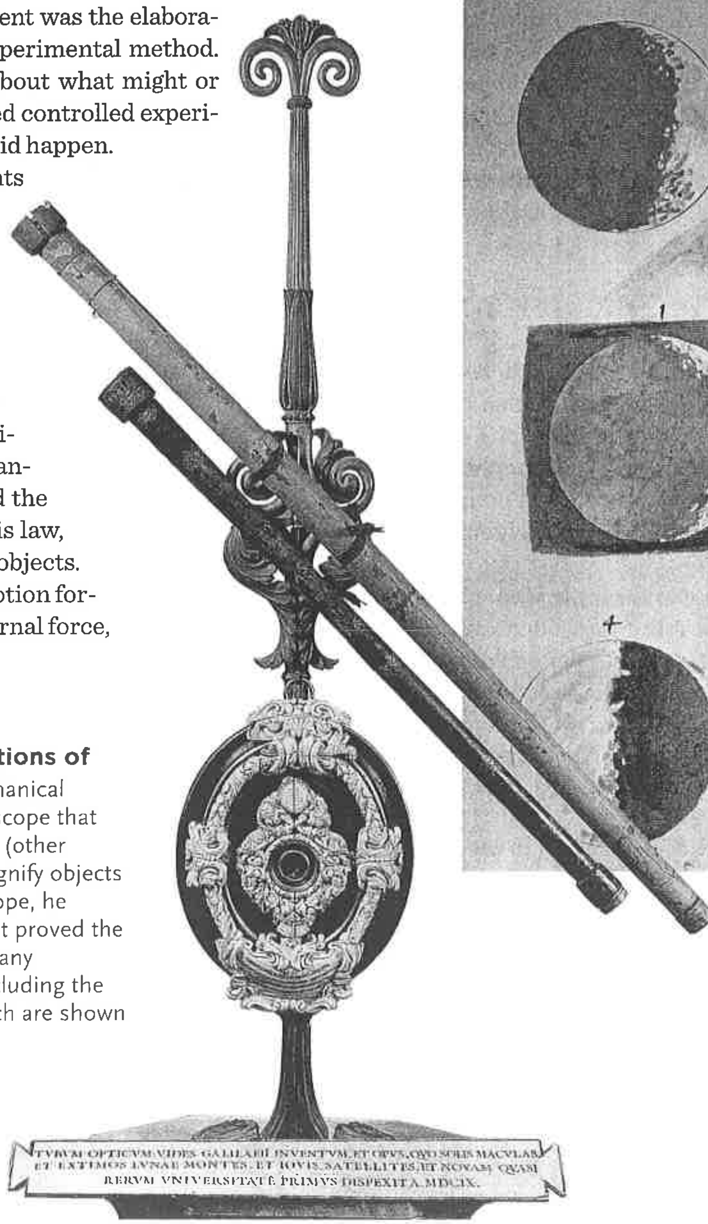
While Kepler was unraveling the mysteries of planetary motion, a young Florentine named Galileo Galilei (1564–1642) was challenging old ideas about motion on earth. Galileo's achievement was the elaboration and consolidation of the experimental method. That is, rather than speculate about what might or should happen, Galileo conducted controlled experiments to find out what actually did happen.

In some of his experiments Galileo measured the movement of a rolling ball across a surface, repeating the action again and again to verify his results. In his famous acceleration experiment, he showed that a uniform force — in this case, gravity — produced a uniform acceleration. Through another experiment, he formulated the **law of inertia**. According to this law, rest is not the natural state of objects. Rather, an object continues in motion forever unless stopped by some external force, such as friction. His discoveries thus proved Aristotelian physics wrong.

Galileo also applied the experimental method to astronomy. On hearing details about the invention of the telescope in Holland, Galileo made one for himself. He quickly discovered the first four moons of Jupiter, which clearly suggested that Jupiter could not possibly be embedded in an impenetrable crystal sphere as Aristotle and Ptolemy maintained. This discovery provided new evidence for the Copernican theory, in which Galileo already believed. Galileo then pointed his telescope at the moon. He wrote in 1610 in *Siderus Nuncius*:

> By the aid of a telescope anyone may behold [the Milky Way] in a manner which so distinctly appeals to the senses that all the disputes which have tormented philosophers through so many ages are exploded by the irrefutable evidence of our eyes, and we are freed from wordy disputes upon the subject.[4]





Galileo's Telescopic Observations of the Moon Among the many mechanical devices Galileo invented was a telescope that could magnify objects twenty times (other contemporary telescopes could magnify objects only three times). Using this telescope, he obtained the empirical evidence that proved the Copernican system. He sketched many illustrations of his observations, including the six phases of the moon, two of which are shown here. (Scala/Art Resource, NY)

Reading these famous lines, one feels a crucial corner in Western civilization being turned. A new method of learning and investigating was being developed, in which scholars relied more on observable evidence and critical thinking than on established authority. This method proved useful in any field of inquiry. A historian investigating documents of the past, for example, is not so different from a Galileo studying stars and rolling balls.

As early as 1597, when Johannes Kepler sent Galileo an early publication defending Copernicus, Galileo wrote back agreeing with his position and confessing he lacked the courage to follow Kepler's example. Within the Catholic world, expressing public support for Copernicus was increasingly dangerous. In 1616 the Holy Office placed the works of Copernicus and his supporters, including Kepler, on a list of books Catholics were forbidden to read.

Out of caution Galileo silenced his beliefs for several years, until in 1623 he saw new hope with the ascension of Pope Urban VIII, a man sympathetic to developments in the new science. However, Galileo's 1632 *Dialogue on the Two Chief Systems of the World* went too far. Published in Italian and widely read, this work openly lampooned the traditional views of Aristotle and Ptolemy and defended those of Copernicus. In 1633 Galileo was tried for heresy by the papal Inquisition. Imprisoned and threatened with torture, the aging Galileo recanted, "renouncing and cursing" his Copernican errors.

Newton's Synthesis

Despite the efforts of the church, by about 1640 the work of Brahe, Kepler, and Galileo had been largely accepted by the scientific community. But the new findings failed to explain what forces controlled the movement of the planets and objects on earth. That challenge was taken up by English scientist Isaac Newton (1642–1727).

Although he was a genius who united the experimental and theoretical-mathematical sides of modern science, Newton — like Kepler and other practitioners of the scientific revolution — was far from being the perfect rationalist so glorified by writers in the eighteenth and nineteenth centuries. For example, he was intensely religious and also fascinated by alchemy, whose practitioners believed (among other things) that base metals could be turned into gold.

Nevertheless, Newton dedicated himself to scientific pursuits from a young age. Born into the lower English gentry, he enrolled at Cambridge University in 1661. He arrived at some of his most basic ideas about physics in 1666 at age twenty-four but was unable to prove them mathematically. In 1684, after years of studying optics, Newton returned to physics for eighteen extraordinarily intensive months. The result was his towering accomplishment, a single explanatory system that integrated the astronomy of Copernicus, as corrected by Kepler's laws, with the physics of Galileo and his predecessors. Newton did this through a set of mathematical laws that explain motion and mechanics. These laws were published in 1687 in Newton's *Mathematical Principles of Natural Philosophy* (also known as the *Principia*). Because of their complexity, it took scientists and engineers two hundred years to work out all their implications.

The key feature of the Newtonian synthesis was the **law of universal gravitation**. According to this law, each body in the universe attracts every other body in a precise mathematical relationship, whereby the force of attraction is proportional to the quantity of matter of the objects and inversely proportional to the square of the distance between them. The whole universe — from Kepler's elliptical orbits to Galileo's rolling balls — was unified in one majestic system. Newton's synthesis prevailed until the twentieth century.

Bacon, Descartes, and the Scientific Method

One of the keys to achieving a better understanding of the world was the development of better ways of obtaining knowledge. Two important thinkers, Francis Bacon (1561–1626) and René Descartes (day-KAHRT; 1596–1650), were influential in describing and advocating for improved scientific methods based, respectively, on experimentation and mathematical reasoning.

The English politician and writer Francis Bacon was the greatest early propagandist for the new experimental method. Rejecting the Aristotelian and medieval method of using speculative reasoning to build general theories, Bacon argued that new knowledge had to be pursued through empirical research. The researcher who wants to learn more about leaves or rocks, for example, should not speculate about the subject but should rather collect a multitude of specimens and then compare and analyze them to derive general principles. Bacon's contribution was to formalize the empirical method, which had already been used by Brahe and Galileo, into the general theory of inductive reasoning known as **empiricism**.

- **law of universal gravitation** Newton's law that all objects are attracted to one another and that the force of attraction is proportional to the object's quantity of matter and inversely proportional to the square of the distance between them.
- **empiricism** A theory of inductive reasoning that calls for acquiring evidence through observation and experimentation rather than reason and speculation.
- **Cartesian dualism** Descartes's view that all of reality could ultimately be reduced to mind and matter.

On the continent, more speculative methods retained support. In 1619, as a twenty-three-year-old soldier serving in the Thirty Years' War (1618–1648), the French philosopher René Descartes experienced a life-changing intellectual vision one night. Descartes saw that there was a perfect correspondence between geometry and algebra and that geometrical spatial figures could be expressed as algebraic equations and vice versa. A major step forward in the history of mathematics, Descartes's discovery of analytic geometry provided scientists with an important new tool.

Descartes used mathematics to elaborate a highly influential vision of the workings of the cosmos. Drawing on ancient Greek atomist philosophies, Descartes developed the idea that matter was made up of identical "corpuscules" (tiny particles) that collided together in an endless series of motions. All occurrences in nature could be analyzed as matter in motion, and, according to Descartes, the total "quantity of motion" in the universe was constant. Descartes's mechanistic view of the universe depended on the idea that a vacuum was impossible, so that every action had an equal reaction, continuing in an eternal chain reaction. Although Descartes's hypothesis about the vacuum was proved wrong, his notion of a mechanistic universe intelligible through the physics of motion proved highly influential.

Descartes's greatest achievement was to develop his initial vision into a whole philosophy of knowledge and science. The Aristotelian cosmos was appealing in part because it corresponded with the evidence of the human senses. However, Descartes acknowledged that impressions of the world gained through the senses can sometimes be proved wrong. Thus, they can be doubted. Only things about which there can be no doubt should be accepted as truths, Descartes argued, and from these truths, or general principles, people can arrive at additional truths. This process of moving from general principles to specific truths is known as deductive reasoning. Descartes's reasoning ultimately reduced all substances to "matter" and "mind" — that is, to the physical and the spiritual. Descartes believed that God had endowed man with reason for a purpose and that rational speculation could provide a path to the truths of creation. His view of the world as consisting of two fundamental entities is known as **Cartesian dualism**. Descartes's thought was highly influential in France and the Netherlands but less so in England, where an emphasis on experimentation won the day.

Both Bacon's inductive experimentalism and Descartes's deductive mathematical reasoning had faults. Bacon's inability to appreciate the importance of mathematics and his obsession with practical results clearly showed the limitations of antitheoretical empiricism. Likewise, some of Descartes's positions — he believed, for example, that it was possible to deduce the whole science of medicine from a set of foundational first principles — demonstrated the inadequacy of rigid, dogmatic rationalism. Although insufficient on their own, Bacon's and Descartes's extreme approaches are combined in the modern scientific method, which began to crystallize in the late seventeenth century.

MAJOR CONTRIBUTORS TO THE SCIENTIFIC REVOLUTION

Nicolaus Copernicus (1473–1543)	Published *On the Revolutions of the Heavenly Spheres* (1543); theorized that the sun, rather than the earth, was the center of the galaxy
Paracelsus (1493–1541)	Pioneered the use of chemicals and drugs to address perceived chemical imbalances
Andreas Vesalius (1514–1564)	Published *On the Structure of the Human Body* (1543)
Tycho Brahe (1546–1601)	Built observatories and compiled data for the *Rudolfine Tables*, a new table of planetary data
Francis Bacon (1561–1626)	Advocated experimental method, formalizing theory of inductive reasoning known as empiricism
Galileo Galilei (1564–1642)	Used telescopic observation to provide evidence for Copernican hypothesis; experimented to formulate laws of physics, such as inertia
Johannes Kepler (1571–1630)	Used Brahe's data to mathematically prove the Copernican hypothesis; his new laws of planetary motion united for the first time natural philosophy and mathematics; completed the *Rudolfine Tables* in 1627
William Harvey (1578–1657)	Discovered blood circulation (1628)
René Descartes (1596–1650)	Used deductive reasoning to formulate theory of Cartesian dualism
Robert Boyle (1627–1691)	Founded the modern science of chemistry; created the first vacuum; discovered Boyle's law on the properties of gases
Isaac Newton (1642–1727)	Introduced the law of universal gravitation, synthesizing the theories of Copernicus and Galileo

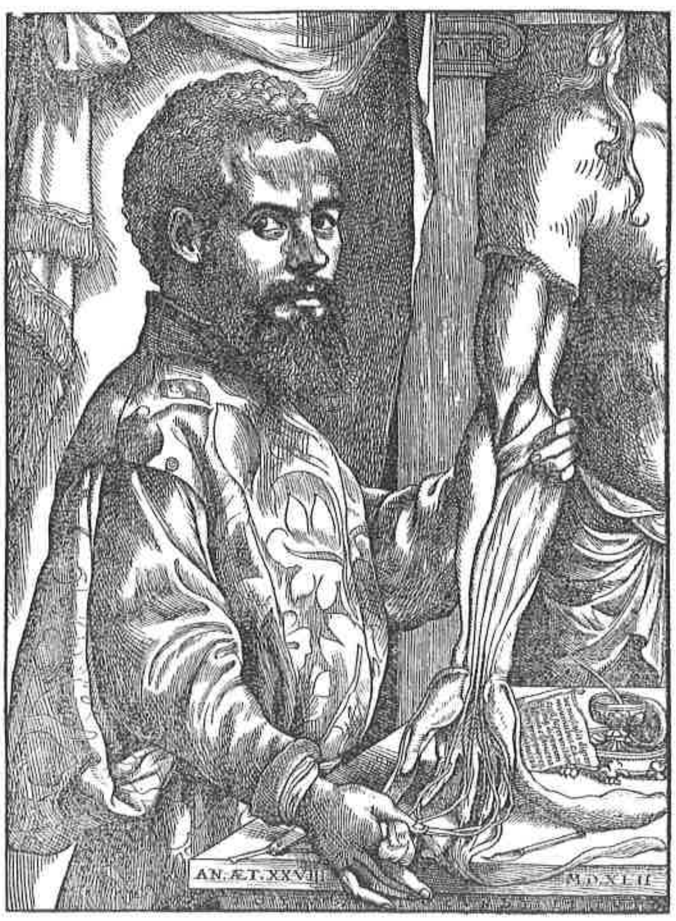
Medicine, the Body, and Chemistry

The scientific revolution, which began with the study of the cosmos, soon inspired renewed study of the microcosm of the human body. For many centuries the ancient Greek physician Galen's explanation of the body carried the same authority as Aristotle's account of the universe. According to Galen, the body contained four humors: blood, phlegm, black bile, and yellow bile. Illness was believed to result from an imbalance of these humors.

Swiss physician and alchemist Paracelsus (1493–1541) was an early proponent of the experimental method in medicine and pioneered the use of chemicals and drugs to address what he saw as chemical, rather than humoral, imbalances. Another experimentalist, Flemish physician Andreas Vesalius (1514–1564), studied anatomy by dissecting human bodies. In 1543, the same year Copernicus published *On the Revolutions of the Heavenly Spheres*, Vesalius issued *On the Structure of the Human Body*. Its two hundred precise drawings revolutionized the understanding of human anatomy. The experimental approach also led English royal physician William Harvey (1578–1657) to discover the circulation of blood through the veins and arteries in 1628. Harvey was the first to explain that the heart worked like a pump and to explain the function of its muscles and valves.

Irishman Robert Boyle (1627–1691) founded the modern science of chemistry. Following Paracelsus's lead, he undertook experiments to discover the basic elements of nature, which he believed was composed of infinitely small atoms. Boyle was the first to create a vacuum, thus disproving Descartes's belief that a vacuum could not exist in nature, and he discovered Boyle's law (1662), which states that the pressure of a gas varies inversely with volume.

Frontispiece to *De Humani Corporis Fabrica* (*On the Structure of the Human Body*) The frontispiece to Vesalius's pioneering work, published in 1643, shows him dissecting a corpse before a crowd of students. This was a revolutionary new hands-on approach for physicians, who usually worked from a theoretical, rather than a practical, understanding of the body. Based on direct observation, Vesalius replaced ancient ideas drawn from Greek philosophy with a much more accurate account of the structure and function of the body. (© SSPL/Science Museum/The Image Works)



Science and Society

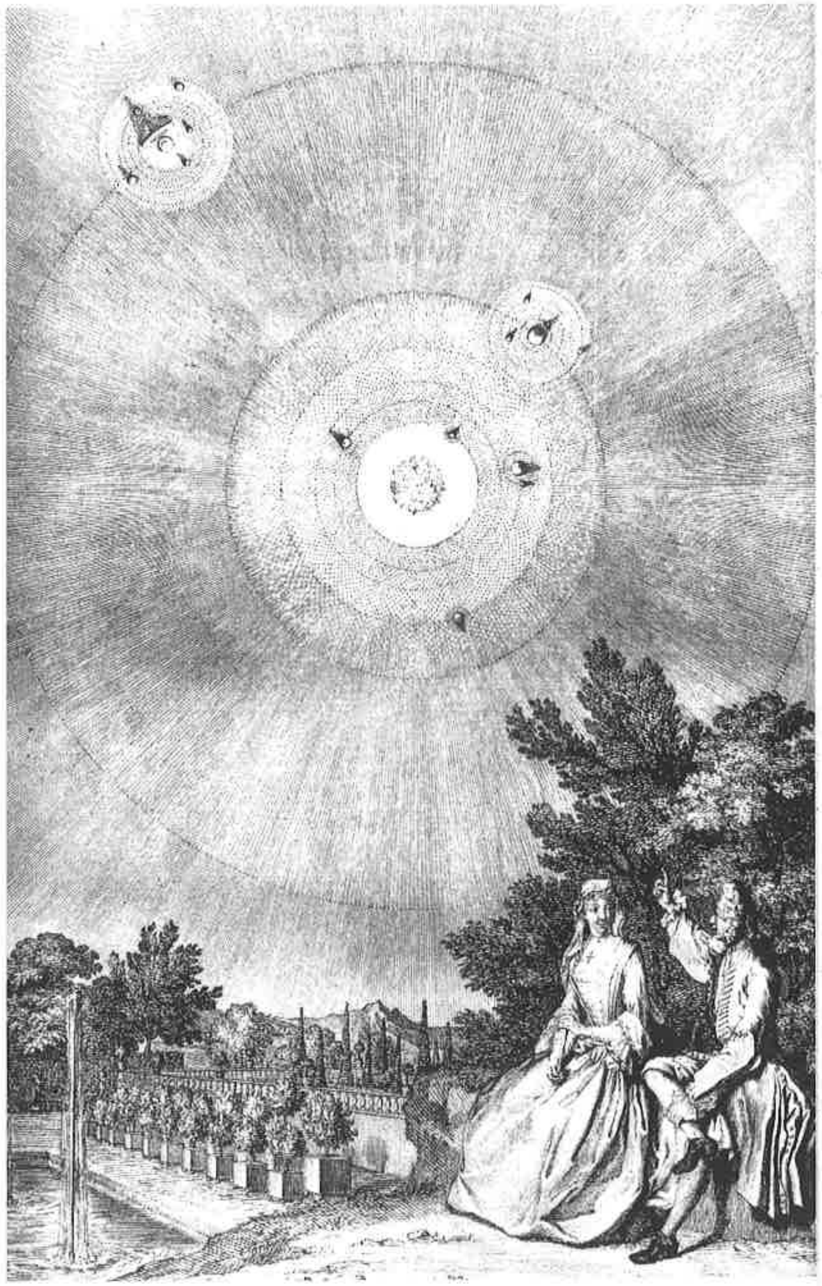
The rise of modern science had many consequences. First, it led to the rise of a new and expanding social group — the international scientific community. Members of this community were linked together by common interests and shared values as well as by journals and learned scientific societies. The personal success of scientists and scholars depended on making new discoveries, and as a result science became competitive. Second, as governments intervened to support and sometimes direct research, the new scientific community became closely tied to the state and its agendas. National academies of science were created under state sponsorship in London in 1662, Paris in 1666, Berlin in 1700, and later across Europe. At the same time, some scientists developed a critical attitude toward established authority that would inspire thinkers to question traditions in other domains as well, such as politics and religion.

Some things did not change in the scientific revolution. For example, new "rational" methods for approaching nature did not question traditional inequalities between the sexes — and may have worsened them in some ways. When Renaissance courts served as centers of learning, talented noblewomen could find niches in study and research. But the rise of a professional scientific community raised barriers for women because the new academies that furnished professional credentials did not accept female members.

There were, however, a number of noteworthy exceptions. In Italy, universities and academies did offer posts to women. Moreover, women across Europe were allowed to work as makers of wax anatomical models and as botanical and zoological illustrators. They were also very much involved in informal scientific communities, attending salons (see page 539), participating in scientific experiments, and writing learned treatises. Some female intellectuals were recognized as full-fledged participants in the philosophical dialogue.

The scientific revolution had few consequences for economic life and the living standards of the masses until the late eighteenth century, when its insights helped create new manufacturing technologies. Instead, it was first and foremost an intellectual revolution. For more than a hundred years its greatest impact was on how people thought and believed.

Finally, there is the question of the role of religion in the development of science. All Western religious authorities — Catholic, Protestant, and Jewish — opposed the Copernican system to a greater or lesser extent until about 1630, by which time the scientific revolution was definitely in progress. The Catholic Church was initially less hostile than Protestant and Jewish religious leaders, and Italian scientists played a crucial role in scientific progress right up to the trial of Galileo in 1633. Thereafter, the Counter-Reformation church became more hostile to science, a change that helped account for the decline of science in Italy (but not in Catholic France) after 1640. At the same time, Protestant countries — especially those lacking a strong religious authority capable of imposing religious orthodoxy on scientific questions — became quite "pro-science." Such countries included the Netherlands, Denmark, and England.



Popularizing Science The frontispiece illustration of Fontenelle's *Conversations on the Plurality of Worlds* (1686) invites the reader to share the pleasures of astronomy with an elegant lady and an entertaining teacher. The drawing shows the planets revolving around the sun. (© Roger-Viollet/The Image Works)