17 The Scientific Revolution

In 1609 Galileo Galilei, an Italian mathematician at the University of Padua, directed a new scientific instrument, the telescope, toward the heavens. Having heard that a Dutch artisan had put together two lenses in a way that magnified distant objects, Galileo built his own such device. Anyone who has looked through a telescope can appreciate his excitement. Objects that appeared one way to the naked eye looked entirely different when magnified by his new "spyglass," as he called it. The surface of the moon, long believed to be smooth, uniform, and perfectly spherical, now appeared full of mountains and craters. Galileo's spyglass showed that the sun, too, was imperfect, marred by spots that appeared to move across its surface. Such sights challenged traditional science, which assumed that "the heavens," the throne of God, were perfect and thus never changed. Traditional science was shaken even further when Galileo showed that Venus, viewed over many months, appeared to change its shape, much as the moon did in its phases. This discovery provided evidence for the relatively new

LEARNING OBJECTIVES

17.1 What were the achievements and discoveries of the Scientific Revolution?

17.2 What methods did scientists use during this period to investigate nature, and how did they think nature operated?

17.3 Why did the Scientific Revolution take place in western Europe at this time?

17.4 How did the Scientific Revolution influence philosophical and religious thought in the seventeenth and early eighteenth centuries?

17.5 How did the Scientific Revolution change the way in which seventeenth- and eighteenth-century Europeans thought of the place of human beings in nature?

THE TELESCOPE The telescope was the most important of the new scientific instruments that facilitated discovery. This engraving depicts an astronomer using the telescope in 1647.

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theory that the planets, including Earth, revolved around the sun rather than the sun and the planets around the Earth.

Galileo shared the discoveries he made not only with fellow scientists, but also with other educated members of society. He also staged a number of public demonstrations of his new astronomical instrument, the first of which took place on top of one of the city gates of Rome in 1611. To convince those who doubted the reality of the images they saw, Galileo turned the telescope toward familiar landmarks in the city. Interest in the new scientific instrument ran so high that a number of amateur astronomers acquired telescopes of their own.

Galileo's discoveries were part of what historians call the Scientific Revolution. This development changed the way Europeans viewed the natural world, the supernatural realm, and themselves. It led to controversies in religion, philosophy, and politics and changes in military technology, navigation, and business. It also set the West apart from the civilizations of the Middle East, Asia, and Africa and provided a basis for claims of Western superiority over the people in those lands.

The scientific culture that emerged in the West by the end of the seventeenth century was the product of a series of cultural encounters. It resulted from a complex interaction among scholars proposing different ideas of how nature operated. Some of these ideas originated in Greek philosophy. Others came from Christian sources. Still other ideas came from a tradition of late medieval science that had been influenced by the scholarship of the Islamic Middle East.

The main question this chapter seeks to answer is this:

How did European scientists in the sixteenth and seventeenth centuries change the way in which people in the West viewed the natural world?

The Discoveries and Achievements of the Scientific Revolution

17.1 What were the achievements and discoveries of the Scientific Revolution?

Unlike political revolutions, such as the English Revolution of the 1640s discussed in the last chapter, the Scientific Revolution developed gradually over a long period of time. It began in the mid-sixteenth century and continued into the eighteenth century. Even though it took a relatively long time to unfold, it was revolutionary in the sense that it transformed human thought, just as political revolutions have fundamentally changed systems of government. The most important changes in seventeenth-century science took place in astronomy, physics, chemistry, and biology.

Astronomy: A New Model of the Universe

The most significant change in astronomy was the acceptance of the view that the sun, not the Earth, was the center of the universe. Until the mid-sixteenth century, most natural philosophers—as scientists were known at the time—accepted the views of the ancient Greek astronomer Claudius Ptolemy (100–170 C.E.). Ptolemy's observations and calculations supported the cosmology of the Greek philosopher Aristotle (384–322 B.C.E.). According to

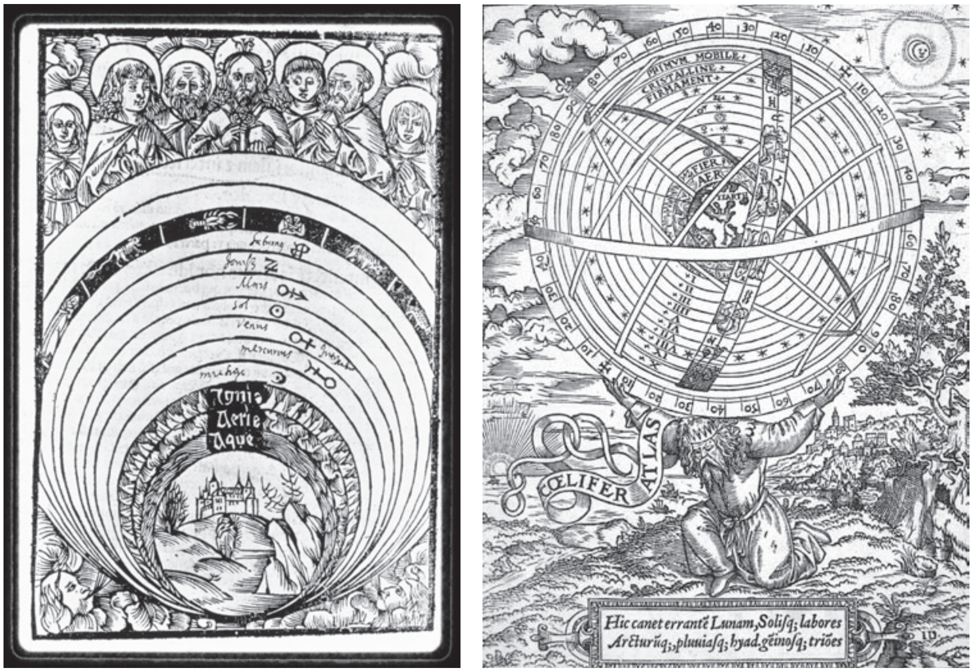
Ptolemy and Aristotle, the center of the universe was a stationary Earth, around which the moon, the sun, and the other planets revolved in circular orbits. Beyond the planets a large sphere carried the stars, which stood in a fixed relationship to each other, around the Earth from east to west once every 24 hours, thus accounting for the rising and setting of the stars. Each of the four known elements—earth, water, air, and fire—had a natural place within this universe, with the heavy elements, earth and water, being pulled down toward the center of the Earth and the light ones, air and fire, hovering above it. All heavenly bodies, including the sun and the planets, were composed of a fifth element, called ether, which unlike matter on Earth was thought to be eternal and could not be altered, corrupted, or destroyed.

This traditional view of the cosmos had much to recommend it, and some educated people continued to accept it well into the eighteenth century. The Bible, which in a few passages referred to the motion of the sun, reinforced the authority of Aristotle. And human observation seemed to confirm the motion of the sun. We do, after all, see the sun "rise" and "set" every day, so the idea that the Earth rotates at high speed and revolves around the sun contradicts the experience of our senses. Nevertheless, the Earth-centered model of the universe failed to explain many patterns that astronomers observed in the sky, most notably the paths followed by planets. Whenever ancient or medieval astronomers confronted a new problem as a result of their observations, they tried to accommodate the results to the Ptolemaic model. By the sixteenth century this model had been modified or adjusted so many times that it had gradually become a confused collection of planets and stars following different motions.

Faced with this situation, a Polish cleric, Nicolaus Copernicus (1473–1543), looked for a simpler and more plausible model of the universe. In *On the Revolutions of the Heavenly Spheres*, which was published shortly after his death, Copernicus proposed that the center of the universe was not the Earth but the sun. The book was widely circulated, but it did not win much support for the sun-centered theory of the universe. Only the most learned astronomers could understand Copernicus's mathematical arguments, and even they were not prepared to adopt his central thesis. In the late sixteenth century the great Danish astronomer Tycho Brahe (1546–1601) accepted the

Read the **Document**

On the Revolution of the Heavenly Spheres (1500s) Nicolaus Copernicus



TWO VIEWS OF THE PTOLEMAIC OR PRE-COPERNICAN UNIVERSE (*Left*) In this sixteenth-century engraving the Earth lies at the center of the universe and the elements of water, air, and fire are arranged in ascending order above the Earth. The orbit that is shaded in black is the firmament or stellar sphere. The presence of Christ and the saints at the top reflects the view that Heaven lay beyond the stellar sphere. (*Right*) A medieval king representing Atlas holds a Ptolemaic cosmos. The Ptolemaic universe is often referred to as a two-sphere universe: The inner sphere of the Earth lies at the center and the outer sphere encompassing the entire universe rotates around the Earth.

View the **Closer Look**

The Copernican Universe

TWO EARLY MODERN VIEWS OF THE SUN-CENTERED UNIVERSE (*Left*) The depiction by Copernicus. Note that all the orbits are circular, rather than elliptical, as Kepler was to show they were. The outermost sphere is that of the fixed stars. (*Right*) A late-seventeenth-century depiction of the cosmos by Andreas Cellarius in which the planets follow elliptical orbits. It illustrates four different positions of the Earth as it orbits the sun.

argument of Copernicus that the planets revolved around the sun but still insisted that the sun revolved around the Earth.

Significant support for the Copernican model of the universe among scientists began to materialize only in the seventeenth century. In 1609 a German astronomer, Johannes Kepler (1571–1630), using data that Brahe had collected, confirmed the central position of the sun in the universe. In *New Astronomy* (1609) Kepler also demonstrated that the planets, including the Earth, followed elliptical rather than circular orbits and that physical laws governed their movements. Not many people read Kepler's book, however, and his achievement was not fully appreciated until many decades later.

Galileo Galilei (1564–1642) was far more successful in gaining support for the sun-centered model of the universe. Galileo had the literary skill, which Kepler lacked, of being able to write for a broad audience. Using the evidence gained from his observations with the telescope, and presenting his views in the form of a dialogue between the advocates of the two competing worldviews, Galileo demonstrated the plausibility and superiority of Copernicus's theory.

The publication of Galileo's *Dialogue Concerning the Two Chief World Systems—Ptolemaic and Copernican* in 1632 won many converts to the sun-centered theory of the universe, but it lost him the support of Pope Urban VIII, who had been one of his patrons. The character in *Dialogue* who defends the Ptolemaic system is named Simplicio (that is, a simple—or stupid—person). Urban wrongly concluded that Galileo was mocking him. In 1633 Galileo was tried before the Roman Inquisition, an ecclesiastical court whose purpose was to maintain theological orthodoxy. The charge against him was that he had challenged the authority of Scripture and was therefore guilty of heresy, the denial of the theological truths of the Roman Catholic Church. (See *Justice in History* in this chapter.)

As a result of this trial, Galileo was forced to abandon his support for the Copernican model of the universe, and *Dialogue* was placed on the Index of Prohibited Books, a list compiled by the papacy of all printed works containing heretical ideas. Despite this setback, by 1700 Copernicanism commanded widespread support among scientists and the educated public. *Dialogue,* however, was not removed from the Index until 1822.

Physics: The Laws of Motion and Gravitation

Galileo made his most significant contributions to the Scientific Revolution in physics. In the seventeenth century the main branches of physics were mechanics (the study of motion and its causes) and optics (the study of light). Galileo formulated a set of laws governing the motion of material objects that challenged the accepted theories of Aristotle regarding motion and laid the foundation of modern physics.

According to Aristotle, whose views dominated science in the late Middle Ages, the motion of every object—except the natural motion of falling toward the center of the Earth—required another object to move it. If the mover stopped, the object fell to the ground or simply stopped moving. But this theory could not explain why a projectile, such as a discus or a spear, continued to move after a person threw it. Galileo's answer to that question was a theory of inertia, which became the basis of a new theory of motion. According to Galileo, an object continues to move or lie at rest until something external to it intervenes to change its motion. Thus, motion is neither a quality inherent in an object nor a force that it acquires from another object. It is simply a state in which the object finds itself.

Galileo also discovered that the motion of an object occurs only in relation to things that do not move. A ship moves through the water, for example, but the goods that the ship carries do not move in relationship to the moving ship. This insight explained to the critics of Copernicus how the Earth can move even though we do not experience its motion. Galileo's most significant contribution to mechanics was his formulation of a

SIR ISAAC NEWTON This portrait was painted by Sir Godfrey Kneller in 1689, two years after the publication of *Mathematical Principles of Natural Philosophy.*

CHRONOLOGY: DISCOVERIES OF THE SCIENTIFIC REVOLUTION

1543 Copernicus publishes *On the Revolutions of the Heavenly Spheres.*

1609 Johannes Kepler publishes *New Astronomy.*

1628 William Harvey publishes *On the Motion of the Heart and Blood in Animals.*

1632 Galileo publishes *Dialogue Concerning the Two Chief World Systems.*

1638 Galileo publishes *Discourses on the Two New Sciences of Motion and Mechanics.*

1659 Robert Boyle invents the air pump and conducts experiments on the elasticity and compressibility of air.

1687 Newton publishes *Mathematical Principles of Natural Philosophy.*

mathematical law of motion that explained how the speed and acceleration of a falling object are determined by the distance it travels during equal intervals of time.

The greatest achievements of the Scientific Revolution in physics belong to English scientist Sir Isaac Newton (1642–1727). His research changed the way future generations viewed the world. As a boy Newton felt out of place in his small village, where he worked on his mother's farm and attended school. Fascinated by mechanical devices, he spent much of his time building wooden models of windmills and other machines. When playing with his friends he always found ways to exercise his mind, calculating, for example, how he could use the wind to win jumping contests. It became obvious to all who knew him that Newton belonged at a university. In 1661 he entered Cambridge University, where, at age 27, he became a chaired professor of mathematics.

Newton formulated a set of mathematical laws to explain the operation of the entire physical world. In 1687 he published his theories in *Mathematical Principles of Natural Philosophy.* The centerpiece of this monumental work was the **universal law of gravitation**, which demonstrated that the same force holding an object to the Earth also holds the planets in their orbits. This law represented a synthesis of the work of other scientists, including Kepler on planetary motion and Galileo on inertia. Newton paid tribute to the work of these men when he said, "If I have seen farther, it is by standing on the shoulders of giants." But Newton went further than any of them by establishing the existence of a single gravitational force and by giving it precise mathematical expression. His book revealed the unity and order of the entire physical world and thus offered a scientific model to replace that of Aristotle.

universal law of gravitation A law of nature established by Isaac Newton in 1687 holding that any two bodies attract each other with a force that is directly proportional to the product of their masses and indirectly proportional to the square of the distance between them. The law was presented in mathematical terms.

Read the Document

Isaac Newton, from *Opticks*

Chemistry: Discovering the Elements of Nature

The science today called chemistry originated in the study and practice of **alchemy**, the art of attempting to turn base metals into gold or silver and to identify natural substances that could be used in the practice of medicine. Alchemy has often been ridiculed as a form of magic that is the antithesis of modern science, but alchemists performed experiments that contributed to the growth of the empirical study of nature. The Swiss physician and alchemist Paracelsus (1493–1541), who rejected the traditional method of curing patients by altering the balance of fluids (such as blood and bile) in the body, occupies a significant place in the early history of chemistry. In his effort to find what he called a panacea, or a remedy for all diseases, Paracelsus treated his patients with chemicals, such as mercury and sulfur. In this way chemistry became an accepted part of medical science.

alchemy The practice, rooted in a philosophical tradition, of attempting to turn base metals into precious ones. It also involved the identification of natural substances for medical purposes. Alchemy was influential in the development of chemistry and medicine in the sixteenth and seventeenth centuries.

During the seventeenth century chemistry gained further recognition as a legitimate field of scientific research, largely as the result of the work of Robert Boyle (1627–1691). Boyle, who also had an interest in alchemy, destroyed the prevailing idea

PORTRAIT OF ROBERT BOYLE WITH HIS AIR PUMP IN THE BACKGROUND (1664) Boyle's pump became the center of a series of experiments carried on at the Royal Society in London.

that all basic constituents of matter share the same structure. He contended that the arrangement of their components, which he identified as corpuscles or atoms, determined their characteristics. He also conducted experiments on the volume, pressure, and density of gas and the elasticity of air. Boyle's most famous experiments, undertaken with an air pump, proved the existence of a vacuum. Largely as a result of Boyle's discoveries, chemists won acceptance as members of the company of scientists.

Biology: The Circulation of the Blood

The English physician William Harvey (1578–1657) made one of the great medical discoveries of the seventeenth century by demonstrating in 1628 that blood circulates throughout the human body. Traditional science had maintained that blood originated in the liver and then flowed outward through the veins. A certain amount of blood flowed from the liver into the heart, where it passed from one ventricle to the other and then traveled through the arteries to different parts of the body. During its journey this arterial blood was enriched by a special *pneuma* or "vital spirit" that was necessary to sustain life. When this enriched blood reached the brain, it became the body's "psychic spirits," which influenced human behavior.

Through experiments on human cadavers and live animals in which he weighed the blood that the heart pumped every hour, Harvey demonstrated that rather than sucking in blood, the heart pumped it through the arteries by means of contraction and constriction. The only gap in his theory was the question of how blood went from the ends of the arteries to the ends of the veins. This question was answered in 1661, when scientists, using a new instrument known as a microscope, could see the capillaries connecting the veins and arteries. Harvey, however, had set the standard for future biological research.

Read the Document
William Harvey, *Address to the Royal College of Physicians*, 1628

The Search for Scientific Knowledge

17.2 What methods did scientists use during this period to investigate nature, and how did they think nature operated?

The natural philosophers who made these scientific discoveries worked in different disciplines, and each followed his own procedures for discovering scientific truth. In the sixteenth and seventeenth centuries there was no "scientific method." Many natural philosophers, however, shared similar views about how nature operated and the means by which humans could acquire knowledge of it. In searching for scientific knowledge, these scientists observed and experimented, used deductive reasoning, expressed their theories in mathematical terms, and argued that nature operated like a machine. These features of scientific research ultimately defined a distinctly Western approach to solving scientific problems.

Observation and Experimentation

The most prominent feature of scientific research in sixteenth- and seventeenth-century Europe was the observation of nature, combined with the testing of hypotheses by rigorous experimentation. This was primarily a process of **induction**, in which theories emerged only after the accumulation and analysis of data. It assumed a willingness to abandon preconceived ideas and base scientific conclusions on experience and observation. This approach is also described as empirical: **empiricism** demands that all scientific theories be tested by experiments based on observation of the natural world.

In *New Organon* (1620), the English philosopher Francis Bacon (1561–1626) promoted this empirical approach to scientific research. Bacon complained that all previous scientific endeavors, especially those of ancient Greek philosophers, relied

induction The process of reasoning that formulates general hypotheses and theories on the basis of specific observation and the accumulation of data.

empiricism The practice of testing scientific theories by observation and experiment.

DISSECTION The Dutch surgeon Nicolaes Tulp giving an anatomy lesson in 1632. As medical science developed in the sixteenth and seventeenth centuries, the dissection of human corpses became a standard practice in European universities and medical schools. Knowledge of the structure and composition of the human body, which was central to the advancement of physiology, could best be acquired by cutting open a corpse to reveal the organs, muscles, and bones of human beings. The practice reflected the emphasis scientists placed on observation and experimentation in conducting scientific research.

too little on experimentation. In contrast, his approach involved the thorough and systematic investigation of nature, a process that Bacon, who was a lawyer and judge, compared to the interrogation of a person suspected of committing a crime. For Bacon, scientific experimentation was "putting nature to the question," a phrase that referred to questioning a prisoner under torture to determine the facts of a case.

Read the Document

Francis Bacon, from *Novum Organum*

Deductive Reasoning

The second feature of sixteenth- and seventeenth-century scientific research was the use of **deductive reasoning** to establish basic scientific truths or principles. From these principles other ideas or laws could be deduced logically. Just as induction is linked to empiricism, so deduction is connected to **rationalism**. Unlike empiricism—the idea that we know truth through what the senses can experience—rationalism insists that the mind contains rational categories independent of sensory observation.

deductive reasoning The logical process by which ideas and laws are derived from basic truths or principles.

rationalism The theory that the mind contains rational categories independent of sensory observation; more generally that reason is the primary source of truth.

Unlike the inductive experimental approach, which found its most enthusiastic practitioners in England, the deductive approach had its most zealous advocates on the European continent. The French philosopher and mathematician René Descartes (1596–1650) became the foremost champion of this methodology. In his *Discourse on the Method* (1637), Descartes recommended that to solve any intellectual problem, a person should first establish fundamental principles or truths and then proceed from those ideas to specific conclusions.

Mathematics, in which one also moves logically from certain premises to conclusions by means of equations, provided the model for deductive reasoning. Although rational deduction proved to be an essential feature of scientific methodology, the limitations of an exclusively deductive approach became apparent when Descartes and his followers deduced a theory of gravitation from the principle that objects could influence each other only if they actually touched. This theory, as well as the principle upon which it was based, lacked an empirical foundation and eventually had to be abandoned.

Mathematics and Nature

The third feature of scientific research in the sixteenth and seventeenth centuries was the application of mathematics to the study of the physical world. Scientists working in both the inductive and the deductive traditions used mathematics. Descartes shared with Galileo the conviction that nature had a geometrical structure and could therefore be understood in mathematical terms. The physical dimensions of matter, which Descartes claimed were its only properties, could of course be expressed mathematically. Galileo claimed that mathematics was the language in which philosophy was written in "the book of the universe."

Isaac Newton's work provided the best illustration of the application of mathematics to scientific problems. Newton used observation and experimentation to confirm his theory of universal gravitation, but he wrote his *Mathematical Principles of Natural Philosophy* in the language of mathematics. His approach to scientific problems, which became a model for future research, used examples derived from experiments and deductive, mathematical reasoning to discover the laws of nature.

The Mechanical Philosophy

mechanical philosophy The seventeenth-century philosophy of nature, championed by René Descartes, holding that nature operated in a mechanical way, just like a machine made by a human being.

Much of seventeenth-century scientific experimentation and deduction assumed that the natural world operated as if it were a machine made by a human being. This **mechanical philosophy** of nature appeared most clearly in the work of Descartes. Medieval philosophers had argued that natural bodies had an innate tendency to change, whereas artificial objects, that is, those constructed by humans, did not. Descartes, as well as Kepler, Galileo, and Bacon, denied that assumption. Mechanists argued that nature operated in a mechanical way, just like a piece of machinery. The only difference was that the operating structures of natural mechanisms could not be observed as readily as the structures of a machine.

Mechanists perceived the human body itself as a machine. Harvey, for example, described the heart as "a piece of machinery in which, though one wheel gives motion to another, yet all the wheels seem to move simultaneously." The only difference between the body and other machines was that the mind could move the body, although how it did so was controversial. According to Descartes, the mind was completely different from the body and the rest of the material world. Unlike the body, the mind was an immaterial substance that could not be extended in space, divided, or measured mathematically, the way one could record the dimensions of the body. Because Descartes made this sharp distinction between the mind and the body, we describe his philosophy as **dualistic**.

dualistic A term used to describe a philosophy or a religion in which a rigid distinction is made between body and mind, good and evil, or the material and the immaterial world.

Descartes and other mechanists argued that matter was completely inert or dead. It did not possess a soul or any innate purpose. Its only property was "extension," or the physical dimensions of length, width, and depth. Without a spirit or any other internal force directing its action, matter simply responded to the power of the other bodies with which it came in contact. According to Descartes, all physical phenomena could be explained by reference to the dimensions and the movement of particles of matter. He once claimed, "Give me extension and motion and I will construct the universe."[1]

The view of nature as a machine implied that it operated in a regular, predictable way in accordance with unchanging laws of nature. Scientists could use reason to discover what those laws were and thus learn how nature performed under any circumstances. The scientific investigations of Galileo and Kepler were based on those assumptions, and Descartes made them explicit. The immutability of the laws of nature implied that the entire universe was uniform in structure, an assumption that underlay Newton's formulation of the laws of motion and universal gravitation.

The Causes of the Scientific Revolution

17.3 Why did the Scientific Revolution take place in western Europe at this time?

Why did the Scientific Revolution take place at this particular time, and why did it originate in western European countries? There is no simple answer to this question. We can, however, identify developments that inspired these scientific discoveries. Some of these developments arose out of earlier investigations conducted by natural philosophers in the late Middle Ages, the Renaissance, and the sixteenth century. Others emerged from the religious, political, social, and economic life of early modern Europe.

Developments Within Science

The three internal causes of the Scientific Revolution were the research into motion conducted by natural philosophers in the fourteenth century, the scientific investigations conducted by Renaissance humanists, and the collapse of the dominant conceptual frameworks, or paradigms, that had governed scientific inquiry and research for centuries.

LATE MEDIEVAL SCIENCE Modern science can trace some of its origins to the fourteenth century, when the first significant modifications of Aristotle's scientific theories began to emerge. The most significant of these refinements was the theory of impetus. Aristotle had argued that an object would stop as soon as it lost contact with the object that moved it. Late medieval scientists claimed that objects in motion acquire a force that stays with them after they lose contact with the mover. This theory of impetus questioned Aristotle's authority, and it influenced some of Galileo's early thought on motion.

Natural philosophers of the fourteenth century also began to recommend direct, empirical observation in place of the traditional tendency to accept preconceived notions regarding the operation of nature. This approach to answering scientific questions did not result in the type of rigorous experimentation that Bacon demanded three centuries later, but it did encourage scientists to base their theories on the facts that emerged from an empirical study of nature.

The contribution of late medieval science to the Scientific Revolution should not be exaggerated. Philosophers of the fourteenth century continued to accept Ptolemy's cosmology and the anatomical and medical theories of the Greek physician Galen (129–200 C.E.). The unchallenged position of theology as the dominant subject in late medieval universities also guaranteed that new scientific ideas would receive little favor if they challenged Christian doctrine.

RENAISSANCE SCIENCE Natural philosophers during the Renaissance contributed more than their late medieval predecessors to the rise of modern science. Many of the scientific discoveries of the late sixteenth and seventeenth centuries drew their inspiration from Greek scientific works that had been rediscovered during the Renaissance. Copernicus, for example, found the idea of his sun-centered universe in the writings of Aristarchus of Samos, a Greek astronomer of the third century B.C.E. whose work had been unknown during the Middle Ages. Similarly, the works of the ancient Greek philosopher Democritus in the late fifth century B.C.E. introduced the idea, developed by Boyle and others in the seventeenth century, that matter was divisible into small particles known as atoms. The works of Archimedes (287–212 B.C.E.), which had been virtually unknown in the Middle Ages, stimulated interest in the science of mechanics. The recovery and translation of previously unknown texts also made scientists aware that Greek scientists did not always agree with each other and thus provided a stimulus to independent observation and experimentation as a means of resolving their differences.

Neoplatonism A philosophy based on the teachings of Plato and his successors that flourished in Late Antiquity, especially in the teachings of Plotinus. Neoplatonism influenced Christianity in Late Antiquity. During the Renaissance Neoplatonism was linked to the belief that the natural world was charged with occult forces that could be used in the practice of magic.

Renaissance revival of the philosophy of **Neoplatonism** (see Chapter 7) made an even more direct contribution to the birth of modern science. While most medieval natural philosophers relied on the ideas of Aristotle, Neoplatonists drew on the work of Plotinus (205–270 C.E.), the last great philosopher of antiquity who synthesized the work of Plato, other ancient Greek philosophers, and Persian religious traditions. Neoplatonists stressed the unity of the natural and spiritual worlds. Matter is alive, linked to the divine soul that governs the entire universe. To unlock the mysteries of this living world, Neoplatonists turned to mathematics, because they believed the divine expressed itself in geometrical harmony, and to alchemy, because they sought to uncover the shared essence that linked all creation. They also believed that the sun, as a symbol of the divine soul, logically stood at the center of the universe.

Neoplatonic ideas influenced seventeenth-century scientists. Copernicus, for example, took from Neoplatonism his idea of the sun sitting at the center of the universe, as "on a royal throne ruling his children, the planets which circle around him." From his reading in Neoplatonic sources Kepler acquired his belief that the universe was constructed according to geometric principles. Newton was fascinated by the subject of alchemy, and the original inspiration of his theory of gravitation probably came from his Neoplatonist professor at Cambridge, who insisted on the presence of spiritual forces in the physical world. Modern science resulted from an encounter between the mechanical philosophy, which held that matter was inert, and Neoplatonism, which claimed that the natural world was alive.

THE COLLAPSE OF PARADIGMS The third internal cause of the Scientific Revolution was the collapse of the intellectual frameworks that had governed scientific research since antiquity. In all historical periods scientists prefer to work within an established conceptual framework, or what the scholar Thomas Kuhn has referred to as a **paradigm**, rather than introduce new theories. Every so often, however, the paradigm that has governed scientific research for an extended period of time can no longer account for many different observable phenomena. A scientific revolution occurs when the old paradigm collapses and a new paradigm replaces it.[2]

paradigm A conceptual model or intellectual framework within which scientists conduct their research and experimentation.

The revolutionary developments we have discussed in astronomy and biology were partly the result of the collapse of old paradigms. In astronomy the paradigm that had governed scientific inquiry in antiquity and the Middle Ages was the Ptolemaic model, in which the sun and the planets revolved around the Earth. By the sixteenth century, however, new observations had so confused and complicated this model that, to men like Copernicus, it no longer provided a satisfactory explanation for the material universe. Copernicus looked for a simpler and more plausible model of the universe. His sun-centered theory became the new paradigm within which Kepler, Galileo, and Newton all worked.

In biology a parallel development occurred when the old paradigm constructed by Galen, in which the blood originated in the liver and traveled through the veins and arteries, also collapsed because it could not explain the findings of medical scholars. Harvey introduced a new paradigm, in which the blood circulated through the body. As in astronomy, Harvey's new paradigm served as a framework for subsequent biological research and helped shape the Scientific Revolution.

Developments Outside Science

Nonscientific developments also encouraged the development and acceptance of new scientific ideas. These developments include the spread of Protestantism, the patronage of scientific research, the invention of the printing press, and military and economic change.

PROTESTANTISM Protestantism played a limited role in causing the Scientific Revolution. In the early years of the Reformation, Protestants were just as hostile as Catholics to the new science. Reflecting the Protestant belief in the literal truth of the Bible, Luther referred to Copernicus as "a fool who went against Holy Writ." Throughout the sixteenth and seventeenth centuries, moreover, Catholics as well as Protestants engaged in scientific research. Indeed, some of the most prominent European natural philosophers, including Galileo and Descartes, were devout Catholics. Nonetheless, Protestantism encouraged the emergence of modern science in three ways.

First, as the Scientific Revolution gained steam in the seventeenth century, Protestant governments were more willing than Catholic authorities to allow the publication and dissemination of new scientific ideas. Protestant governments, for example, did not prohibit the publication of books that promoted novel scientific ideas on the grounds that they were heretical, as the papacy did in compiling the Index of Prohibited Books. The greater willingness of Protestant governments, especially those of England and the Dutch Republic, to tolerate the expression of new scientific ideas helps to explain why the main geographical arena of scientific investigation shifted from the Catholic Mediterranean to the Protestant North Atlantic in the second half of the seventeenth century. (See *Different Voices* in this chapter.)

Second, seventeenth-century Protestant writers emphasized the idea that God revealed his intentions not only in the Bible, but also in nature itself. They claimed that individuals therefore had a duty to study nature, just as it was their duty to read Scripture to gain knowledge of God's will. Kepler's claim that the astronomer was "as a priest of God to the book of nature" reflected this Protestant outlook.

Third, many seventeenth-century Protestant scientists believed that the millennium, a period of one thousand years when Christ would come again and rule the world, was about to begin. Millenarians believed that during this period knowledge would increase, society would improve, and humans would gain control over nature. Protestant scientists, including Boyle and Newton, conducted their research and experiments believing that their work would contribute to this improvement of human life after the Second Coming of Christ.

PATRONAGE Scientists could not have succeeded without financial and institutional support. Only an organizational structure could give science a permanent status, let it develop as a discipline, and give its members a professional identity. The universities, which today support scientific research, were not the main source of that support in the seventeenth century. They remained predominantly clerical institutions with a vested interest in defending the medieval fusion of Christian theology and Aristotelian science. Instead of the universities, scientists depended on the patronage of wealthy and influential individuals, especially the kings, princes, and great nobles who ruled European states. This group included Pope Urban VIII, ruler of the Papal States.

Patronage, however, could easily be withdrawn. Scientists had to conduct themselves and their research to maintain the favor of their patrons. Galileo referred to the new moons of Jupiter that he observed through his telescope as the Medicean stars to flatter the Medici family that ruled Florence. His publications were inspired as much by his obligation to glorify Grand Duke Cosimo II as by his belief in the sun-centered theory.

Academies in which groups of scientists could share ideas and work served as a second important source of patronage. One of the earliest of these institutions was the Academy of the Lynx-Eyed in Rome, named after the animal whose sharp

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Different Voices

Copernicus and the Papacy

In dedicating his book, On the Revolution of the Heavenly Spheres *(1543), to Pope Paul II (r. 1464–1471), Copernicus explained that he drew inspiration from ancient philosophers who had imagined that the Earth moved. Anticipating condemnation from those who based their astronomical theories on the Bible, he appealed to the pope for protection while showing contempt for the theories of his opponents. Paul II neither endorsed nor condemned Copernicus's work, but in 1616, the papacy suspended the book's publication because it contradicted Scripture.*

Copernicus on Heliocentrism and the Bible

. . . I began to chafe that philosophers could by no means agree on any one certain theory of the mechanism of the Universe, wrought for us by a supremely good and orderly Creator . . . I therefore took pains to read again the works of all the philosophers on whom I could lay my hand to seek out whether any of them had ever supposed that the motions of the spheres were other than those demanded by the mathematical schools. I found first in Cicero that Hicetas had realized that the Earth moved. Afterwards I found in Plutarch that certain others had held the like opinion. . . .

Taking advantage of this I too began to think of the mobility of the Earth; and though the opinion seemed absurd, yet knowing now that others before me had been granted freedom to imagine such circles as they chose to explain the phenomena of the stars, I considered that I also might easily be allowed to try whether, by assuming some motion of the Earth, sounder explanations than theirs for the revolution of the celestial spheres might so be discovered.

Thus assuming motions, which in my work I ascribe to the Earth, by long and frequent observations I have at last discovered that, if the motions of the rest of the planets be brought into relation with the circulation of the Earth and be reckoned in proportion to the circles of each planet . . . the orders and magnitudes of all stars and spheres, nay the heavens themselves, become so bound together that nothing in any part thereof could be moved from its place without producing confusion of all the other parts and of the Universe as a whole. . . .

It may fall out, too, that idle babblers, ignorant of mathematics, may claim a right to pronounce a judgment on my work, by reason of a certain passage of Scripture basely twisted to serve their purpose. Should any such venture to criticize and carp at my project, I make no account of them; I consider their judgment rash, and utterly despise it.

SOURCE: From Nicolaus Copernicus, *De Revolutionibus Orbium Coelestium* (1543), trans. by John F. Dobson and Selig Brodetsky in *Occasional Notes of the Royal Astronomical Society, 2*(10), 1947. Reprinted by permission of Blackwell Publishing.

Papal Decree Against Heliocentrism, 1616

Decree of the Holy Congregation of his Most Illustrious Lord Cardinals especially charged by His Holiness Pope Paul V and by the Holy Apostolic See with the index of books and their licensing, prohibition, correction and printing in all of Christendom. . . .

This Holy Congregation has also learned about the spreading and acceptance by many of the false Pythagorean doctrine, altogether contrary to the Holy Scripture, that the earth moves and the sun is motionless, which is also taught by Nicholaus Copernicus's *On the Revolutions of the Heavenly Spheres* and by Diego de Zuñiga's *On Job*. This may be seen from a certain letter published by a certain Carmelite Father, whose title is *Letter of the Reverend Father Paolo Antonio Foscarini on the Pythagorean and Copernican Opinion of the Earth's Motion and Sun's Rest and on the New Pythagorean World System* . . . in which the said Father tries to show that the above mentioned doctrine of the sun's rest at the center of the world and the earth's motion is consonant with the truth and does not contradict Holy Scripture. Therefore, in order that this opinion may not creep any further to the prejudice of Catholic truth, the Congregation has decided that the books by Nicholaus Copernicus (*On the Revolutions of Spheres*) and Diego de Zuñiga (*On Job*) be suspended until corrected; but that the book of the Carmelite Father Paolo Antonini Foscarini be completely prohibited and condemned; and that all other books which teach the same be likewise prohibited, according to whether with the present decree it prohibits[,] condemns and suspends them respectively. In witness thereof this decree has been signed by the hand and stamped with the seal of the Most Illustrious and reverend Lord cardinal of St. Cecilia. Bishop of Albano, on March 5, 1616.

SOURCE: From *The Galileo Affair: A Documentary History,* ed. and trans. by Maurice A. Finocchairo, copyright © 1989 by The Regents of the University of California, is reprinted by permission of the University of California Press.

For Discussion

1. Why did the papal authorities prohibit and condemn the work by Antonini Foscarini but only suspend those of Copernicus and Diego de Zuñiga?
2. How did Copernicus and the papal authorities differ about classical antiquity and the truth of Holy Scripture?

CHRONOLOGY: THE FORMATION OF SCIENTIFIC SOCIETIES

1603 Prince Cesi founds the Academy of the Lynx-Eyed in Rome.

1657 Cosimo II de' Medici founds the Academy of Experiment in Florence.

1662 Founding of the Royal Society of London under the auspices of Charles II.

1666 Founding of the Academy of Sciences in Paris.

vision symbolized the power of observation required by the new science. Founded in 1603 by Prince Cesi, the Academy published many of Galileo's works. In 1657 Cosimo II founded a similar institution in Florence, the Academy of Experiment. These academies offered a more regular source of patronage than scientists could acquire from individual positions at court, but they still served the function of glorifying their founders, and they depended on patrons for their continued existence. The royal academies established in the 1660s, however, especially the Royal Academy of Sciences in France (1666) and the Royal Society in England (1662), became in effect public institutions that operated with a minimum of royal intervention and made possible a continuous program of work.

The mission of the Royal Society in England was the promotion of scientific knowledge through experimentation. It also placed the results of scientific research at the service of the state. Members of the Royal Society, for example, did research on ship construction and military technology. These attempts to use scientific technology to strengthen the power of the state show how the growth of the modern state and the emergence of modern science were related.

THE FOUNDING OF THE FRENCH ACADÈMIE DES SCIENCES Like the Royal Society in England, the French Academy of Sciences was dependent upon royal patronage. Louis XIV, seen sitting in the middle of the painting, used the occasion to glorify himself as a patron of the sciences as well as the arts. The painting also commemorates the building of the Royal Observatory in Paris, which is shown in the background.

THE PRINTING PRESS Printing made it much easier for scientists to share their discoveries with others. During the Middle Ages, books were handwritten. Errors could creep into the text as it was being copied, and the number of copies that could be made of a manuscript limited the spread of scientific knowledge. The spread of printing ensured that scientific achievements could be preserved more accurately and presented to a broader audience. The availability of printed copies also made it much easier for other scientists to correct or supplement the data that the authors supplied. Illustrations, diagrams, tables, and other schematic drawings that helped to convey the author's findings could also be printed. The entire body of scientific knowledge thus became cumulative. Printing also made members of the nonscientific community aware of the latest advances in physics and astronomy and so helped to make science an integral part of the culture of educated Europeans.

MILITARY AND ECONOMIC CHANGE The Scientific Revolution occurred at roughly the same time that both the conduct of warfare and the European economy were undergoing dramatic changes. As territorial states increased the size of their armies and arsenals, they demanded more accurate weapons with longer range. Some of the work that physicists did during the seventeenth century was deliberately meant to improve weaponry. Members of the Royal Society in England, for example, conducted extensive scientific research on the trajectory and velocity of missiles, and so followed Francis Bacon's recommendation that scientists place their research at the service of the state.

The needs of the emerging capitalist economy also influenced scientific research. The study of mechanics, for example, led to new techniques to ventilate mines and raise coal or ore from them, thus making mining more profitable. Some of the questions discussed at the meetings of the Royal Society suggest that its members undertook research to make capitalist ventures more productive and profitable. The research did not always produce immediate results, but ultimately it increased economic profitability and contributed to the English economy in the eighteenth century.

The Intellectual Consequences of the Scientific Revolution

17.4 How did the Scientific Revolution influence philosophical and religious thought in the seventeenth and early eighteenth centuries?

The Scientific Revolution profoundly affected the intellectual life of educated Europeans. The discoveries of Copernicus, Kepler, Galileo, and Newton, as well as the assumptions on which their work was based, influenced what educated people in the West studied, how they approached intellectual problems, and what they thought about the supernatural realm.

Education

During the seventeenth and early eighteenth centuries, especially between 1680 and 1720, science and the new philosophy that was associated with it became an important part of university education. Outside academia, learned societies, public lectures, discussions in coffeehouses, and popular scientific publications spread the knowledge of science among the educated members of society. In this way science secured a permanent foothold in Western culture.

The spread of science did not go unchallenged. It encountered academic rivals committed not only to traditional Aristotelianism but also to Renaissance humanism. In the late seventeenth century, a conflict arose between "the ancients," who revered the wisdom of classical authors, and "the moderns," who emphasized the superiority of the new scientific culture. The most concrete expression of this conflict was the Battle of the Books, an intellectual debate that raged over the question of which group of thinkers had contributed more to human knowledge. No clear winner in this battle emerged, and the conflict between the ancients and the moderns was never completely resolved. The humanities and the sciences, while included within the same curriculum at many universities, are still often regarded as representing separate cultural traditions.

Skepticism and Independent Reasoning

The Scientific Revolution encouraged the habit of **skepticism**, the tendency to doubt what we have been taught and are expected to believe. This skepticism formed part of the method that seventeenth-century scientists adopted to solve philosophical problems. As we have seen, Descartes, Bacon, Galileo, and Kepler all refused to acknowledge the authority of classical or medieval texts. They preferred to rely upon the knowledge they acquired from observing nature and using their own rational faculties.

skepticism A tendency to doubt what one has been taught or is expected to believe.

In *Discourse on the Method,* Descartes showed the extremes to which this skepticism could be taken. Descartes doubted the reality of his own sense perceptions and even his own existence until he realized that the very act of doubting proved his existence as a thinking being. As he wrote in words that have become famous, "I think, therefore I am."[3] Upon this foundation Descartes went on to prove the existence of God and the material world, thereby conquering the skepticism with which he began his inquiry. In the process, however, he developed an approach to solving intellectual problems that asked people to question authority and think clearly and systematically for themselves. The effects of this method became apparent in the late seventeenth century, when skeptics invoked Descartes's methodology to challenge both orthodox Judaism and Christianity. Some of the most radical of those opinions came from Baruch Spinoza (1632–1677), who grew up in Amsterdam in a community of Spanish and Portuguese Jews who had fled the Inquisition. Although educated as an Orthodox Jew, Spinoza also studied Latin and read Descartes and other Christian writers. From Descartes, Spinoza learned "that nothing ought to be admitted as true but what has

CHRONOLOGY: THE IMPACT OF THE SCIENTIFIC REVOLUTION

1620
Francis Bacon argues for the necessity of rigorous experimentation.

1633
Galileo tried by the Roman Inquisition.

1637
René Descartes publishes *Discourse on the Method.*

1670
Baruch Spinoza publishes *A Treatise on Religion and Political Philosophy,* challenging the distinction between spirit and matter.

1686
Bernard de Fontenelle publishes *Conversations on the Plurality of Worlds.*

been proved by good and solid reason." This skepticism and independence of thought led to his excommunication from the Jewish community at age 24.

Spinoza used Descartes's skepticism to challenge Descartes himself. He rejected Descartes's separation of the mind and the body and his radical distinction between the spiritual and the material. For Spinoza there was only one substance in the universe, which he identified with both God and nature. The claim that God and nature were two names for the same reality challenged not only the ideas of Descartes, but also the fundamental tenets of Christianity, including the belief in a personal God who had created the natural world by design and continued to govern it. In *A Treatise on Religion and Political Philosophy* (1670), Spinoza described "a universe ruled only by the cause and effect of natural laws, without purpose or design."

Spinoza's skeptical approach to solving philosophical and scientific problems revealed the radical intellectual potential of the new science. The freedom of thought that Spinoza advocated, as well as the belief that nature followed unchangeable laws

BARUCH SPINOZA Spinoza was one of the most radical thinkers of the seventeenth century. His identification of God with nature made him vulnerable to charges of atheism. His followers in the Dutch Republic, who were known as freethinkers, laid the foundations for the Enlightenment in the eighteenth century.

and could be understood in mathematical terms, served as important links between the Scientific Revolution and the Enlightenment of the eighteenth century. We will discuss those connections more fully in Chapter 19.

Science and Religion

The new science presented two challenges to traditional Christian belief. The first involved the apparent contradiction between the sun-centered theory of the universe and biblical references to the sun's mobility. Because the Bible was considered the inspired word of God, the Church took everything it said, including any passages regarding the operation of the physical world, as literally true. The Bible's reference to the sun moving across the sky served as the basis of the papal condemnation of sun-centered theories in 1616 and the prosecution of Galileo in 1633.

The second challenge to traditional Christian belief was the implication that if the universe functioned as a machine, on the basis of unchanging natural laws, then God played little part in its operation. God was akin to an engineer, who had designed the perfect machine, and therefore had no need to interfere with its workings. This position, which thinkers known as **deists** adopted in the late seventeenth and eighteenth centuries, denied the Christian belief that God was constantly active in the operation of the world. More directly, it rejected the possibility of miracles. None of the great scientists of the seventeenth century were themselves deists, but their acceptance of the mechanical philosophy made them vulnerable to the charge that they denied Christian doctrine.

deists Seventeenth- and eighteenth-century thinkers who believed that God created the universe and established immutable laws of nature but did not subsequently intervene in the operation of nature or in human affairs.

Although the new science and seventeenth-century Christianity appeared to be on a collision course, some scientists and theologians insisted that there was no conflict between them. They argued that religion and science had different concerns. Religion dealt with the relationship between humanity and God. Science explained how nature operated. As Galileo wrote in 1615, "The intention of the Holy Ghost is to teach us how one goes to heaven, not how heaven goes."[4] Scripture was not intended to explain natural phenomena, but to convey religious truths that human reason could not grasp.

Read the document

Galileo Galilei, *Letter to the Grand Duchess Christina*, 1615

Another argument for the compatibility of science and religion was the claim that the mechanical philosophy, rather than relegating God to the role of a retired engineer, actually manifested God's unlimited power. In a mechanistic universe God was still the creator of the physical world and the maker of the laws by which nature operated. He was still all-powerful and present everywhere. According to Boyle and Newton, moreover, God played a supremely active role in governing the universe. Not only had he created the universe, but as Boyle argued, he also continued to keep all matter constantly in motion. This theory served the purpose of redefining God's power without diminishing it in any way. Newton arrived at a similar position in his search for an immaterial agent who would cause gravity to operate. He proposed that God himself, who he believed "endures always and is present everywhere," made bodies move according to gravitational laws. Throughout the early eighteenth century this feature of Newtonian natural philosophy served as a powerful argument for the active involvement of God in the universe.

As the new science became more widely accepted, many theologians, especially Protestants, accommodated scientific knowledge to their religious beliefs. Some Protestants welcomed the discoveries of science as an opportunity to purify the Christian religion by combating the superstition, magic, and ignorance that they claimed the Catholic Church had been promoting. Clergymen argued that because God worked through the processes of nature, scientific inquiry could lead to knowledge of God. Religion and science could illuminate each other.

Theologians and philosophers also began to expand the role that reason played in religion. The English philosopher John Locke (1632–1704) argued that reason should be the final judge of the existence of the supernatural and the true meaning of the Bible. This new emphasis on the role of reason in religion coincided with a rejection of the religious zeal that had prevailed during the Reformation and the wars of religion. Increasingly, political and ecclesiastical authorities condemned religious enthusiasm as dangerous and irrational.

Justice in History

The Trial of Galileo

Read the Document
Galileo Galilei, *"Third Letter on Sunspots"*

The events leading to the trial of Galileo for heresy in 1633 began in 1616, when a committee of theologians reported to the Roman Inquisition that the sun-centered theory of Copernicus was heretical. Those who accepted this theory were declared to be heretics not only because they questioned the Bible itself, but because they denied the exclusive authority of the Catholic Church to interpret the Bible. The day after this report was submitted, Pope Paul V (r. 1605–1621) instructed Cardinal Robert Bellarmine (1542–1621), a theologian who was on good terms with Galileo, to warn him to abandon his Copernican views. Galileo had written extensively in support of the sun-centered thesis, especially in his *Letters on Sunspots* (1613) and his *Letter to the Grand Duchess Christina* (1615), although he had never admitted that the theory was proved conclusively. Then he was told not to hold, teach, or defend in any way the opinion that the sun was stable or the Earth moved. If he ignored that warning, he would be prosecuted as a heretic.

During the next 16 years Galileo published two books. The first, *The Assayer* (1623), attacked the views of an Italian philosopher regarding comets. The book won Galileo support, especially from the new pope, Urban VIII (r. 1623–1644), who was eager to be associated with the most fashionable intellectual trends. Urban took Galileo under his wing and made him the intellectual star of his court. Urban even declared that support for Copernicanism was rash but not heretical.

THE TRIAL OF GALILEO, 1633 Galileo is shown here presenting one of his four defenses to the Inquisition. He claimed that his book *Dialogue Concerning the Two Chief World Systems* did not endorse the Copernican model of the universe.
SOURCE: Gérard Blot/Art Resource/Reunion des Musees Nationaux

The pope's patronage may have emboldened Galileo to exercise less caution in writing his second book of this period, *Dialogue Concerning the Two Chief World Systems* (1632). Ostensibly an impartial presentation of the rival Ptolemaic and Copernican cosmologies, this book promoted Copernicanism in its own quiet way. Galileo sought proper authorization from ecclesiastical authorities to put the book in print, but he allowed it to be published in Florence before it received official approval from Rome.

The publication of *Dialogue* precipitated Galileo's fall from the pope's favor. Urban, accused of leniency with heretics, ordered the book taken out of circulation in the summer of 1632 and appointed a commission to investigate Galileo's activities. After receiving their report, he turned the matter over to the Roman Inquisition, which charged Galileo with heresy.

The Roman Inquisition had been established in 1542 to preserve the Catholic faith and prosecute heresy. Like the Spanish Inquisition, this Roman ecclesiastical court has acquired a reputation for being harsh and arbitrary, for administering torture, for proceeding in secrecy, and for denying the accused the right to know the charges before the trial. There is some validity to these criticisms, although the Inquisition did not torture Galileo or deny him the opportunity to defend himself. The most unfair aspect of the proceeding, and of inquisitorial justice in general, was that the same judges who had brought the charges against the accused and conducted the interrogation also decided the case. This meant that in a politically motivated trial such as Galileo's, the verdict was a foregone conclusion. To accept Galileo's defense would have been a sign of weakness and a repudiation of the pope.

Although the underlying issue in the trial was whether Galileo was guilty of heresy for denying the sun's motion and the Earth's immobility, the more technical question was whether by publishing *Dialogue* he had violated the prohibition of 1616. In his defense Galileo claimed he had only written *Dialogue* to present "the physical and astronomical reasons that can be advanced for one side or the other." He denied holding Copernicus's opinion to be true.

In the end the court determined that by publishing *Dialogue,* Galileo had violated the injunction of 1616. He had disseminated "the false opinion of the Earth's motion and the sun's stability," and he had "defended the said opinion already condemned." Even Galileo's efforts "to give the impression of leaving it undecided and labeled as probable" was still a serious error, because there was no way that "an opinion declared and defined contrary to divine Scripture may be probable." The court also declared that Galileo had obtained permission to publish the book in Florence without telling the authorities there that he was under the injunction of 1616.

Throughout the trial every effort was made to distance the pope from his former protégé. The papal court feared that because the pope had been Galileo's patron and had allowed him to develop his ideas, he himself would be implicated in Galileo's heresy. Information regarding the pope's earlier support for Galileo would not be allowed to surface during the trial. The court made sure, for example, that no one from the court of the Grand Duke of Tuscany in Florence, who had secured Galileo's appointment at the University of Padua and had defended him throughout this crisis, would testify for him. The trial tells us

(continued on next page)

(continued from previous page)

as much about Urban VIII's efforts to save face as about the Catholic Church's hostility to the new science.

The Inquisition required Galileo to renounce his views and avoid further defense of Copernicanism. After making this humiliating submission to the court, he was sent to Siena and later that year was allowed to return to his villa near Florence, where he remained under house arrest until his death in 1642.

For Discussion

1. Galileo was silenced because of what he had printed. Why had he published these works, and why did the Church consider his publications a threat?
2. Should disputes between science and religion be resolved in a court of law? Why or why not?

Taking It Further

Finocchiaro, Maurice (ed). *The Galileo Affair: A Documentary History*. 1989. A collection of original documents regarding the controversy between Galileo and the Roman Catholic Church.

Sharratt, Michael. *Galileo: Decisive Innovator.* 1994. A study of Galileo's place in the history of science that provides full coverage of his trial and papal reconsiderations of it in the late twentieth century.

The new emphasis on the reasonableness of religion and the decline of religious enthusiasm are often viewed as evidence of a trend toward the **secularization** of European life, a process in which religion gave way to more worldly concerns. In one sense this secular trend was undeniable. By 1700, theology had lost its dominant position at the universities and religion had lost much of its influence on politics, diplomacy, and economic activity.

secularization The reduction of the importance of religion in society and culture.

Religion, however, had not lost its relevance. It remained a vital force in the lives of most Europeans. Many of those who accepted the new science continued to believe in a providential God and the divinity of Christ. Moreover, a small but influential group of educated people, following the lead of the French scientist and philosopher Blaise Pascal (1623–1662), argued that religious faith occupied a higher sphere of knowledge that reason and science could not penetrate. Pascal, the inventor of a calculating machine and the promoter of a system of public coach service in Paris, was an advocate of the new science. He endorsed the Copernican model of the universe and opposed the condemnation of Galileo. He introduced a new scientific theory regarding fluids that later became known as Pascal's law of pressure. But by claiming that knowledge of God comes from the heart rather than the mind, Pascal challenged the contention of Locke and Spinoza that reason was the ultimate arbiter of religious truth.

Humans and the Natural World

17.5 How did the Scientific Revolution change the way in which seventeenth- and eighteenth-century Europeans thought of the place of human beings in nature?

The spread of scientific knowledge not only redefined the views of educated people regarding the supernatural, but also led them to reconsider their relationship to nature. This process involved three separate but related inquiries: to determine the place of human beings in a sun-centered universe, to investigate how science and technology had given human beings greater control over nature, and to reconsider the relationship between men and women in light of new scientific knowledge about the human mind and body.

The Place of Human Beings in the Universe

The astronomical discoveries of Copernicus, Kepler, and Galileo offered a new outlook about the position of human beings in the universe. The Earth-centered Ptolemaic cosmos that dominated scientific thought during the Middle Ages was also human-centered. Human beings inhabited the planet at the very center of the universe, and on that planet they enjoyed a privileged position. They were, after all, created in the image of God, according to Christian belief.

The acceptance of a sun-centered model of the universe began to change these views of humankind. Once it became apparent that the Earth was not the center of the universe, human beings began to lose their privileged position in nature. The Copernican universe was neither Earth-centered nor human-centered. Scientists such as Descartes continued to claim that human beings were the greatest of nature's creatures, but their habitation of a tiny planet circling the sun inevitably reduced the sense of their own importance. Moreover, as astronomers began to recognize the incomprehensible size of the cosmos, the possibility emerged that there were other habitable worlds in the universe, calling into further question the unique status of humankind.

In the late sixteenth and seventeenth centuries a number of literary works explored the possibility of other inhabited worlds and forms of life. Kepler's *Somnium,* or *Lunar Astronomy* (1634), a book that combined science and fiction, described various species of moon dwellers, some of whom were rational and superior to humans. The most ambitious of these books on extraterrestrial life was Bernard de Fontenelle's *Conversations on the Plurality of Worlds* (1686). This fictional work by a dramatist and poet who was also well versed in scientific knowledge became immensely popular throughout Europe and was more responsible than any purely scientific achievement for leading the general reading public to call into question the centrality of human beings in Creation.

The Control of Nature

The Scientific Revolution strengthened the confidence human beings had in their ability to control nature. By disclosing the laws governing the operation of the universe, the new science gave humans the tools they needed to make nature serve them more effectively than it had in the past. Francis Bacon, for example, believed that knowledge of the laws of nature could restore the dominion over nature that humans had lost in the biblical Garden of Eden. Bacon thought that nature existed for human beings to control and exploit for their own benefit. His famous saying, "knowledge is power," conveyed his confidence that science would give human beings this type of control. This optimism regarding human control of nature found support in the belief that God permitted such mastery, first by creating a regular and uniform universe and then by giving humans the rational faculties by which they could understand nature's laws.

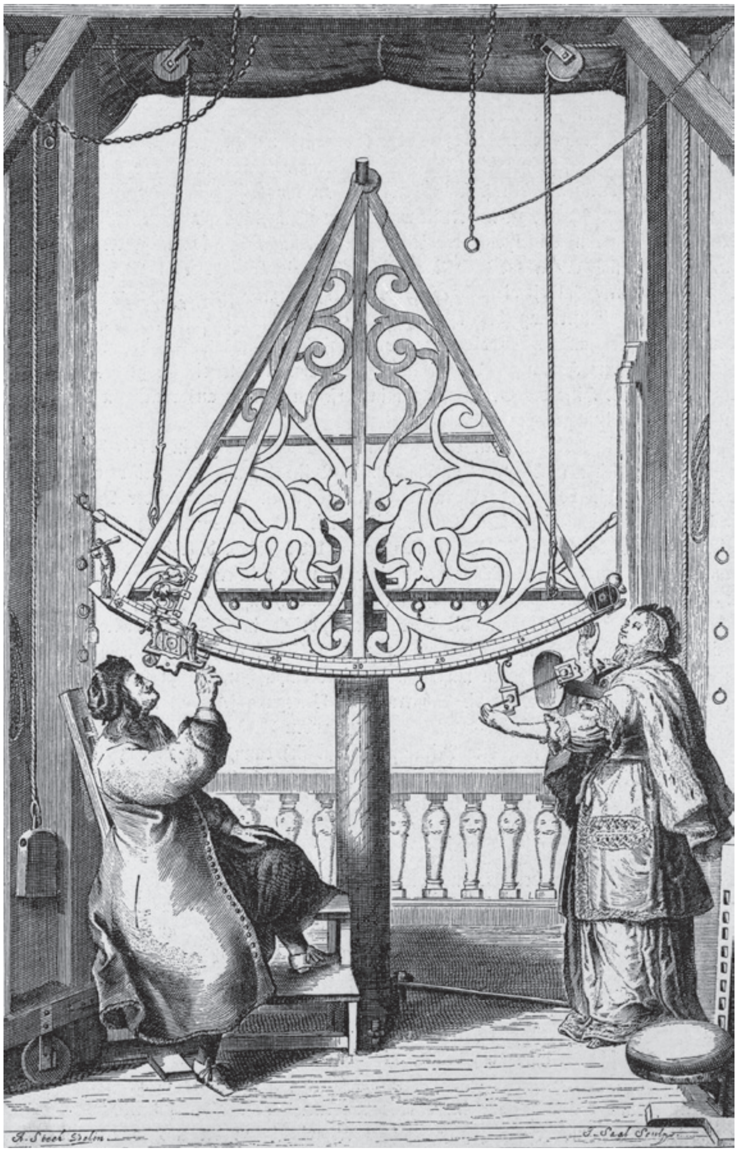
Many seventeenth-century scientists emphasized the practical applications of their research, just as scientists often do today. Descartes, who used his knowledge of optics to improve the grinding of lenses, considered how scientific knowledge could drain marshes, increase the velocity of bullets, and use bells to make clouds give rain. In his celebration of the French Academy of Sciences in 1699, Fontenelle wrote that "the application of science to nature will constantly grow in scope and intensity and we shall go on from one marvel to the next; the day will come when man will be able to fly by fitting on wings to keep him in the air . . . till one day we shall be able to fly to the moon."[5]

The hopes of seventeenth-century scientists for the improvement of human life by means of technology remained in large part unfulfilled until the eighteenth century. Only then did the technological promise of the Scientific Revolution begin to be realized, most notably with the innovations that preceded or accompanied the Industrial Revolution (see Chapter 21). By the middle of the eighteenth century, the belief that science would improve human life became an integral part of Western culture. Faith in human progress also became one of the main themes of the Enlightenment, which will be discussed in Chapter 19.

Women, Men, and Nature

The new scientific and philosophical ideas challenged ancient and medieval notions about women's physical and mental inferiority to men but not other traditional ideas about gender roles.

Until the seventeenth century, a woman's sexual organs were thought to be imperfect versions of a man's, an idea that made woman an inferior version of man and, in some respects, a freak of nature. During the sixteenth and seventeenth centuries, scientific literature advanced the new idea that women's sexual organs were perfect in their own right and served distinct functions in reproduction. Aristotle's view that men made a more important contribution to reproduction than women also came under attack. Semen was long believed to contain the form of both the body and the soul, while a woman only contributed the formless matter on which the semen acted. By 1700, however, most scholars agreed that both sexes contributed equally to the process of reproduction.



ASTRONOMERS IN SEVENTEENTH-CENTURY GERMANY Elisabetha and Johannes Hevelius working together with a sextant in a German astronomical observatory. More than 14 percent of all German astronomers were female. Most of them collaborated with their husbands in their work.

Some seventeenth-century natural philosophers also questioned ancient and medieval ideas about women's mental inferiority to men. In making a radical separation between the mind and the human body, Descartes, for example, found no difference between the minds of men and women. As one of his followers wrote in 1673, "The mind has no sex."[6] A few upper-class women provided evidence to support this revolutionary claim of female intellectual equality. Princess Elisabeth of Bohemia, for example, carried on a long correspondence with Descartes during the 1640s and challenged many of his ideas on the relationship between the body and the soul. The English noblewoman Margaret Cavendish (1623–1673) wrote scientific and philosophical works and conversed with leading philosophers. In early eighteenth-century France, small groups of women and men gathered in the salons or private sitting rooms of the nobility to discuss philosophical and scientific ideas. In Germany women helped their husbands run astronomical observatories.

Although seventeenth-century science laid the foundations for a theory of sexual equality, it did not challenge other traditional ideas that compared women unfavorably with men. Most educated people continued to ground female behavior in the humors, claiming that because women were cold and wet, as opposed to hot and dry, they were naturally more deceptive, unstable, and melancholic than men. They also continued to identify women with nature itself, which had always been depicted as female. Bacon's use of masculine metaphors to describe science and his references to "man's mastery over nature" therefore seemed to reinforce traditional ideas of male dominance over women. His language also reinforced traditional notions of men's superior rationality.[7] In 1664 the secretary of the Royal Society, which excluded women from membership, proclaimed that the mission of that institution was to develop a "masculine philosophy."[8]

The new science thus strengthened the theoretical foundations for the male control of women at a time when many men expressed concern over women's "disorderly" and "irrational" conduct. In a world populated with witches, rebels, and other women who refused to adhere to conventional standards of proper feminine behavior, the adoption of a masculine philosophy was associated with the reassertion of patriarchy.

CONCLUSION

Science and Western Culture

Unlike many of the cultural developments in the history of the West, the Scientific Revolution owes very little to Eastern influences. During the Middle Ages the Islamic civilizations of the Middle East produced a rich body of scientific knowledge that influenced the development of medieval science in Europe, but by the time of the Scientific Revolution, Middle Eastern science no longer occupied the frontlines of scientific research. Middle Eastern natural philosophers had little to offer their European counterparts as they made their contributions to the Scientific Revolution.

China and India had also accumulated a large body of scientific knowledge in ancient and medieval times. When Jesuit missionaries began teaching Western science and mathematics to the Chinese in the sixteenth and seventeenth centuries, they learned about earlier Chinese technological advances, including the invention of the compass, gunpowder, and printing. They also learned that ancient Chinese astronomers had been the first to observe solar eclipses and comets. By the time the Jesuits arrived, however, Chinese science had entered a period of decline. When those missionaries returned home, they introduced Europeans to many aspects of Chinese culture but very few scientific ideas that European natural philosophers found useful.

None of these Eastern civilizations had a scientific revolution comparable to the one that occurred in the West in the late sixteenth and seventeenth centuries. For China the explanation probably lies in the absence of military and political incentives to promote scientific research at a time when the vast Chinese empire was relatively stable. In the Middle East the explanation is more likely that Islam during these years failed to give priority to the study of the natural world. In Islam nature was either entirely secular (that is, not religious) and hence not worthy of study on its own terms or so heavily infused with spiritual value that it could not be subjected to rational analysis. In Europe, however, religious and cultural traditions allowed scientists to view nature as both a product of supernatural forces and something that was separate from the supernatural. Nature could therefore be studied objectively without losing its religious significance. Only when nature was viewed as both the creation of God and at the same time as independent of God could it be subjected to mathematical analysis and brought under human control.

Scientific and technological knowledge became a significant component of Western culture, and in the eighteenth century Western science gave many educated Europeans a new source of identity. These people believed that their knowledge of science, in conjunction with their Christian religion, their classical culture, and their political institutions, made them different from, if not superior to, people living in the East.

The rise of Western science and technology played a role in the growth of European dominance over Africa, Asia, and the Americas. Science gave Western states the military and navigational technology that helped them gain control of foreign lands. Knowledge of botany and agriculture allowed Western powers to develop the resources of the areas they colonized and use these resources to improve their own societies. Some Europeans even appealed to science to justify their dominance of the people in the lands they settled and ruled. To this process of Western imperial expansion we now turn.

MAKING CONNECTIONS

1. Were the changes in astronomy, physics, chemistry, and biology in the sixteenth and seventeenth centuries revolutionary? In which field were the changes most significant?
2. Scientists today often refer to the scientific method. Was there a scientific method in the seventeenth century or did scientists employ various methods?
3. Why did the Scientific Revolution occur at this time? Did it owe its development more to internal or external developments?
4. What does the conflict between the supporter of a sun-centered theory and the Catholic Church suggest about the compatibility of science and religion in the seventeenth century?

TAKING IT FURTHER

For suggested readings see page R-1.

Chapter Review

The Discoveries and Achievements of the Scientific Revolution

17.1 What were the achievements and discoveries of the Scientific Revolution?

Discoveries in astronomy, physics, chemistry, and biology transformed human thought in the seventeenth century. The most significant change in astronomy was due to Kepler and Galileo supporting the Copernican model of the universe, which claimed that the sun, not the Earth, was the center of the universe. In the field of physics, Sir Isaac Newton offered a scientific model of the physical world based on the laws of motion and gravitation. In chemistry, the discovery of atoms by Robert Boyle advanced the idea that the arrangement of a subject's atoms determined its characteristics, and William Harvey's demonstration of how blood circulates through the human body set the standard for future research in biology and medicine.

The Search for Scientific Knowledge

17.2 What methods did scientists use during this period to investigate nature, and how did they think nature operated?

Scientists used an empirical or inductive approach, which demands testing all scientific theories through rigorous experiments based on observation of the natural world. They also used deductive reasoning to establish basic truths or principles, and from these premises then arrived at other logical conclusions or laws. Scientific research conducted in both traditions applied mathematics to the study of a natural world that was believed to operate as if it were a machine made by a human being.

The Causes of the Scientific Revolution

17.3 Why did the Scientific Revolution take place in western Europe at this time?

Within the realm of science, the research into motion conducted by natural philosophers in the fourteenth century, the scientific investigations by Renaissance humanists, and the collapse of the dominant conceptual frameworks, or paradigms, that had governed scientific inquiry and research for centuries were factors in the revolution of scientific thought. Outside of science, the spread of Protestantism; the patronage, or sponsorship, of scientific research; the invention of the printing press; and military and economic change all created a favorable environment for the development of new ideas.

The Intellectual Consequences of the Scientific Revolution

17.4 How did the Scientific Revolution influence philosophical and religious thought in the seventeenth and early eighteenth centuries?

Science and its associated philosophies became an important part of the university education system. Outside academia, scientific knowledge was spread by way of popular scientific publications and coffeehouse debate. Both of these trends helped popularize skepticism among educated people, an approach to solving philosophical and scientific problems that emphasizes independent thought. While religion remained a vital force in most people's lives, a trend of secularization, the process by which belief in religion is displaced by more worldly concerns, marked the end of the seventeenth century.

Humans and the Natural World

17.5 How did the Scientific Revolution change the way in which seventeenth- and eighteenth-century Europeans thought of the place of human beings in nature?

Three separate but related areas of inquiry led people to reconsider their relationship to nature. The newly accepted sun-centered model of the universe forced humans to question their status as unique and central to the universe, while the new science hinted at the potential to make the natural world serve people more effectively than in the past. Even long established differences in equality between the sexes were called into question when new scientific knowledge about the human body advanced the idea that female sex organs were perfect in their own right and served a crucial function in reproduction.

Chapter Time Line

1543
Copernicus publishes *On the Revolutions of the Heavenly Spheres.*

1609
Johannes Kepler publishes *New Astronomy.*

1628
William Harvey publishes *On the Motion of the Heart and Blood in Animals.*

1632
Galileo publishes *Dialogue Concerning the Two Chief World Systems.*

1633
Galileo tried by the Roman Inquisition.

1637
René Descartes publishes *Discourse on the Method.*

1659
Robert Boyle invents the air pump and conducts experiments on the elasticity and compressibility of air.

1662
Founding of the Royal Society of London under the auspices of Charles II.

1687
Newton publishes *Mathematical Principles of Natural Philosophy.*