CHAPTER

16

Toward a New Heaven and a New Earth: The Scientific Revolution and the Emergence of Modern Science


Louvre, Paris//Erich Lessing/Art Resource, NY

A nineteenth-century painting of Galileo before the Holy Office in the Vatican in 1633

CHAPTER OUTLINE AND FOCUS QUESTIONS

Background to the Scientific Revolution

Q What developments during the Middle Ages and the Renaissance contributed to the Scientific Revolution of the seventeenth century?

Toward a New Heaven: A Revolution in Astronomy

Q What did Copernicus, Kepler, Galileo, and Newton contribute to a new vision of the universe, and how did it differ from the Ptolemaic conception of the universe?

Advances in Medicine and Chemistry

Q What did Paracelsus, Vesalius, and Harvey contribute to a scientific view of medicine?

Women in the Origins of Modern Science

Q What role did women play in the Scientific Revolution?

Toward a New Earth: Descartes, Rationalism, and a New View of Humankind

Q Why is Descartes considered the "founder of modern rationalism"?

The Scientific Method and the Spread of Scientific Knowledge

Q How were the ideas of the Scientific Revolution spread, and what impact did they have on society and religion?

CRITICAL THINKING

Q In what ways were the intellectual, political, social, and religious developments of the seventeenth century related?

CONNECTIONS TO TODAY

Q What scientific discoveries of the twentieth and twenty-first centuries have had as great an impact on society as those of the Scientific Revolution?

IN ADDITION TO the political, economic, social, and international crises of the seventeenth century, we need to add an intellectual one. The Scientific Revolution questioned and ultimately challenged conceptions and beliefs about the nature of the external world and reality that had crystallized into a rather strict orthodoxy by the Later Middle Ages. Derived from the works of ancient Greeks and Romans and grounded in Christian thought, the medieval worldview had become formidable. But the breakdown of Christian unity during the Reformation and the subsequent religious wars had created an environment in which Europeans became more comfortable with challenging both the ecclesiastical and the political realms. Should it surprise us that a challenge to intellectual authority soon followed?

The Scientific Revolution taught Europeans to view the universe and their place in it in a new way. The shift from an earth-centered to a sun-centered cosmos had an emotional as well as an intellectual effect on the people who understood it. Thus, the Scientific Revolution, popularized in the eighteenth-century Enlightenment, stands as the major force in the transition to the largely secular, rational, and materialistic perspective that has defined the modern Western mentality since its full acceptance in the nineteenth and twentieth centuries.

The transition to a new worldview, however, was far from easy. In the seventeenth century, the Italian scientist Galileo Galilei (gal-li-LAY-oh GAL-li-lay), an outspoken advocate of the new worldview, found that his ideas were strongly opposed by the authorities of the Catholic Church. Galileo's position was clear: "I hold the sun to be situated motionless in the center of the revolution of the celestial bodies, while the earth rotates on its axis and revolves about the sun." Moreover, "nothing physical that sense-experience sets before our eyes . . . ought to be called in question (much less condemned) upon the testimony of Biblical passages." But the church had a different view, and in 1633, Galileo, now sixty-eight and in ill health, was called before the dreaded Inquisition in Rome. He was kept waiting for two months before he was tried and found guilty of heresy and disobedience. Completely shattered by the experience, he denounced his errors: "With a sincere heart and unfeigned faith I curse and detest the said errors and heresies contrary to the Holy Church." Legend holds that when he left the trial room, Galileo muttered to himself: "And yet it does move!" Galileo had been silenced, but his writings remained, and they spread throughout Europe. The Inquisition had failed to stop the new ideas of the Scientific Revolution.

In one sense, the Scientific Revolution was not a revolution. It was not characterized by the explosive change and rapid overthrow of traditional authority that we normally associate with the word *revolution*. The Scientific Revolution did overturn centuries of authority, but only in a gradual and piecemeal fashion. Nevertheless, its results were truly revolutionary. The Scientific Revolution was a key factor in setting Western civilization along its modern secular and materialistic path. ↞

Background to the Scientific Revolution

FOCUS QUESTION: What developments during the Middle Ages and the Renaissance contributed to the Scientific Revolution of the seventeenth century?

To say that the **Scientific Revolution** brought about a dissolution of the medieval worldview is not to say that the Middle Ages was a period of scientific ignorance. Many educated Europeans took an intense interest in the world around them since it was, after all, "God's handiwork" and therefore an appropriate subject for study. Late medieval scholastic philosophers had advanced mathematical and physical thinking in many ways, but the subjection of these thinkers to a strict theological framework and their unquestioning reliance on a few ancient authorities, especially Aristotle and Galen, limited where they could go. Many "natural philosophers," as medieval scientists were called, preferred refined logical analysis to systematic observations of the natural world. A number of changes and advances in the fifteenth and sixteenth centuries may have played a major role in helping "natural philosophers" abandon their old views and develop new ones.

Ancient Authors and Renaissance Artists

Whereas medieval scholars had made use of Aristotle, Galen, and Ptolemy in Latin translations to develop many of their positions in the fields of physics, medicine, and astronomy, the Renaissance humanists had mastered Greek and made available new works of Galen, Ptolemy, and Archimedes as well as Plato and the pre-Socratics. These writings made it apparent that even the unquestioned authorities of the Middle Ages, Aristotle and Galen, had been contradicted by other thinkers. The desire to discover which school of thought was correct stimulated new scientific work that sometimes led to a complete rejection of the Classical authorities.

Renaissance artists have also been credited with making an impact on scientific study. Their desire to imitate nature led them to a close observation of nature. Their accurate renderings of rocks, plants, animals, and human anatomy established new standards for the study of natural phenomena. At the same time, the "scientific" study of the problems of perspective and correct anatomical proportions led to new insights. "No painter," one Renaissance artist declared, "can paint well without a thorough knowledge of geometry."[1] Renaissance artists were frequently called on to be practicing mathematicians as well. Leonardo da Vinci devised "war machines," and Albrecht Dürer made designs for the fortifications of cities.

Technological Innovations and Mathematics

Technical problems such as accurately calculating the tonnage of ships also stimulated scientific activity because they required careful observation and precise measurements. The relationship between technology and the Scientific Revolution was not a simple one, however, for many technological experts did not believe in abstract or academic learning. Indeed, many of the technical innovations of the Middle Ages and the Renaissance were accomplished outside the universities by people who emphasized practical rather than theoretical knowledge. In any case, the invention of new instruments and machines, such as the telescope and the microscope, often made new scientific discoveries possible. The printing press had an indirect but crucial role in spreading innovative ideas quickly and easily.

Mathematics, so fundamental to the scientific achievements of the sixteenth and seventeenth centuries, was promoted in the Renaissance by the rediscovery of the works of ancient mathematicians and the influence of Plato, who had emphasized the importance of mathematics in explaining the universe. Applauded as the key to navigation, military science, and geography, mathematics was also regarded as the key to understanding the nature of things. According to Leonardo da Vinci, since

God eternally geometrizes, nature is inherently mathematical: "Proportion is not only found in numbers and measurements but also in sounds, weights, times, positions, and in whatsoever power there may be."[2] Moreover, mathematical reasoning was seen as promoting a degree of certainty that was otherwise impossible. In the words of Leonardo da Vinci: "There is no certainty where one can neither apply any of the mathematical sciences nor any of those which are based upon the mathematical sciences."[3] Copernicus, Kepler, Galileo, and Newton were all great mathematicians who believed that the secrets of nature were written in the language of mathematics.

Renaissance Magic

Another factor in the origins of the Scientific Revolution may have been magic. Renaissance magic was the preserve of an intellectual elite from all of Europe. By the end of the sixteenth century, Hermetic magic had become fused with alchemical thought into a single intellectual framework. This tradition believed that the world was a living embodiment of divinity. Humans, who it was believed also had that spark of divinity within, could use magic, especially mathematical magic, to understand and dominate the world of nature or employ the powers of nature for beneficial purposes. Was it Hermeticism, then, that inaugurated the shift in consciousness that made the Scientific Revolution possible, since the desire to control and dominate the natural world was a crucial motivating force in the Scientific Revolution? One scholar has argued:

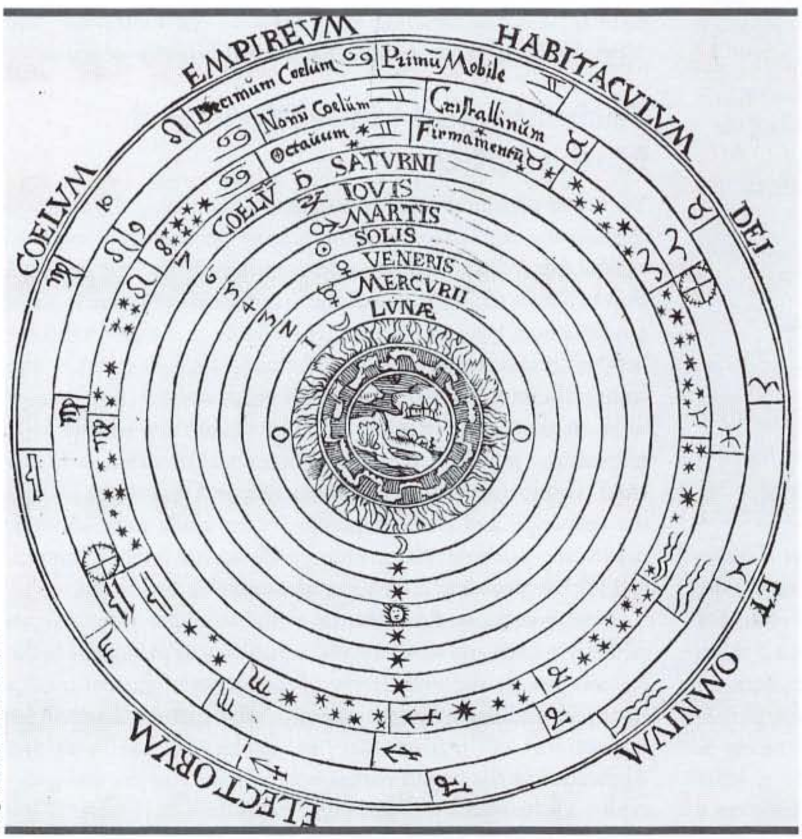
> It is a movement of the will which really originates an intellectual movement. A new center of interest arises, surrounded by emotional excitement; the mind turns where the will has directed it and new attitudes, new discoveries follow. Behind the emergence of modern science there was a new direction of the will toward the world, its marvels, and mysterious workings, a new longing and determination to understand those workings and to operate with them.[4]

"This time," the author continues, "the return to the occult [Hermetic tradition] stimulates the genuine science."[5] Scholars debate the issue, but histories of the Scientific Revolution frequently overlook the fact that the great names we associate with the revolution in cosmology—Copernicus, Kepler, Galileo, and Newton—all had a serious interest in Hermetic ideas and the fields of astrology and alchemy. The mention of these names also reminds us of one final consideration in the origins of the Scientific Revolution: it largely resulted from the work of a handful of great intellectuals.

Toward a New Heaven: A Revolution in Astronomy

FOCUS QUESTION: What did Copernicus, Kepler, Galileo, and Newton contribute to a new vision of the universe, and how did it differ from the Ptolemaic conception of the universe?

The greatest achievements in the Scientific Revolution of the sixteenth and seventeenth centuries came in the fields most dominated by the ideas of the Greeks—astronomy, mechanics,



Medieval Conception of the Universe. As this sixteenth-century illustration shows, the medieval cosmological view placed the earth at the center of the universe, surrounded by a series of concentric spheres. The earth was imperfect and constantly changing, whereas the heavenly bodies that surrounded it were perfect and incorruptible. Beyond the tenth and final sphere was heaven, where God and all the saved souls were located. (The circles read, from the center outward: 1. Moon, 2. Mercury, 3. Venus, 4. Sun, 5. Mars, 6. Jupiter, 7. Saturn, 8. Firmament (of the Stars), 9. Crystalline Sphere, 10. Prime Mover; and around the outside, Empyrean Heaven—Home of God and All the Elect, that is, saved souls.)

and medicine. The cosmological views of the Later Middle Ages had been built on a synthesis of the ideas of Aristotle, Ptolemy (the greatest astronomer of antiquity, who lived in the second century C.E.), and Christian theology. In the resulting Ptolemaic (tahl-uh-MAY-ik) or **geocentric conception**, the universe was seen as a series of concentric spheres with a fixed or motionless earth at its center. Composed of the material substances of earth, air, fire, and water, the earth was imperfect and constantly changing. The spheres that surrounded the earth were made of a crystalline, transparent substance and moved in circular orbits around the earth. Circular movement, according to Aristotle, was the most "perfect" kind of motion and hence appropriate for the "perfect" heavenly bodies thought to consist of a nonmaterial, incorruptible "quintessence." These heavenly bodies, pure orbs of light, were embedded in the moving, concentric spheres, which in 1500 were believed to number ten. Working outward from the earth, eight spheres contained the moon, Mercury, Venus, the sun, Mars, Jupiter, Saturn, and the fixed stars. The ninth sphere imparted to the eighth sphere of the fixed stars its motion, and the tenth sphere was frequently described as the prime mover that moved itself and imparted motion to the other spheres. Beyond the tenth sphere was the Empyrean Heaven—the location of God and all the saved souls. This Christianized Ptolemaic universe, then, was finite. It had a fixed outer boundary in harmony with Christian thought and expectations. God and the saved souls were at one end of the universe, and humans were at the center. They had been given power over the earth, but their real purpose was to achieve salvation.

This conception of the universe, however, did not satisfy professional astronomers, who wished to ascertain the precise paths of the heavenly bodies across the sky. Finding that their observations did not always correspond to the accepted scheme, astronomers tried to "save appearances" by developing an elaborate system of devices. They proposed, for example, that the planetary bodies traveled on epicycles, concentric spheres within spheres, that would enable the paths of the planets to correspond more precisely to observations while adhering to Aristotle's ideas of circular planetary movement.

Copernicus

Nicolaus Copernicus (nee-koh-LAU-uss kuh-PURR-nuh-kuss) (1473–1543) had studied both mathematics and astronomy first at Krakow in his native Poland and later at the Italian universities of Bologna and Padua. Before he left Italy in 1506, he had become aware of ancient views that contradicted the Ptolemaic, earth-centered conception of the universe. Between 1506 and 1530, he completed the manuscript of his famous book, *On the Revolutions of the Heavenly Spheres*, but his own timidity and fear of ridicule from fellow astronomers kept him from publishing it until May 1543, shortly before his death.

Copernicus was not an accomplished observational astronomer and relied for his data on the records of his predecessors. But he was a mathematician who felt that Ptolemy's geocentric system was too complicated and failed to accord

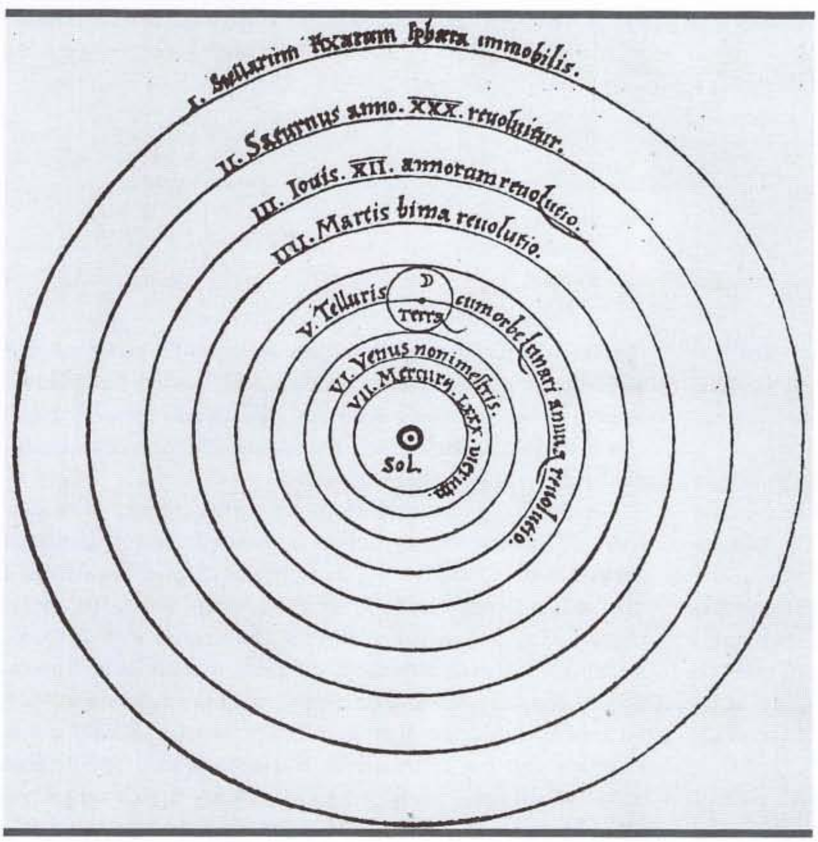


Image Select/Art Resource, NY

The Copernican System. The Copernican system was presented in *On the Revolutions of the Heavenly Spheres*, published shortly before Copernicus's death. As shown in this illustration from the first edition of the book, Copernicus maintained that the sun was the center of the universe and that the planets, including the earth, revolved around it. Moreover, the earth rotated daily on its axis. (The circles read, from the inside out: 1. Sun; 2. Mercury, orbit of 80 days; 3. Venus; 4. Earth, with the moon, orbit of one year; 5. Mars, orbit of 2 years; 6. Jupiter, orbit of 12 years; 7. Saturn, orbit of 30 years; 8. Immobile Sphere of the Fixed Stars.)

On the Revolutions of the Heavenly Spheres

NICOLAUS COPERNICUS BEGAN A REVOLUTION in astronomy when he argued that the sun and not the earth was at the center of the universe. Expecting controversy and scorn, Copernicus hesitated to publish the work in which he put forth his heliocentric theory. He finally relented, however, and managed to see a copy of it just before he died.

Nicolaus Copernicus, *On the Revolutions of the Heavenly Spheres*

For a long time, then, I reflected on this confusion in the astronomical traditions concerning the derivation of the motions of the universe's spheres. I began to be annoyed that the movements of the world machine, created for our sake by the best and most systematic Artisan of all [God], were not understood with greater certainty by the philosophers, who otherwise examined so precisely the most insignificant trifles of this world. For this reason I undertook the task of rereading the works of all the philosophers which I could obtain to learn whether anyone had ever proposed other motions of the universe's spheres than those expounded by the teachers of astronomy in the schools. And in fact first I found in Cicero that Hicetas supposed the earth to move. Later I also discovered in Plutarch that certain others were of this opinion. I have decided to set his words down here, so that they may be available to everybody:

> Some think that the earth remains at rest. But Philolaus the Pythagorean believes that, like the sun and moon, it revolves around the fire in an oblique circle. Heraclides of Pontus and Ecphantus the Pythagorean make the earth move, not in a progressive motion, but like a wheel in a rotation from the west to east about its own center.

Therefore, having obtained the opportunity from these sources, I too began to consider the mobility of the earth. And even though the idea seemed absurd, nevertheless I knew that others before me had been granted the freedom to imagine any circles whatever for the purpose of explaining the heavenly phenomena. Hence I thought that I too would be readily permitted to ascertain whether explanations sounder than those of my predecessors could be found for the revolution of the celestial spheres on the assumption of some motion of the earth.

Having thus assumed the motions which I ascribe to the earth later on in the volume, by long and intense study I finally found that if the motions of the other planets are correlated with the orbiting of the earth, and are computed for the revolution of each planet, not only do their phenomena follow therefrom but also the order and size of all the planets and spheres, and heaven itself is so linked together that in no portion of it can anything be shifted without disrupting the remaining parts and the universe as a whole . . .

Hence I feel no shame in asserting that this whole region engirdled by the moon, and the center of the earth, traverse this grand circle amid the rest of the planets in an annual revolution around the sun. Near the sun is the center of the universe. Moreover, since the sun remains stationary, whatever appears as a motion of the sun is really due rather to the motion of the earth,

Q *What major new ideas did Copernicus discuss in this excerpt? What was the source of these ideas? Why might one say that European astronomers had finally destroyed the Middle Ages?*

with the observed motions of the heavenly bodies (see the box above). Copernicus hoped that his **heliocentric** or sun-centered **conception** would offer a simpler and more accurate explanation.

Copernicus argued that the universe consisted of eight spheres with the sun motionless at the center and the sphere of the fixed stars at rest in the eighth sphere. The planets revolved around the sun in the order of Mercury, Venus, the earth, Mars, Jupiter, and Saturn. The moon, however, revolved around the earth. Moreover, according to Copernicus, what appeared to be the movement of the sun and the fixed stars around the earth was really explained by the daily rotation of the earth on its axis and the journey of the earth around the sun each year.

Copernicus, however, was basically conservative. He did not reject Aristotle's principle of the existence of heavenly spheres moving in circular orbits. As a result, when he put forth the calculations to prove his new theory, he retained about half of Ptolemy's epicycles and wound up with a system somewhat simpler than that of the Alexandrian astronomer but still extremely complicated.

Nevertheless, the shift from an earth-centered to a sun-centered system was significant and raised serious questions about Aristotle's astronomy and physics despite Copernicus's own adherence to Aristotle. It also seemed to create uncertainty about the human role in the universe as well as God's location. Protestant reformers, adhering to a literal interpretation of Scripture, were the first to attack the new ideas. Martin Luther thundered against "the new astrologer who wants to prove that the earth moves and goes round. . . . The fool wants to turn the whole art of astronomy upside down. As Holy Scripture tells us, so did Joshua bid the sun stand still and not the earth." Luther's cohort at Wittenberg, Philip Melanchthon, condemned Copernicus as well:

> The eyes are witness that the heavens revolve in the space of twenty-four hours. But certain men, either from the love of novelty, or to make a display of ingenuity, have concluded that the earth moves, and they maintain that neither the eighth sphere [of the fixed stars] nor the sun revolves. . . . Now it is a want of honesty and decency to assert such notions publicly, and the example is pernicious. It is the part of a good mind to accept the truth as revealed by God and to acquiesce in it.[6]

The Catholic Church remained silent for the time being; it did not denounce Copernicus until the work of Galileo appeared. The denunciation came at a time when an increasing number of astronomers were being attracted to Copernicus's ideas.

Brahe

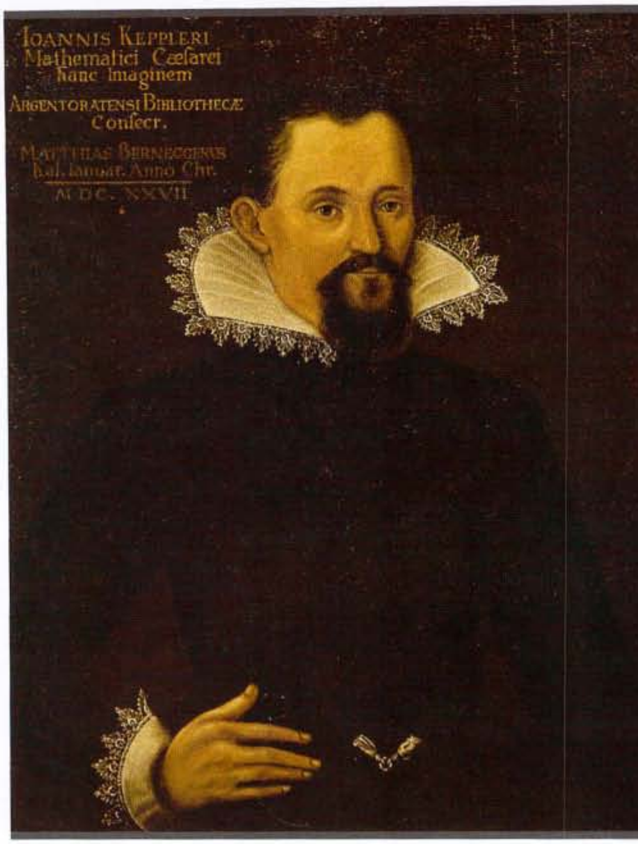
Copernicus did not have a great impact immediately, but doubts about the Ptolemaic system were growing. The next step in destroying the geocentric conception and supporting the Copernican system was taken by Johannes Kepler. It has been argued, however, that Kepler's work would not have occurred without the material provided by Tycho Brahe (TY-koh BRAH).

A Danish nobleman, Tycho Brahe (1546–1601) was granted possession of an island near Copenhagen by King Frederick II. On it, Brahe built the elaborate Uraniborg Castle, which he outfitted with a library, observatories, and instruments he had designed for more precise astronomical observations. For twenty years, Brahe patiently concentrated on compiling a detailed record of his observations of the positions and movements of the stars and planets, a series of observations described as the most accurate up to that time. This body of data led him to reject the Aristotelian-Ptolemaic system, but at the same time he was unable to accept Copernicus's suggestion that the earth actually moved. Brahe's last years were spent in Prague as imperial mathematician to Emperor Rudolf II, who took a keen interest in astronomy, astrology, and the Hermetic tradition. While he was in Prague, Brahe took on an assistant by the name of Johannes Kepler.

Kepler

Johannes Kepler (yoh-HAHN-us KEP-lur) (1571–1630) had been destined by his parents for a career as a Lutheran minister. While studying theology at the university at Tübingen (TOO-bing-un), however, he fell under the influence of Michael Mästlin (MEST-lin), Germany's best-known astronomer, and spent much time pursuing his real interests, mathematics and astronomy. He abandoned theology and became a teacher of mathematics and astronomy at Graz in Austria.

Kepler's work illustrates well the narrow line that often separated magic and science in the early Scientific Revolution. An avid astrologer, Kepler had a keen interest in Hermetic mathematical magic. In a book written in 1596, he elaborated on his theory that the universe was constructed on the basis of geometric figures, such as the pyramid and the cube. Believing that the harmony of the human soul (a divine



Musée de l'Oeuvre Notre Dame, Strasbourg/Imagno/Getty Images

Johannes Kepler. Abandoning theology in favor of mathematics and astronomy, Kepler became a key figure in the rise of the new astronomy. Using Tycho Brahe's vast store of astronomical data, Kepler discovered the three laws of planetary motion that both confirmed and modified the Copernican theory. They also eliminated the Aristotelian-Ptolemaic ideas of uniform circular motion and crystalline spheres moving in circular orbits. This portrait was done by an unknown painter three years before Kepler's death.

attribute) was mirrored in the numerical relationships existing between the planets, he focused much of his attention on discovering the "music of the spheres." Kepler was also a brilliant mathematician and astronomer and, after Brahe's death, succeeded him as imperial mathematician to Rudolf II. There he gained possession of Brahe's detailed astronomical data and, using them, arrived at his three laws of planetary motion. These laws may have confirmed Kepler's interest in the "music of the spheres," but more important, they confirmed Copernicus's heliocentric theory while modifying it in some ways. Above all, they drove another nail into the coffin of the Aristotelian-Ptolemaic system.

Kepler published his first two laws of planetary motion in 1609. Although at Tübingen he had accepted Copernicus's heliocentric ideas, in his first law he rejected Copernicus by showing that the orbits of the planets around the sun were not circular but elliptical, with the sun at one focus of the ellipse rather than at the center. In his second law, he demonstrated that the speed of a planet is greater when it is closer to the sun and decreases as its distance from the sun increases. This proposition destroyed a fundamental Aristotelian tenet that Copernicus had shared—that the motion of the planets was steady

Kepler and the Emerging Scientific Community

THE EXCHANGE OF LETTERS BETWEEN INTELLECTUALS was an important avenue for scientific communication. After receiving a copy of Johannes Kepler's first major work, the Italian Galileo Galilei wrote to Kepler, inaugurating a correspondence between them. This selection contains samples of their letters to each other.

Galileo to Kepler, Padua, August 4, 1597

Your book, highly learned gentleman, which you sent me through Paulus Amberger, reached me not days ago but only a few hours ago, and as this Paulus just informed me of his return to Germany, I should think myself indeed ungrateful if I should not express to you my thanks by this letter. I thank you especially for having deemed me worthy of such a proof of your friendship. ... So far I have read only the introduction, but have learned from it in some measure your intentions and congratulate myself on the good fortune of having found such a man as a companion in the exploration of truth. For it is deplorable that there are so few who seek the truth and do not pursue a wrong method of philosophizing. But this is not the place to mourn about the misery of our century but to rejoice with you about such beautiful ideas proving the truth. ... I would certainly dare to approach the public with my ways of thinking if there were more people of your mind. As this is not the case, I shall refrain from doing so. ... I shall always be at your service. Farewell, and do not neglect to give me further good news of yourself.

Yours in sincere friendship,
Galilaeus Galilaeus
Mathematician at the Academy of Padua

Kepler to Galileo, Graz, October 13, 1597

I received your letter of August 4 on September 1. It was a double pleasure to me. First because I became friends with you, the Italian, and second because of the agreement in which we find ourselves concerning Copernican cosmography. As you invite me kindly at the end of your letter to enter into correspondence with you, and I myself feel greatly tempted to do so, I will not let pass the occasion of sending you a letter with the present young nobleman. For I am sure, if your time has allowed it, you have meanwhile obtained a closer knowledge of my book. And so a great desire has taken hold of me, to learn your judgment. For this is my way, to urge all those to whom I have written to express their candid opinion. Believe me, the sharpest criticism of one single understanding man means much more to me than the thoughtless applause of the great masses.

I would, however, have wished that you who have such a keen insight into everything would choose another way to reach your practical aims. By the strength of your personal example you advise us, in a cleverly veiled manner, to go out of the way of general ignorance and warn us against exposing ourselves to the furious attacks of the scholarly crowd. ... But after the beginning of a tremendous enterprise has been made in our time, and furthered by so many learned mathematicians, and after the statement that the earth moves can no longer be regarded as something new, would it not be better to pull the rolling wagon to its destination with united effort? ... For it is not only you Italians who do not believe that they move unless they feel it, but we in Germany, too, in no way make ourselves popular with this idea. Yet there are ways in which we protect ourselves against these difficulties. ... Be of good cheer, Galileo, and appear in public. If I am not mistaken there are only a few among the distinguished mathematicians of Europe who would dissociate themselves from us. So great is the power of truth. If Italy seems less suitable for your publication and if you have to expect difficulties there, perhaps Germany will offer us more freedom. But enough of this. Please let me know, at least privately if you do not want to do so publicly, what you have discovered in favor of Copernicus.

Q *What does the correspondence between Galileo and Kepler reveal about an emerging spirit of scientific inquiry? What other notable achievements must European society have reached even to make this exchange of letters possible? What aspects of European material culture made the work of these scientists easier?*

and unchanging. Published ten years later, Kepler's third law established that the square of a planet's period of revolution is proportional to the cube of its average distance from the sun. In other words, planets with larger orbits revolve at a slower average velocity than those with smaller orbits.

Kepler's three laws effectively eliminated the idea of uniform circular motion as well as the idea of crystalline spheres revolving in circular orbits. The basic structure of the traditional Ptolemaic system had been disproved, and people had been freed to think in new ways about the actual paths of planets revolving around the sun in elliptical orbits. By the end of Kepler's life, the Ptolemaic system was rapidly losing ground to the new ideas (see the box above). Important questions remained unanswered, however: What were the planets made of? And how could motion in the universe be explained? It was an Italian scientist who achieved the next important breakthrough to a new cosmology by answering the first question and making important strides toward answering the second.

Galileo

Galileo Galilei (1564–1642) taught mathematics, first at Pisa and later at Padua, one of the most prestigious universities in Europe. Galileo was the first European to make systematic observations of the heavens by means of a telescope, thereby inaugurating a new age in astronomy. He had heard of a Flemish lens grinder who had created a "spyglass" that magnified objects seen at a distance and soon constructed his own after reading about it. Instead of peering at terrestrial objects, Galileo turned his telescope to the skies and made a remarkable series of discoveries: mountains and craters on the moon, four moons revolving around Jupiter, the phases of Venus, and sunspots. Galileo's observations demolished yet another aspect of the traditional cosmology in that the universe seemed to be composed of material substance similar to that of the earth rather than ethereal or perfect and unchanging substance.

Galileo's revelations, published in *The Starry Messenger* in 1610 (see the box on p. 484), stunned his contemporaries and probably did more to make Europeans aware of the new picture of the universe than the mathematical theories of Copernicus and Kepler did. The English ambassador in Venice wrote to the chief minister of King James I in 1610:

> I send herewith unto His Majesty the strangest piece of news ... that he has ever yet received from any part of the world; which is the annexed book of the Mathematical Professor at Padua [Galileo], who by the help of an optical instrument ... has discovered four new planets rolling about the sphere of Jupiter.... So upon the whole subject he has first overthrown all former astronomy.... By the next ship your Lordship shall receive from me one of the above instruments [a telescope], as it is bettered by this man.[7]

During a trip to Rome, Galileo was received by scholars as a conquering hero. Grand Duke Cosimo II of Florence offered him a new position as his court mathematician, which Galileo readily accepted. But even in the midst of his newfound acclaim, Galileo found himself increasingly suspect by the authorities of the Catholic Church.

GALILEO AND THE INQUISITION In *The Starry Messenger*, Galileo had revealed himself as a firm proponent of Copernicus's heliocentric system. The Roman Inquisition (or Holy Office) of the Catholic Church condemned Copernicanism and ordered Galileo to reject the Copernican thesis. As one cardinal commented, "The intention of the Holy Spirit is to teach us not how the heavens go, but how to go to heaven." The report of the Inquisition ran:

> That the doctrine that the sun was the center of the world and immovable was false and absurd, formally heretical and contrary to Scripture, whereas the doctrine that the earth was not the center of the world but moved, and has further a daily motion, was philosophically false and absurd and theologically at least erroneous.[8]

Galileo was told, however, that he could continue to discuss Copernicanism as long as he maintained that it was not a fact but a mathematical supposition. It is apparent from the Inquisition's response that the church attacked the Copernican

Bibliothèque Nationale, Paris/SuperStock

Museo della Scienza, Florence//Scala/Art Resource, NY

The Telescope. The invention of the telescope enabled Europeans to inaugurate a new age in astronomy. Shown here is Johannes Hevelius (huh-VAY-lee-uss), an eminent German-Polish astrologer (1611–1697), making an observation with his telescope. Hevelius's observations were highly regarded. He located his telescope on the roof of his own house, and by the 1660s, his celestial observatory was considered one of the best in Europe. The photograph above shows Galileo's original telescope, built in 1609.

The Starry Messenger

THE ITALIAN GALILEO GALILEI WAS THE FIRST European to use a telescope to make systematic observations of the heavens. His observations, as reported in *The Starry Messenger* in 1610, stunned European intellectuals by revealing that the celestial bodies were not perfect and immutable but composed of material substance similar to that of the earth. In this selection, Galileo describes how he devised a telescope and what he saw with it.

Galileo Galilei, *The Starry Messenger*

About ten months ago a report reached my ears that a certain Fleming had constructed a spyglass by means of which visible objects, though very distant from the eye of the observer, were distinctly seen as if nearby. Of this truly remarkable effect several experiences were related, to which some persons gave credence while others denied them. A few days later the report was confirmed to me in a letter from a noble Frenchman at Paris, Jacques Badovere, which caused me to apply myself wholeheartedly to inquire into the means by which I might arrive at the invention of a similar instrument. This I did shortly afterwards, my basis being the theory of refraction. First I prepared a tube of lead, at the ends of which I fitted two glass lenses, both plane on one side while on the other side one was spherically convex and the other concave. Then placing my eye near the concave lens I perceived objects satisfactorily large and near, for they appeared three times closer and nine times larger than when seen with the naked eye alone. Next I constructed another one, more accurate, which represented objects as enlarged more than sixty times. Finally, sparing neither labor nor expense, I succeeded in constructing for myself so excellent an instrument that objects seen by means of it appeared nearly one thousand times larger and over thirty times closer than when regarded without natural vision.

It would be superfluous to enumerate the number and importance of the advantages of such an instrument at sea as well as on land. But forsaking terrestrial observations, I turned to celestial ones, and first I saw the moon from as near at hand as if it were scarcely two terrestrial radii. After that I observed often with wondering delight both the planets and the fixed stars, and since I saw these latter to be very crowded, I began to seek (and eventually found) a method by which I might measure their distances apart. . . .

Now let us review the observations made during the past two months, once more inviting the attention of all who are eager for true philosophy to the first steps of such important contemplations. Let us speak first of that surface of the moon which faces us. For greater clarity I distinguish two parts of this surface, a lighter and a darker; the lighter part seems to surround and to pervade the whole hemisphere, while the darker part discolors the moon's surface like a kind of cloud, and makes it appear covered with spots. . . . From observation of these spots repeated many times I have been led to the opinion and conviction that the surface of the moon is not smooth, uniform, and precisely spherical as a great number of philosophers believe it (and the other heavenly bodies) to be, but is uneven, rough, and full of cavities and prominences, being not unlike the face of the earth, relieved by chains of mountains and deep valleys.

Q *What was the significance of Galileo's invention? What impressions did he receive of the moon? Why were his visual discoveries so stunning, and how did he go about publicizing them?*

system because it threatened not only Scripture but also an entire conception of the universe (see the box on p. 485). The heavens were no longer a spiritual world but a world of matter. Humans were no longer at the center, and God was no longer in a specific place. The new system raised such uncertainties that it seemed prudent simply to condemn it.

Galileo, however, never really accepted his condemnation. In 1632, he published his most famous work, *Dialogue on the Two Chief World Systems: Ptolemaic and Copernican*. Unlike most scholarly treatises, it was written in Italian rather than Latin, making it more widely available to the public, which no doubt alarmed the church authorities. The work took the form of a dialogue among Simplicio, a congenial but somewhat stupid supporter of Aristotle and Ptolemy; Sagredo, an open-minded layman; and Salviati, a proponent of Copernicus's ideas. There is no question who wins the argument, and the *Dialogue* was quickly perceived as a defense of the Copernican system. Galileo was dragged once more before the Inquisition in 1633, found guilty of teaching the condemned Copernican system, and forced to recant his errors. Placed under house arrest on his estate near Florence, he spent the remaining eight years of his life studying mechanics, a field in which he made significant contributions.

GALILEO AND THE PROBLEM OF MOTION One of the problems that fell under the heading of mechanics was the principle of motion. The Aristotelian conception, which dominated the late medieval world, held that an object remained at rest unless a force was applied against it. If a force was constantly exerted, then the object moved at a constant rate, but if it was removed, then the object stopped. This conception encountered some difficulties, especially with a projectile thrown out of a cannon. Late medieval theorists had solved this problem by arguing that the rush of air behind the projectile kept it in motion. The Aristotelian principle of motion also raised problems in the new

OPPOSING ✕ VIEWPOINTS

A New Heaven? Faith Versus Reason

IN 1614, GALILEO WROTE A LETTER TO THE Grand Duchess Christina of Tuscany in which he explained why his theory that the earth rotated around the sun was not necessarily contrary to Scripture. To Galileo, it made little sense for the church to determine the nature of physical reality on the basis of biblical texts that were subject to different interpretations. One year later, Cardinal Robert Bellarmine, a Jesuit and now a member of the church's Inquisition, wrote a letter to one of Galileo's followers that laid out the Catholic Church's approach to the issue of Galileo's theory.

Galileo, Letter to the Grand Duchess Christina, 1614

Some years ago, as Your Serene Highness well knows, I discovered in the heavens many things that had not been seen before our own age. The novelty of these things, as well as some consequences which followed from them in contradiction to the physical notions commonly held among academic philosophers, stirred up against me no small number of professors—as if I had placed these things in the sky with my own hands in order to upset nature and overturn the sciences. . . .

Contrary to the sense of the Bible and the intention of the holy Fathers, if I am not mistaken, they would extend such authorities until even in purely physical matters—where faith is not involved—they would have us altogether abandon reason and the evidence of our senses in favor of some biblical passage, though under the surface meaning of its words this passage may contain a different sense. . . .

The reason produced for condemning the opinion that the earth moves and the sun stands still is that in many places in the Bible one may read that the sun moves and the earth stands still. Since the Bible cannot err, it follows as a necessary consequence that anyone takes an erroneous and heretical position who maintains that the sun is inherently motionless and the earth movable.

With regard to this argument, I think in the first place that it is very pious to say and prudent to affirm that the holy Bible can never speak untruth—whenever its true meaning is understood. But I believe nobody will deny that it is often very abstruse, and may say things which are quite different from what its bare words signify. Hence, in expounding the Bible if one were always to confine oneself to the unadorned grammatical meaning, one might fall into error. Not only contradictions and propositions far from true might thus be made to appear in the Bible, but even grave heresies and follies. Thus, it would be necessary to assign to God feet, hands, and eyes, as well as corporeal and human affections, such as anger, repentance, hatred, and sometimes even the forgetting of things past and ignorance of those to come. These propositions uttered by the Holy Ghost were set down in that manner by the sacred scribes in order to accommodate them to the capacities of the common people, who are rude and unlearned. For the sake of those who deserve to be separated from the herd, it is necessary that wise expositors should produce the true senses of such passages, together with the special reasons for which they were set down in these words. . . .

This being granted, I think that in discussions of physical problems we ought to begin not from the authority of scriptural passages, but from sense-experiences and necessary demonstrations; for the holy Bible and the phenomena of nature proceed alike from the divine Word. . . . For that reason it appears that nothing physical which sense-experience sets before our eyes, or which necessary demonstrations prove to us, ought to be called in question (much less condemned) upon the testimony of biblical passages which may have some different meaning beneath their words.

Robert Bellarmine, Letter to Paolo Foscarini, 1615

First. I say that it seems to me that Your Reverence and Galileo did prudently to content yourself with speaking hypothetically, and not absolutely, as I have always believed that Copernicus spoke. For to say that, assuming the earth moves and the sun stands still, all the appearances are saved better than with eccentrics and epicycles, is to speak well; there is no danger in this, and it is sufficient for mathematicians. But to want to affirm that the sun really is fixed in the center of the heavens and only revolves around itself (i.e., turns upon its axis) without traveling from east to west, and that the earth is situated in the third sphere and revolves with great speed around the sun, is a very dangerous thing, not only by irritating all the philosophers and scholastic theologians, but also by injuring our holy faith and rendering the Holy Scriptures false. For Your Reverence has demonstrated many ways of explaining Holy Scripture, but you have not applied them in particular, and without a doubt you would have found it most difficult if you had attempted to explain all the passages which you yourself have cited.

Second. I say that, as you know, the Council [of Trent] prohibits expounding the Scriptures contrary to the common agreement of the holy Fathers. And if Your Reverence would read not only the Fathers but also the commentaries of modern writers on Genesis, Psalms, Ecclesiastes and Josue, you would find that all agree in explaining literally (*ad litteram*) that the sun is in the heavens and moves swiftly around the earth, and that the earth is far from the heavens and stands immobile in the center of the universe. Now consider whether in all prudence the Church could encourage giving to Scripture a sense contrary to the holy Fathers and all the Latin and Greek commentators. Nor may it be answered that this is not a matter of faith, for if it is not a matter of faith from the point of view of the subject matter, it is on the part of the ones who have spoken. . . .

(continued)

(Opposing Viewpoints continued)

Third. I say that if there were a true demonstration that the sun was in the center of the universe and the earth in the third sphere, and that the sun did not travel around the earth but the earth circled the sun, then it would be necessary to proceed with great caution in explaining the passages of Scripture which seemed contrary, and we would rather have to say that we did not understand them than to say that something was false which has been demonstrated. But I do not believe that there is any such demonstration; none has been shown to me. It is not the same thing to show that the appearances are saved by assuming that the sun really is in the center and the earth in the heavens. I believe that the first demonstration might exist, but I have grave doubts about the second, and in a case of doubt, one may not depart from the Scriptures as explained by the holy Fathers.

Q *What does Galileo think is the difference between knowledge about the natural world and knowledge about the spiritual world? What does Galileo suggest that his opponents should do before dismissing his ideas? In what ways does Cardinal Bellarmine attempt to refute Galileo's ideas? Why did Galileo's ideas represent a threat to the Catholic Church?*

Copernican system. In the Ptolemaic system, the concentric spheres surrounding the earth were weightless, but in the Copernican system, if a constant force had to be applied to objects to cause movement, then what power or force kept the heavy earth and other planets in motion?

Galileo made two contributions to the problem of motion. First, he demonstrated by experiments that if a uniform force was applied to an object, it would move at an accelerated speed rather than a constant speed. Moreover, Galileo discovered the principle of inertia when he argued that a body in motion continues in motion forever unless deflected by an external force. Thus, a state of uniform motion is just as natural as a state of rest. Before Galileo, natural philosophers had tried to explain motion; now their task was to explain changes in motion.

The condemnation of Galileo by the Inquisition, coming at a time of economic decline, seriously undermined further scientific work in Italy, which had been at the forefront of scientific innovation. Leadership in science now passed to the northern countries, especially England, France, and the Dutch Netherlands. By the 1630s and 1640s, no reasonable astronomer could overlook that Galileo's discoveries, combined with Kepler's mathematical laws, had made nonsense of the Aristotelian-Ptolemaic world system and clearly established the reasonableness of the Copernican model. Nevertheless, the problem of explaining motion in the universe and tying together the ideas of Copernicus, Galileo, and Kepler had not yet been solved. This would be the work of an Englishman who has long been considered the greatest genius of the Scientific Revolution.

Newton

Born in the English village of Woolsthorpe in 1642, Isaac Newton was an unremarkable young man until he attended Cambridge University. His first great burst of creative energy came in 1666, when fear of the plague closed Cambridge and forced him to return to Woolsthorpe for eighteen months. There Newton discovered his creative talents: "In those days I was in the prime of my life for invention and minded mathematics and philosophy more than at any time since."[9] During this period, he invented the calculus, a mathematical means of calculating rates of change; began his investigations into the composition of light; and inaugurated his work on the law of universal gravitation. Two years after his return to Cambridge, in 1669, he accepted a chair in mathematics at the university. During a second intense period of creativity from 1684 to 1686, he wrote his famous *Principia* (prin-SIP-ee-uh) (see the box on p. 487). After a nervous breakdown in 1693, he sought and received an administrative post as warden of the royal mint and was advanced to master of the mint by 1699, a post he held until his death in 1727. Made president of the Royal Society (see "The Scientific Societies" later in this chapter) in 1703 and knighted in 1705 for his great achievements, Sir Isaac Newton is to this day the only English scientist to be buried in Westminster Abbey.

NEWTON AND THE OCCULT Although Newton occupies a very special place in the history of modern science, we need to remember that he, too, remained extremely interested in aspects of the occult world. He left behind hundreds of manuscript pages of his studies of alchemy, and in fact, his alchemical experiments were a major feature of his life until he moved to London in 1696 to become warden of the royal mint. The British economist John Maynard Keynes said of Newton after examining his manuscripts in 1936:

> Newton was not the first of the age of reason. He was the last of the magicians.... He looked on the whole universe and all that is in it as a riddle, as a secret which could be read by applying pure thought to certain evidence, certain mystic clues which God had laid about the world to allow a sort of philosopher's treasure hunt to the esoteric brotherhood. He believed that these clues were to be found partly in the evidence of the heavens and in the constitution of elements, ... but also partly in certain papers and traditions handed down by the brethren in an unknown chain back to the original cryptic revelation in Babylonia.[10]

Newton's Rules of Reasoning

IN 1687, ISAAC NEWTON PUBLISHED HIS MASTERPIECE, the *Mathematical Principles of Natural Philosophy*, or *Principia*. In this work, Newton demonstrated the mathematical proofs for his universal law of gravitation and completed the new cosmology begun by Copernicus, Kepler, and Galileo. He also described the rules of reasoning by which he arrived at his universal law.

Isaac Newton, *Rules of Reasoning in Philosophy*

Rule 1

We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.

To this purpose the philosophers say that Nature does nothing in vain, and more is in vain when less will serve; for Nature is pleased with simplicity, and affects not the pomp of superfluous causes.

Rule 2

Therefore to the same natural effects we must, as far as possible, assign the same causes.

As to respiration in a man and in a beast; the descent of stones in Europe and in America; the light of our culinary fire and of the sun; the reflection of light in the earth and in the planets.

Rule 3

The qualities of bodies, which admit neither intensification nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.

For since qualities of bodies are only known to us by experiments, we are to hold for universal all such as universally agree with experiments; and such as are not liable to diminution can never be quite taken away.

Rule 4

In experimental philosophy we are to look upon propositions inferred by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions.

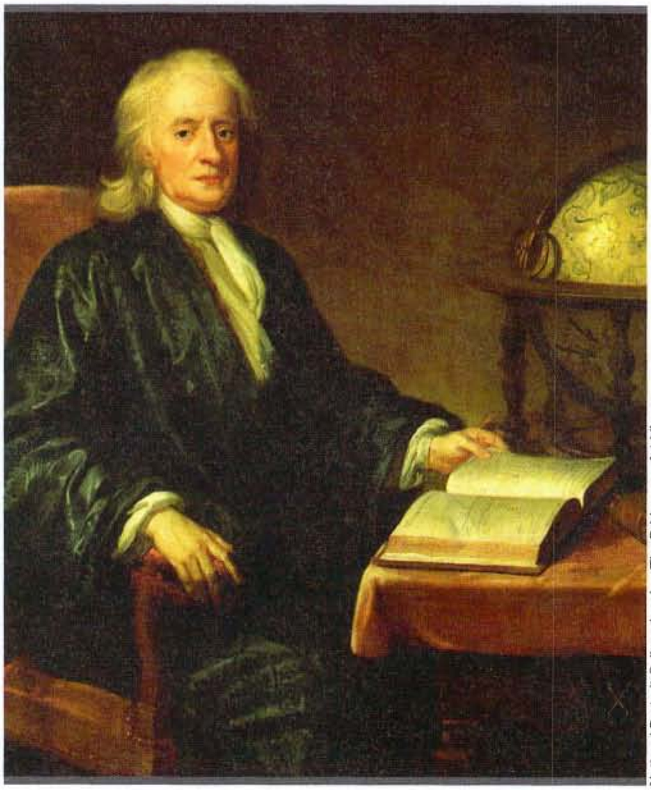
This rule we must follow, that the argument of induction may not be evaded by hypotheses.

Q *What are Newton's rules of reasoning? How important were they to the development of the Scientific Revolution? How would following these rules change a person's view of the world, of European religious traditions, and of ancient "science"?*

Source: From Isaac Newton, *The Mathematical Principles of Natural Philosophy*, 2 volumes (London, 1803), vol. 2: pp. 160–62.

Although Newton may have considered himself a representative of the Hermetic tradition, he chose, it has been recently argued, for both political and psychological reasons to repress that part of his being, and it is as the "symbol of Western science" that he came to be viewed.

UNIVERSAL LAW OF GRAVITATION Newton's major work, the "hinge point of modern scientific thought," was his *Mathematical Principles of Natural Philosophy*, known simply as the *Principia*, the first word of its Latin title. In this work, the last highly influential book in Europe to be written in Latin, Newton spelled out the mathematical proofs demonstrating his universal law of gravitation. Newton's work was the culmination of the theories of Copernicus, Kepler, and Galileo. Though each had undermined some part of the Aristotelian-Ptolemaic cosmology, until Newton no one had pieced together a coherent synthesis for a new cosmology.



National Portrait Gallery, London/The Bridgeman Art Library

Isaac Newton. With a single law, that of universal gravitation, Isaac Newton was able to explain all motion in the universe. His great synthesis of the work of his predecessors created a new picture of the universe, one in which the universe was viewed as a great machine operating according to natural laws. Enoch Seeman painted this portrait of Newton one year before his death.

In the first book of the *Principia*, Newton defined the basic concepts of mechanics by elaborating the three laws of motion: every object continues in a state of rest or uniform motion in a straight line unless deflected by a force, the rate of change of motion of an object is proportional to the force acting on it, and to every action there is always an equal and opposite reaction. In book 3, Newton applied his theories of mechanics to the problems of astronomy by demonstrating that these three laws of motion govern the planetary bodies as well as terrestrial objects. Integral to his whole argument was the universal law of gravitation, which explained why the planetary bodies did not go off in straight lines but continued in elliptical orbits about the sun. In mathematical terms, Newton explained that every object in the universe was attracted to every other object with a force (gravity) that is directly proportional to the product of their masses and inversely proportional to the square of the distances between them.

The implications of Newton's universal law of gravitation were enormous, even though another century would pass before they were widely recognized. Newton had demonstrated that one universal law, mathematically proved, could explain all motion in the universe, from the movements of the planets in the celestial world to an apple falling from a tree in the terrestrial world. The secrets of the natural world could be known by human investigations. At the same time, the Newtonian synthesis created a new cosmology in which the world was seen largely in mechanistic terms. The universe was one huge, regulated, and uniform machine that operated according to natural laws in absolute time, space, and motion. Although Newton believed that God was "everywhere present" and acted as the force that moved all bodies on the basis of the laws he had discovered, later generations dropped his spiritual assumptions. Newton's **world-machine**, conceived as operating absolutely in time, space, and motion, dominated the Western worldview until the twentieth century, when the Einsteinian revolution, based on the concept of relativity, superseded the Newtonian mechanistic concept.

Newton's ideas were soon accepted in England, possibly out of national pride and conviction and, as has been argued recently, for political reasons (see "Science and Society" later in this chapter). Natural philosophers on the Continent resisted Newton's ideas, and it took much of the eighteenth century before they were generally accepted everywhere in Europe. They were also reinforced by developments in other fields, especially medicine.

Advances in Medicine and Chemistry

FOCUS QUESTION: What did Paracelsus, Vesalius, and Harvey contribute to a scientific view of medicine?

Although the Scientific Revolution of the sixteenth and seventeenth centuries is associated primarily with the dramatic changes in astronomy and mechanics that precipitated a new perception of the universe, a third field that had been dominated by Greek thought in the Later Middle Ages, that of medicine, also experienced a transformation. Late medieval medicine was dominated not by the teachings of Aristotle but by those of the Greek physician Galen (GAY-len, who had lived in the second century C.E.

Galen's influence on the medieval medical world was pervasive in anatomy, physiology, and disease. Galen had relied on animal, rather than human, dissection to arrive at a picture of human anatomy that was quite inaccurate in many instances. Even when Europeans began to practice human dissection in the Later Middle Ages, instruction in anatomy still relied on Galen. While a professor read a text of Galen, an assistant dissected a cadaver for illustrative purposes. Physiology, or the functioning of the body, was also dominated by Galenic hypotheses, including the belief that there were two separate blood systems. One controlled muscular activities and contained bright red blood moving upward and downward through the arteries; the other governed the digestive functions and contained dark red blood that ebbed and flowed in the veins.

Treatment of disease was highly influenced by Galen's doctrine of four bodily humors: blood, considered warm and moist; yellow bile, warm and dry; phlegm, cold and moist; and black bile, cold and dry. Since disease was supposedly the result of an imbalance of humors that could be discerned from the quantity and color of urine, the examination of a patient's urine became the chief diagnostic tool. Although purging and bleeding to remedy the imbalance were often harmful to patients, treatment with traditional herbal medicines sometimes proved beneficial.

Paracelsus

Three figures are associated with the changes in medicine in the sixteenth and seventeenth centuries: Paracelsus (par-uh-SELL-suss), Andreas Vesalius (ahn-DRAY-uss vuh-SAY-lee-uss), and William Harvey. Philippus Aureolus von Hohenheim (1493–1541), who renamed himself Paracelsus ("greater than Celsus," an ancient physician), traveled widely and may have been awarded a medical degree from the University of Ferrara in Italy. He achieved a moment of glory when he was appointed city physician and professor of medicine at Basel in 1527. But this, like so many other appointments, proved short-lived due to his vanity and quick temper. He could never disguise his contempt for universities and physicians who did not agree with his new ideas:

> I am *monarcha medicorum*, monarch of physicians, and I can prove to you what you cannot prove.... It was not the constellations that made me a physician: God made me.... I need not don a coat of mail or a buckler against you, for you are not learned or experienced enough to refute even one word of mine.... Let me tell you this: every little hair on my neck knows more than you and all your scribes, and my shoebuckles are more learned than your Galen and Avicenna, and my beard has more experience than all your high colleges.[11]

Paracelsus was not easy to get along with, and he was forced to wander from one town to another until his death in 1541.

Paracelsus rejected the work of both Aristotle and Galen and attacked the universities as centers of their moribund philosophy. He and his followers hoped to replace the traditional system with a new chemical philosophy that was based on a new understanding of nature derived from fresh observation and experiment. This chemical philosophy was in turn closely connected to a view of the universe based on the macrocosm-microcosm analogy. According to this view, a human being was a small replica (microcosm) of the larger world (macrocosm). All parts of the universe were represented within each person. As Paracelsus said, "For the sun and the moon and all planets, as well as the stars and the whole chaos, are in man.... For what is outside is also inside; and what is not outside man is not inside. The outer and the inner are one thing."[12] In accordance with the macrocosmic-microcosmic principle, Paracelsus believed that the chemical reactions of the universe as a whole were reproduced in human beings on a smaller scale. Disease, then, was not caused by an imbalance of the four humors, as Galen had argued, but was due to chemical imbalances that were localized in specific organs and could be treated by chemical remedies.

Although others had used chemical remedies, Paracelsus and his followers differed from them in giving careful attention to the proper dosage of their chemically prepared metals and minerals. Paracelsus had turned against the Galenic principle that "contraries cure" in favor of the ancient Germanic folk principle that "like cures like." The poison that caused a disease would be its cure if used in proper form and quantity. Despite the apparent effectiveness of this use of toxic substances as treatment (Paracelsus did have a strong reputation for actually curing his patients), his opponents viewed it as the practice of a "homicide physician." Later generations came to regard Paracelsus more favorably, and historians who have stressed Paracelsus's concept of disease and recognition of "new drugs" for medicine have viewed him as a father of modern medicine. Others have argued that his macrocosmic-microcosmic philosophy and use of "like cures like" drugs make him the forerunner of both homeopathy and the holistic medicine of the postmodern era.

Vesalius

The new anatomy of the sixteenth century was the work of Andreas Vesalius (1514–1564). His study of medicine at Paris involved him in the works of Galen. Especially important to him was a recently discovered text of Galen, *On Anatomical Procedures*, that led Vesalius to emphasize practical research as the principal avenue for understanding human anatomy. After receiving a doctorate in medicine at the University of Padua in 1536, he accepted a position there as professor of surgery. In 1543, he published his masterpiece, *On the Fabric of the Human Body*.

This book was based on his personal dissection of a body to illustrate what he was discussing. Vesalius's anatomical treatise presented a careful examination of the individual organs and general structure of the human body. The book would not have been feasible without both the artistic advances of the Renaissance and technical developments in the art of printing. Together, they made possible the creation of illustrations superior to any done before.

Vesalius's hands-on approach to teaching anatomy enabled him to rectify some of Galen's most glaring errors. He did not hesitate, for example, to correct Galen's assertion that the great blood vessels originated from the liver since his own observations made it apparent that they came from the heart. Nevertheless, Vesalius still clung to a number of Galen's erroneous assertions, including the Greek physician's ideas on the ebb and flow of two kinds of blood in the veins and arteries. It was not until William Harvey's work on the circulation of the blood nearly a century later that this Galenic misperception was corrected.

William Harvey

William Harvey (1578–1657) attended Cambridge University and later Padua, where he received a doctorate in medicine in 1602. His reputation rests on his book *On the Motion of the Heart and Blood*, published in 1628. Although questions had been raised in the sixteenth century about Galen's physiological principles, no major break from his system had occurred. Harvey's work, which was based on meticulous observations and experiments, led him to demolish the ancient Greek's erroneous contentions. Harvey demonstrated that the heart and not the liver was the beginning point of the circulation of blood in the body, that the same blood flows in both veins and arteries, and most important, that the blood makes a complete circuit as it passes through the body. Although Harvey's work dealt a severe blow to Galen's theories, his ideas did not begin to achieve general recognition until the 1660s, when capillaries, which explained how the blood passed from the arteries to the veins, were discovered. Harvey's theory of the circulation of the blood laid the foundation for modern physiology.

Chemistry

Although Paracelsus had proposed a new chemical philosophy in the sixteenth century, it was not until the seventeenth and eighteenth centuries that a science of chemistry arose. Robert Boyle (1627–1691) was one of the first scientists to conduct controlled experiments. His pioneering work on the properties of gases led to Boyle's law, which states that the volume of a gas varies with the pressure exerted on it. Boyle also rejected the medieval belief that all matter consisted of the same components in favor of the view that matter is composed of atoms, which he called "little particles of all shapes and sizes" and which would later be known as the chemical elements.

In the eighteenth century, Antoine Lavoisier (AHN-twahn lah-vwah-ZYAY) (1743–1794) invented a system of naming the chemical elements, much of which is still used today. In helping to show that water is a compound of oxygen and hydrogen, he demonstrated the fundamental rules of chemical combination. He is regarded by many as the founder of modern chemistry. Lavoisier's wife, Marie-Anne, was her husband's scientific collaborator. She learned English in order to translate the work of British chemists for her husband and made engravings to illustrate his scientific experiments. Marie-Anne Lavoisier is a reminder that women too played a role in the Scientific Revolution.

Women in the Origins of Modern Science

FOCUS QUESTION: What role did women play in the Scientific Revolution?

During the Middle Ages, except for members of religious orders, women who sought a life of learning were severely hampered by the traditional attitude that a woman's proper role was as a daughter, wife, and mother. But in the late fourteenth and early fifteenth centuries, new opportunities for elite women emerged as enthusiasm for the new secular learning called humanism led Europe's privileged and learned men to encourage women to read and study Classical and Christian texts. The ideal of a humanist education for some of the daughters of Europe's elite persisted into the seventeenth century, but only for some privileged women.

Margaret Cavendish

Much as they were drawn to humanism, women were also attracted to the Scientific Revolution. Unlike females educated formally in humanist schools, women interested in science had to obtain a largely informal education. European nobles had the leisure and resources that gave them easy access to the world of learning. This door was also open to noblewomen who could participate in the informal scientific networks of their fathers and brothers. One of the most prominent female scientists of the seventeenth century, Margaret Cavendish (KAV-un-dish) (1623–1673), came from an aristocratic background. Cavendish was not a popularizer of science for women but a participant in the crucial scientific debates of her time. Despite her achievements, however, she was excluded from membership in the Royal Society (see "The Scientific Societies" later in this chapter), although she was once allowed to attend a meeting. She wrote a number of works on scientific matters, including *Observations upon Experimental Philosophy* and *Grounds of Natural Philosophy*, published in 1668. In these works, she did not hesitate to attack what she considered the defects of the rationalist and empiricist approaches to scientific knowledge and was especially critical of the growing belief that through science, humans would be masters of nature: "We have no power at all over natural causes and effects ... for man is but a small part.... His powers are but particular actions of Nature, and he cannot have a supreme and absolute power."[13]

As an aristocrat (she was the duchess of Newcastle), Cavendish was a good example of the women in France and England who worked in science (see the box on p. 491). In Germany, women interested in science came from a different background. There the tradition of female participation in craft production enabled some women to become involved in observational science, especially entomology and astronomy. Between 1650 and 1710, one of every seven German astronomers was a woman.

CHRONOLOGY Important Works of the Scientific Revolution	
Copernicus, *On the Revolutions of the Heavenly Spheres*	1543
Vesalius, *On the Fabric of the Human Body*	1543
Galileo, *The Starry Messenger*	1610
Harvey, *On the Motion of the Heart and Blood*	1628
Galileo, *Dialogue on the Two Chief World Systems*	1632
Cavendish, *Grounds of Natural Philosophy*	1668
Newton, *Principia*	1687

Maria Merian

A good example of female involvement in the Scientific Revolution stemming from the craft tradition was Maria Sibylla Merian (MAY-ree-un) (1647–1717), who had established a reputation as an important entomologist by the beginning of the eighteenth century. Merian's training came from working in her father's workshop, where she learned the art of illustration, a training of great importance since her exact observation of insects and plants was demonstrated through the superb illustrations she made. In 1699, she undertook an expedition into the wilds of the Dutch colony of Surinam in South America to collect and draw samples of plants and insect life. This led to her major scientific work, the *Metamorphosis of the Insects of Surinam*, in which she used sixty illustrations to show the reproductive and developmental cycles of Surinam's insect life.

Maria Winkelmann

The craft organization of astronomy also gave women opportunities to become involved in science. Those who did worked in family observatories; hence, daughters and wives received training as apprentices to fathers or husbands. The most famous of the female astronomers in Germany was Maria Winkelmann (VINK-ul-mahn) (1670–1720). She was educated by her father and uncle and received advanced training in astronomy from a nearby self-taught astronomer. When she married Gottfried Kirch, Germany's foremost astronomer, she became his assistant at the astronomical observatory operated in Berlin by the Academy of Science. She made some original contributions, including a hitherto undiscovered comet, as her husband related:

> Early in the morning (about 2:00 A.M.) the sky was clear and starry. Some nights before, I had observed a variable star, and

Margaret Cavendish: The Education of Women

MARGARET CAVENDISH'S HUSBAND, WHO WAS THIRTY YEARS HER SENIOR, encouraged her to pursue her literary interests. In addition to scientific works, she wrote plays, an autobiography, and a biography of her husband titled *The Life of the Thrice Noble, High and Puissant Prince William Cavendish, Duke, Marquess and Earl of Newcastle*. The autobiography and biography led one male literary critic to call her "a mad, conceited and ridiculous woman." In an essay titled "The Philosophical and Physical Opinions," she discussed the constraints placed upon women, including education.

Margaret Cavendish, "The Philosophical and Physical Opinions"

But to answer those objections that are made against me, as first how should I come by so much experience as I have expressed in my several books to have? I answer: I have had by relation the long and much experience of my lord, who hath lived to see and be in many changes of fortune and to converse with many men of sundry nations, ages, qualities, tempers, capacities, abilities, wits, humours, fashions and customs.

And as many others, especially wives, go from church to church, from ball to ball, . . . gossiping from house to house, so when my lord admits me to his company I listen with attention to his edifying discourse and I govern myself by his doctrine: I dance a measure with the muses, feast with sciences, or sit and discourse with the arts.

The second is that, since I am no scholar, I cannot know the names and terms of art and the divers and several opinions of several authors. I answer: that I must have been a natural fool if I had not known and learnt them, for they are customarily taught all children from the nurse's breast, being ordinarily discoursed of in every family that is of quality, and the family from whence I sprung are neither natural idiots or ignorant fools, but the contrary, for they were rational, learned, understanding and witty. . . .

But as I have said my head was so full of my own natural fantasies, as it had not room for strangers to board therein, and certainly natural reason is a better tutor than education. For though education doth help natural reason to a more sudden maturity, yet natural reason was the first educator: for natural reason did first compose commonwealths, invented arts and science, and if natural reason hath composed, invented and discovered, I know no reason but natural reason may find out what natural reason hath composed, invented and discovered with the help of education. . . .

Q *What arguments does Cavendish make to defend her right and ability to be an author?*

Source: From Kate Aughterson, *Renaissance Woman: A Sourcebook* (London and New York: Routledge, 1995); pp. 286–288.

my wife (as I slept) wanted to find and see it for herself. In so doing, she found a comet in the sky. At which time she woke me, and I found that it was indeed a comet. . . . I was surprised that I had not seen it the night before.[14]

Moreover, Winkelmann corresponded with the famous scientist Gottfried Leibniz (who invented the calculus independently of Newton), who praised her effusively as "a most learned woman who could pass as a rarity." When her husband died in 1710, she applied for a position as assistant astronomer for which she was highly qualified. As a woman—with no university degree—she was denied the post by the Berlin Academy, which feared that it would establish a precedent by hiring a woman ("mouths would gape").

Winkelmann's difficulties with the Berlin Academy reflect the obstacles women faced in being accepted in scientific work, which was considered a male preserve. Although no formal statutes excluded women from membership in the new scientific societies, no woman was invited to join either the Royal Society of England or the French Academy of Sciences until the twentieth century. All of these women scientists were exceptional, since a life devoted to any kind of scholarship was still viewed as being at odds with the domestic duties women were expected to perform.

Debates on the Nature of Women

The nature and value of women had been the subject of an ongoing, centuries-long debate known as the ***querelles des femmes*** (keh-REL day FAHM)—arguments about women. Male opinions in the debate were largely a carryover from medieval times and were not favorable. Women were portrayed as inherently base, prone to vice, easily swayed, and "sexually insatiable." Hence, men needed to control them. Learned women were viewed as having overcome female liabilities to become like men. One man in praise of a woman scholar remarked that her writings were so good that you "would hardly believe they were done by a woman at all."

In the early modern era, women joined this debate by arguing against these male images of women. They argued that women also had rational minds and could grow from education. Further, since most women were pious, chaste, and temperate, there was no need for male authority over them. These female defenders of women emphasized education as the key to women's ability to move into the world. How, then, did the changes brought by the Scientific Revolution affect this debate over the nature of women? In an era of intellectual revolution in which traditional authorities were being overthrown, we might expect significant change in

Maria Merian and the Insects of Surinam. Shown in the engraving is a portrait of Maria Merian, the German naturalist and illustrator, whose study and detailed paintings of plants and insects, especially the transformation of caterpillars into butterflies, attracted scientific attention. The illustration from Merian's *Metamorphosis of the Insects of Surinam* (Plate 55), depicting a bell pepper plant, caterpillar, and butterfly, shows her meticulous attention to detail.

men's views of women. But by and large, instead of becoming an instrument for liberation, science was used to find new support for the old, stereotypical views about a woman's place in the scheme of things.

An important project in the new anatomy of the sixteenth and seventeenth centuries was the attempt to illustrate the human body and skeleton. For Vesalius, the portrayal of physical differences between males and females was limited to external bodily form (the outlines of the body) and the sexual organs. Vesalius saw no difference in skeletons and portrayed them as the same for men and women. It was not until the eighteenth century, in fact, that a new anatomy finally prevailed. Drawings of female skeletons between 1730 and 1790 varied, but females tended to have a larger pelvic area, and, in some instances, female skulls were portrayed as smaller than those of males. Eighteenth-century studies on the anatomy and physiology of sexual differences provided "scientific evidence" to reaffirm the traditional inferiority of women. The larger pelvic area "proved" that women were meant to be childbearers, and the larger skull "demonstrated" the superiority of the male mind. Male-dominated science had been used to "prove" male social dominance.

At the same time, during the seventeenth and eighteenth centuries, women even lost the traditional spheres of influence they had possessed, especially in the science-related art of midwifery. Women serving as midwives had traditionally been responsible for birthing. Similar to barber-surgeons or apothecaries (see Chapter 17), midwives had acquired their skills through apprenticeship. But the impact of the Scientific Revolution caused traditional crafts to be upgraded and then even professionalized as males took over. When medical men entered this arena, they also began to use devices and techniques derived from the study of anatomy. These were increasingly used to justify the male takeover of the traditional role of midwives. By the end of the eighteenth century, midwives were simply accessories to the art they had once controlled, except among the poor. Since little money was to be made in serving the lower classes, midwives were allowed to continue to practice their traditional art among them.

Overall, the Scientific Revolution reaffirmed traditional ideas about women. Male scientists used the new science to spread the view that women were inferior by nature, subordinate to men, and suited by nature to play a domestic role as nurturing mothers. The widespread distribution of books ensured the continuation of these ideas. Jean de La Bruyère (ZHAHNH duh lah broo-YARE), the seventeenth-century French moralist, was typical when he remarked that an educated woman was like a gun that was a collector's item, "which one shows to the curious, but which has no use at all, any more than a carousel horse."[15]

Toward a New Earth: Descartes, Rationalism, and a New View of Humankind

FOCUS QUESTION: Why is Descartes considered the "founder of modern rationalism"?

The fundamentally new conception of the universe contained in the cosmological revolution of the sixteenth and seventeenth centuries inevitably had an impact on the Western view of humankind. Nowhere is this more evident than in the work of René Descartes (ruh-NAY day-KART) (1596–1650), an extremely important figure in Western history. Descartes began by reflecting the doubt and uncertainty that seemed pervasive in the confusion of the seventeenth century and ended with a philosophy that dominated Western thought until the twentieth century.

Descartes was born into a family of the French lower nobility. After a Jesuit education, he studied law at Poitiers but traveled to Paris to study by himself. In 1618, at the beginning of the Thirty Years' War, Descartes volunteered for service in the army of Maurice of Nassau, but he seems to have been interested less in military action than in traveling and finding leisure time to think. On the night of November 10, 1619, Descartes underwent what one historian has called an experience comparable to the "ecstatic illumination of the mystic." Having perceived in one night the outlines of a new rational-mathematical system, with a sense of divine approval he made a new commitment to mind, mathematics, and a mechanical universe. For the rest of his life, Descartes worked out the details of his vision.

Descartes. René Descartes was one of the primary figures in the Scientific Revolution. Claiming to use reason as his sole guide to truth, Descartes posited a sharp distinction between mind and matter. He is shown here in a portrait done around 1649 by Frans Hals, one of the painters of the Dutch golden age who was famous for his portraits, especially that of Descartes.

The starting point for Descartes's new system was doubt, as he explained at the beginning of his most famous work, the *Discourse on Method*, written in 1637:

> From my childhood I have been familiar with letters; and as I was given to believe that by their means a clear and assured knowledge can be acquired of all that is useful in life, I was extremely eager for instruction in them. As soon, however, as I had completed the course of study, at the close of which it is customary to be admitted into the order of the learned, I entirely changed my opinion. For I found myself entangled in so many doubts and errors that, as it seemed to me, the endeavor to instruct myself had served only to disclose to me more and more of my ignorance.[16]

Descartes decided to set aside all that he had learned and begin again. One fact seemed beyond doubt—his own existence:

> But I immediately became aware that while I was thus disposed to think that all was false, it was absolutely necessary that I who thus thought should be something; and noting that this truth, *I think, therefore I am*, was so steadfast and so assured that the suppositions of the skeptics, to whatever extreme they might all be carried, could not avail to shake it, I concluded that I might without scruple accept it as being the first principle of the philosophy I was seeking.[17]

With this emphasis on the mind, Descartes asserted that he would accept only those things that his reason said were true.

From his first postulate, Descartes deduced an additional principle, the separation of mind and matter. Descartes argued that since "the mind cannot be doubted but the body and material world can, the two must be radically different." From this came an absolute duality between mind and body that has been called **Cartesian dualism**. Using mind or human reason, the path to certain knowledge, and its best instrument, mathematics, humans can understand the material world because it is pure mechanism, a machine that is governed by its own physical laws because it was created by God, the great geometrician.

Descartes's conclusions about the nature of the universe and human beings had important implications. His separation of mind and matter allowed scientists to view matter as dead or inert, as something that was totally separate from themselves and could be investigated independently by reason. The split between mind and body led Westerners to equate their identity with mind and reason rather than with the whole organism. Descartes has rightly been called the father of modern **rationalism** (see the box on p. 494). His books

The Father of Modern Rationalism

RENÉ DESCARTES HAS LONG BEEN VIEWED as the founder of modern rationalism and modern philosophy because he believed that human beings could understand the world—itself a mechanical system—by the same rational principles inherent in mathematical thinking. In his *Discourse on Method,* he elaborated on his approach to discovering truth.

René Descartes, *Discourse on Method*

In place of the numerous precepts which have gone to constitute logic, I came to believe that the four following rules would be found sufficient, always provided I took the firm and unswerving resolve never in a single instance to fail in observing them.

The first was to accept nothing as true which I did not evidently know to be such, that is to say, scrupulously to avoid precipitance and prejudice, and in the judgments I passed to include nothing additional to what had presented itself to my mind so clearly and so distinctly that I could have no occasion for doubting it.

The second, to divide each of the difficulties I examined into as many parts as may be required for its adequate solution.

The third, to arrange my thoughts in order, beginning with things the simplest and easiest to know, so that I may then ascend little by little, as it were step by step, to the knowledge of the more complex, and in doing so, to assign an order of thought even to those objects which are not of themselves in any such order of precedence.

And the last, in all cases to make enumerations so complete, and reviews so general, that I should be assured of omitting nothing.

Those long chains of reasonings, each step simple and easy, which geometers are wont to employ in arriving even at the most difficult of their demonstrations, have led me to surmise that all the things we human beings are competent to know are interconnected in the same manner, and that none are so remote as to be beyond our reach or so hidden that we cannot discover them—that is, provided we abstain from accepting as true what is not thus related, i.e., keep always to the order required for their deduction one from another. And I had no great difficulty in determining what the objects are with which I should begin, for that I already knew, namely, that it was with the simplest and easiest. Bearing in mind, too, that of all those who in time past have sought for truth in the sciences, the mathematicians alone have been able to find any demonstrations, that is to say, any reasons which are certain and evident, I had no doubt that it must have been by a procedure of this kind that they had obtained them.

Q *Describe Descartes's principles of inquiry and compare them with Newton's rules of reasoning. What are the main similarities between these systems of thinking?*

were placed on the papal Index of Forbidden Books and condemned by many Protestant theologians. The radical Cartesian split between mind and matter, and between mind and body, had devastating implications not only for traditional religious views of the universe but also for how Westerners viewed themselves.

The Scientific Method and the Spread of Scientific Knowledge

Q **FOCUS QUESTION:** How were the ideas of the Scientific Revolution spread, and what impact did they have on society and religion?

During the seventeenth century, scientific learning and investigation began to increase dramatically. Major universities in Europe established new chairs of science, especially in medicine. Royal and princely patronage of individual scientists became an international phenomenon.

The Scientific Method

Of great importance to the work of science was establishing the proper means to examine and understand the physical realm. This development of a **scientific method** was crucial to the evolution of science in the modern world.

FRANCIS BACON Curiously enough, it was an Englishman with few scientific credentials who attempted to put forth a new method of acquiring knowledge that made an impact on English scientists in the seventeenth century and other European scientists in the eighteenth century. Francis Bacon (1561–1626), a lawyer and lord chancellor, rejected Copernicus and Kepler and misunderstood Galileo. And yet in his unfinished work, *The Great Instauration,* he called for his contemporaries "to commence a total reconstruction of sciences, arts, and all human knowledge, raised upon the proper foundations." Bacon did not doubt humans' ability to know the natural world, but he believed that they had proceeded incorrectly: "The entire fabric of human reason which we employ in the inquisition of nature is badly put together and built up, and like some magnificent structure without foundation."

Bacon's new foundation—a correct scientific method—was to be built on inductive principles. Rather than beginning with assumed first principles from which logical conclusions could be deduced, he urged scientists to proceed from the particular to the general. From carefully organized experiments and thorough, systematic observations, correct generalizations could be developed.

Bacon was clear about what he believed his method could accomplish. His concern was for practical results rather than for pure science. He stated that "the true and lawful goal of the sciences is none other than this: that human life be endowed with new discoveries and power." He wanted science to contribute to the "mechanical arts" by creating devices that would benefit industry, agriculture, and trade. Bacon was prophetic when he said that he was "laboring to lay the foundation, not of any sect or doctrine, but of human utility and power." And how would this "human power" be used? To "conquer nature in action."[18] The control and domination of nature became a central proposition of modern science and the technology that accompanied it. Only in the twentieth century did some scientists begin to ask whether this assumption might not be at the heart of the earth's ecological crisis.

DESCARTES Descartes proposed a different approach to scientific methodology by emphasizing deduction and mathematical logic. As Descartes explained in the *Discourse on Method*, each step in an argument should be as sharp and well founded as a mathematical proof:

> Those long chains of reasonings, each step simple and easy, which geometers are wont to employ in arriving even at the most difficult of their demonstrations, have led me to surmise that all the things we human beings are competent to know are interconnected in the same manner, and that none are so remote as to be beyond our reach or so hidden that we cannot discover them—that is, provided we abstain from accepting as true what is not thus related, i.e., keep always to the order required for their deduction one from another.[19]

Descartes believed, then, that one could start with self-evident truths, comparable to geometric axioms, and deduce more complex conclusions. His emphasis on deduction and mathematical order complemented Bacon's stress on experiment and induction. It was Sir Isaac Newton who synthesized them into a single scientific methodology by uniting Bacon's **empiricism** with Descartes's rationalism. This scientific method began with systematic observations and experiments, which were used to arrive at general concepts. New deductions derived from these general concepts could then be tested and verified by precise experiments.

The scientific method, of course, was valuable in answering the question of *how* something works, and its success in doing this gave others much confidence in the method. It did not attempt to deal with the question of *why* something happens or the purpose and meaning behind the world of nature. This allowed religion to retain its central importance in the seventeenth century (see "Science and Religion" later in this chapter).

The Spread of Scientific Knowledge

Also important to the work of science was the emergence of new learned societies and journals that enabled the new scientists to communicate their ideas to each other and to disseminate them to a wider, literate public.

THE SCIENTIFIC SOCIETIES The first of these scientific societies appeared in Italy, but those of England and France were ultimately of greater significance. The English Royal Society evolved out of informal gatherings of scientists at London and Oxford in the 1640s, although it did not receive a formal charter from King Charles II until 1662. The French Royal Academy of Sciences also arose out of informal scientific meetings in Paris during the 1650s. In 1666, Louis XIV formally recognized the group. The French Academy received abundant state support and remained under government control; its members were appointed and paid salaries by the state. In contrast, the Royal Society of England received little government encouragement, and its fellows simply co-opted new members.

Louis XIV and Colbert Visit the Academy of Sciences. In the seventeenth century, individual scientists received royal and princely patronage, and a number of learned societies were established. In France, Louis XIV, urged on by his controller general, Jean-Baptiste Colbert, gave formal recognition to the French Academy in 1666. In this painting by Henri Testelin, Louis XIV is shown seated, surrounded by Colbert and members of the French Royal Academy of Sciences.

© Science Museum/SSPL/The Image Works

The Royal Observatory at Greenwich. To facilitate their astronomical investigations, both the English and the French constructed observatories such as the one pictured here, which was built at Greenwich, England, in 1675. Here the royal astronomer works at the table while his two assistants make observations.

Early on, both the English and the French scientific societies formally emphasized the practical value of scientific research. The Royal Society created a committee to investigate technological improvements for industry; the French Academy collected tools and machines. This concern with the practical benefits of science proved short-lived, however, as both societies came to focus their primary interest on theoretical work in mechanics and astronomy. The construction of observatories at Paris in 1667 and at Greenwich, England, in 1675 greatly facilitated research in astronomy by both groups. Although both the English and the French societies made useful contributions to scientific knowledge in the second half of the seventeenth century, their true significance was that they demonstrated the benefits of science proceeding as a cooperative venture.

Scientific journals furthered this concept of cooperation. The French *Journal des Savants* (zhoor-NAHL day sah-VAHNH), published weekly beginning in 1665, printed results of experiments as well as general scientific knowledge. Its format appealed to both scientists and the educated public interested in the new science. In contrast, the *Philosophical Transactions* of the Royal Society, also initiated in 1665, published papers of its members and learned correspondence and was aimed at practicing scientists. It became a prototype for the scholarly journals of later learned and academic societies and a crucial instrument for circulating news of scientific and academic activities.

SCIENCE AND SOCIETY The importance of science in the history of modern Western civilization is usually taken for granted. No doubt the Industrial Revolution of the nineteenth century provided tangible proof of the effectiveness of science and ensured its victory over Western minds. But how did science become such an integral part of Western culture in the seventeenth and eighteenth centuries? Recent research has stressed that one cannot simply assert that people perceived that science was a rationally superior system. Several factors, however, might explain the relatively rapid acceptance of the new science.

It has been argued that the literate mercantile and propertied elites of Europe were attracted to the new science because it offered new ways to exploit resources for profit. Some of the early scientists made it easier for these groups to accept the new ideas by showing how they could be applied directly to specific industrial and technological needs. Galileo, for example, consciously sought an alliance between science and the material interests of the educated elite when he assured his listeners that the science of mechanics would be quite useful "when it becomes necessary to build bridges or other structures over water, something occurring mainly in affairs of great importance." At the same time, Galileo stressed that science was fit for the "minds of the wise" and not for "the shallow minds of the common people." This made science part of the high culture of Europe's wealthy elites at a time when that culture was being increasingly separated from the popular culture of the lower classes (see Chapter 17).

It has also been argued that political interests used the new scientific conception of the natural world to bolster social stability. One scholar has argued that "no single event in the history of early modern Europe more profoundly shaped the integration of the new science into Western culture than did the English Revolution (1640–1660)."[20] Fed by their millenarian expectations that the end of the world would come and usher in a thousand-year reign of the saints, Puritan reformers felt it was important to reform and renew their society. They seized on the new science as a socially useful instrument to accomplish this goal. The Puritan Revolution's role in the acceptance of science, however, stemmed even more from the reaction to the radicalism spawned by the revolutionary ferment. The upheavals of the Puritan Revolution gave rise to groups, such as the Levellers, Diggers, and Ranters, who advocated not only radical political ideas but also a new radical science based on Paracelsus and the natural magic associated with the Hermetic tradition. The propertied and educated elites responded vigorously to these challenges to the established order by supporting the new mechanistic science and appealing to the material benefits of science. Hence, the founders of the Royal Society were men who wanted to pursue an experimental science that would remain detached from radical reforms of church and state. Although willing to make changes, they now viewed those changes in terms of an increase in food production and commerce.

At the same time, princes and kings who were providing patronage for scientists were doing so not only for prestige but also for practical reasons, especially the military applications of the mathematical sciences. The use of gunpowder, for example, gave new importance to ballistics and metallurgy. Rulers, especially absolute ones, were also concerned about matters of belief in their realms and recognized the need to control and manage the scientific body of knowledge, as we have seen in the French Academy. In appointing its members and paying their salaries, Louis XIV was also ensuring that the members and their work would be under his control.

Science and Religion

In Galileo's struggle with the inquisitorial Holy Office of the Catholic Church, we see the beginning of the conflict between science and religion that has marked the history of modern Western civilization. Since time immemorial, theology had seemed to be the queen of the sciences. It was natural that the churches would continue to believe that religion was the final measure of all things. The emerging scientists, however, tried to draw lines between the knowledge of religion and the knowledge of "natural philosophy" or nature. Galileo had clearly felt that it was unnecessary to pit science against religion when he wrote:

> In discussions of physical problems we ought to begin not from the authority of scriptural passages, but from sense-experiences and necessary demonstrations; for the holy Bible and the phenomena of nature proceed alike from the divine word, the former as the dictate of the Holy Ghost and the latter as the observant executrix of God's commands. It is necessary for the Bible, in order to be accommodated to the understanding of every man, to speak many things which appear to differ from the absolute truth so far as the bare meaning of the words is concerned. But Nature, on the other hand, is inexorable and immutable; she never transgresses the laws imposed upon her, or cares a whit whether her abstruse reasons and methods of operation are understandable to men.[21]

To Galileo, it made little sense for the church to determine the nature of physical reality on the basis of biblical texts that were subject to radically divergent interpretations. The church, however, decided otherwise in Galileo's case and lent its great authority to one scientific theory, the Aristotelian-Ptolemaic cosmology, no doubt because it fit so well with its own philosophical views of reality. But the church's decision had tremendous consequences, just as the rejection of Darwin's ideas did in the nineteenth century. For educated individuals, it established a dichotomy between scientific investigations and religious beliefs. As the scientific beliefs triumphed, it became almost inevitable that religious beliefs would suffer, leading to a growing secularization in European intellectual life—precisely what the church had hoped to combat by opposing Copernicanism. Many seventeenth-century intellectuals were both religious and scientific and believed that the implications of this split would be tragic. Some believed that the split was largely unnecessary, while others felt the need to combine God, humans, and a mechanistic universe into a new philosophical synthesis. Two individuals—Spinoza and Pascal—illustrate the wide diversity in the response of European intellectuals to the implications of the cosmological revolution of the seventeenth century.

SPINOZA Benedict de Spinoza (spi-NOH-zuh) (1632–1677) was a philosopher who grew up in the relatively tolerant atmosphere of Amsterdam. He was excommunicated from the Amsterdam synagogue at the age of twenty-four for rejecting the tenets of Judaism. Ostracized by the local Jewish community and major Christian churches alike, Spinoza lived a quiet, independent life, earning a living by grinding optical lenses and refusing to accept an academic position in philosophy at the University of Heidelberg for fear of compromising his freedom of thought. Spinoza read a great deal of the new scientific literature and was influenced by Descartes.

Spinoza was unwilling to accept the implications of Descartes's ideas, especially the separation of mind and matter and the apparent separation of an infinite God from the finite world of matter. God was not simply the creator of the universe; he was the universe. All that is is in God, and nothing can be apart from God. This philosophy of pantheism (or monism) was set out in Spinoza's book *Ethics Demonstrated in the Geometrical Manner*, which was not published until after his death.

To Spinoza, human beings are not "situated in nature as a kingdom within a kingdom" but are as much a part of God or nature or the universal order as other natural objects. The failure to understand God had led to many misconceptions—for one, that nature exists only for one's use:

> As they find in themselves and outside themselves many means which assist them not a little in their search for what is useful, for instance, eyes for seeing, teeth for chewing, herbs and animals for yielding food, the sun for giving light, the sea for breeding fish, they come to look on the whole of nature as a means for obtaining such conveniences.[22]

Furthermore, unable to find any other cause for the existence of these things, they attributed them to a creator-God who must be worshiped to gain their ends: "Hence also it follows, that everyone thought out for himself, according to his abilities, a different way of worshiping God, so that God might love him more than his fellows, and direct the whole course of nature for the satisfaction of his blind cupidity and insatiable avarice." Then, when nature appeared unfriendly in the form of storms, earthquakes, and diseases, "they declared that such things happen, because the gods are angry at some wrong done them by men, or at some fault committed in their worship," rather than realizing "that good and evil fortunes fall to the lot of pious and impious alike."[23] Likewise, human beings made moral condemnations of others because they failed to understand that human emotions, "passions of hatred, anger, envy and so, considered in themselves, follow from the same necessity and efficacy of nature" and "nothing comes to pass in nature in contravention to her universal laws." To explain human emotions, like everything else, we need to analyze them as we would the movements of planets:

"I shall, therefore, treat of the nature and strength of my emotions according to the same method as I employed heretofore in my investigations concerning God and the mind. I shall consider human actions and desires in exactly the same manner as though I were concerned with lines, planes, and solids."[24] Everything has a rational explanation, and humans are capable of finding it. In using reason, people can find true happiness. Their real freedom comes when they understand the order and necessity of nature and achieve detachment from passing interests.

PASCAL Blaise Pascal (BLEZ pass-KAHL) (1623–1662) was a French scientist who sought to keep science and religion united. An accomplished scientist and a brilliant mathematician, he excelled at both the practical, by inventing a calculating machine, and the abstract, by devising a theory of chance or probability and doing work on conic sections. After a profound mystical vision on the night of November 23, 1654, which assured him that God cared for the human soul, he devoted the rest of his life to religious matters. He planned to write an "apology for the Christian religion" but died before he could do so. He did leave a set of notes for the larger work, however, which in published form became known as the *Pensées* (pahn-SAY) (*Thoughts*).

In the *Pensées,* Pascal tried to convert rationalists to Christianity by appealing to both their reason and their emotions. Humans were, he argued, frail creatures, often deceived by their senses, misled by reason, and battered by their emotions. And yet they were beings whose very nature involved thinking: "Man is but a reed, the weakest in nature; but he is a thinking reed."[25]

Pascal was determined to show that the Christian religion was not contrary to reason: "If we violate the principles of reason, our religion will be absurd, and it will be laughed at." Christianity, he felt, was the only religion that recognized people's true state of being as both vulnerable and great. To a Christian, a human being was both fallen and at the same time God's special creation. But it was not necessary to emphasize one at the expense of the other—to view humans as only rational or only hopeless. Pascal even had an answer for skeptics in his famous wager. God is a reasonable bet; it is worthwhile to assume that God exists. If he does, then we win all; if he does not, we lose nothing.

Despite his own background as a scientist and mathematician, Pascal refused to rely on the scientist's world of order and rationality to attract people to God: "If we submit everything to reason, there will be no mystery and no supernatural element in our religion." In the new cosmology of the seventeenth century, "finite man," Pascal believed, was lost in the new infinite world, a realization that frightened him: "The eternal silence of those infinite spaces strikes me with terror" (see the box on p. 499). The world of nature, then, could never reveal God: "Because they have failed to contemplate these infinites, men have rashly plunged into the examination of nature, as though they bore some proportion to her.... Their assumption is as infinite as their object." A Christian could only rely on a God who through Jesus cared for human beings. In the final analysis, after providing reasonable arguments for Christianity, Pascal came to rest on faith. Reason, he believed, could take people only so far: "The heart has its reasons of which the reason knows nothing." As a Christian, faith was the final step: "The heart feels God, not the reason. This is what constitutes faith: God experienced by the heart, not by the reason."[26]

In retrospect, it is obvious that Pascal failed to achieve his goal of uniting Christianity and science. The gap between science and traditional religion grew ever wider as Europe continued along its path of secularization. Of course, traditional religions were not eliminated, nor is there any evidence that churches had yet lost their followers. That would happen later. Nevertheless, more and more of the intellectual, social, and political elites began to act on the basis of secular rather than religious assumptions.


Private Collection/Giraudon/The Bridgeman Art Library

Blaise Pascal. Blaise Pascal was a brilliant scientist and mathematician who hoped to keep science and Christianity united. In his *Pensées,* he made a passionate argument on behalf of the Christian religion. He is pictured here in a portrait by Philippe de Champaigne, a well-known French portrait painter of the Baroque period.

CHRONOLOGY	Consequences of the Scientific Revolution: Important Works
Bacon, *The Great Instauration*	1620
Descartes, *Discourse on Method*	1637
Pascal, *Pensées*	1669
Spinoza, *Ethics Demonstrated in the Geometrical Manner*	1677

Pascal: "What Is a Man in the Infinite?"

PERHAPS NO INTELLECTUAL IN THE SEVENTEENTH CENTURY gave greater expression to the uncertainties generated by the cosmological revolution than Blaise Pascal, himself a scientist. Pascal's work, the *Pensées*, consisted of notes for a large unfinished work justifying the Christian religion. In this selection, Pascal presents his musings on the human place in an infinite world.

Blaise Pascal, *Pensées*

Let man then contemplate the whole of nature in her full and exalted majesty. Let him turn his eyes from the lowly objects which surround him. Let him gaze on that brilliant light set like an eternal lamp to illumine the Universe; let the earth seem to him a dot compared with the vast orbit described by the sun, and let him wonder at the fact that this vast orbit itself is not more than a very small dot compared with that described by the stars in their revolutions around the firmament. But if our vision stops here, let the imagination pass one; it will exhaust its powers of thinking long before nature ceases to supply it with material for thought. All this visible world is no more than an imperceptible speck in nature's ample bosom. No idea approaches it. We may extend our conceptions beyond all imaginable space; yet produce only atoms in comparison with the reality of things. It is an infinite sphere, the center of which is everywhere, the circumference nowhere. In short, it is the greatest perceptible mark of God's almighty power that our imagination should lose itself in that thought.

Returning to himself, let man consider what he is compared with all existence; let him think of himself as lost in his remote corner of nature; and from this little dungeon in which he finds himself lodged—I mean the Universe—let him learn to set a true value on the earth, its kingdoms, and cities, and upon himself. What is a man in the infinite? . . .

For, after all, what is a man in nature? A nothing in comparison with the infinite, an absolute in comparison with nothing, a central point between nothing and all. Infinitely far from understanding these extremes, the end of things and their beginning are hopelessly hidden from him in an impenetrable secret. He is equally incapable of seeing the nothingness from which he came, and the infinite in which he is engulfed. What else then will he perceive but some appearance in the middle of things, in an eternal despair of knowing either their principle or their purpose? All things emerge from nothing and are borne onward to infinity. Who can follow this marvelous process? The Author of these wonders understands them. None but He can.

Q *Why did Pascal question whether human beings could achieve scientific certainty? What is the significance of Pascal's thoughts for modern science?*

CHAPTER SUMMARY

The Scientific Revolution represents a major turning point in modern Western civilization. In the Scientific Revolution, the Western world overthrew the medieval, Aristotelian-Ptolemaic worldview and geocentric universe and arrived at a new conception of the universe: the sun at the center, the planets as material bodies revolving around the sun in elliptical orbits, and an infinite rather than finite world. This new conception of the heavens was the work of a number of brilliant individuals: Nicolaus Copernicus, who theorized a heliocentric, or sun-centered, universe; Johannes Kepler, who discovered that planetary orbits were elliptical; Galileo Galilei, who, by using a telescope and observing the moon and sunspots, discovered that the universe seemed to be composed of material substance; and Isaac Newton, who tied together all of these ideas with his universal law of gravitation. The contributions of each individual built on the work of the others, thus establishing one of the basic principles of the new science—cooperation in the pursuit of new knowledge.

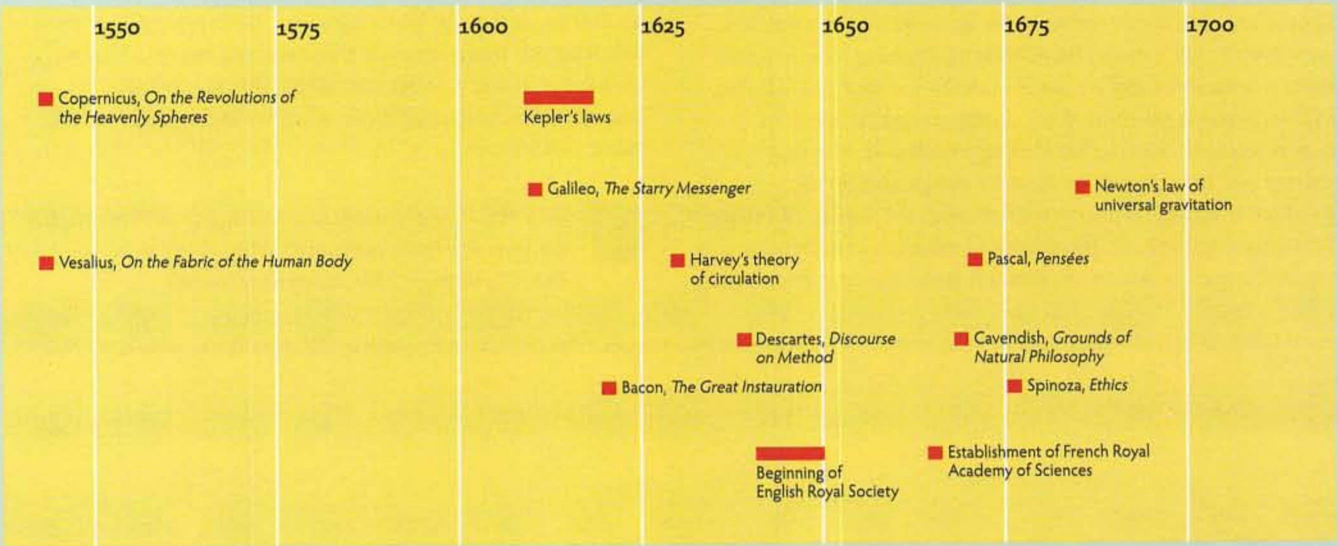
With the changes in the conception of "heaven" came changes in the conception of "earth." The work of Bacon and Descartes left Europeans with the separation of mind and matter and the belief that by using only reason they could in fact understand and dominate the world of nature. The

development of a scientific methodology furthered the work of the scientists, and the creation of scientific societies and learned journals spread its results. The Scientific Revolution was more than merely intellectual theories. It also appealed to nonscientific elites because of its practical implications for economic progress and for maintaining the social order, including the waging of war.

Although traditional churches stubbornly resisted the new ideas and a few intellectuals pointed to some inherent flaws, nothing was able to halt the supplanting of the traditional ways of thinking by new ways of thinking that created a more fundamental break with the past than that represented by the breakup of Christian unity in the Reformation.

The Scientific Revolution forced Europeans to change their conception of themselves. At first, some were appalled and even frightened by its implications. Formerly, humans on earth had viewed themselves as being at the center of the universe. Now the earth was only a tiny planet revolving around a sun that was itself only a speck in a boundless universe. Most people remained optimistic despite the apparent blow to human dignity. After all, had Newton not demonstrated that the universe was a great machine governed by natural laws? Newton had found one—the universal law of gravitation. Could others not find other laws? Were there not natural laws governing every aspect of human endeavor that could be found by the new scientific method? Thus, as we shall see in the next chapter, the Scientific Revolution leads us logically to the Enlightenment in the eighteenth century.

CHAPTER TIMELINE



CHAPTER REVIEW

Upon Reflection

Q How do you explain the emergence of the Scientific Revolution?

Q What do we mean by the "Newtonian world-machine," and what is its significance?

Q Compare the methods used by Bacon and Descartes. Would Pascal agree with the methods and interests of these men? Why or why not?

Key Terms

Scientific Revolution (p. 477)
geocentric conception (p. 479)
heliocentric conception (p. 480)
world-machine (p. 488)
querelles des femmes (p. 491)
Cartesian dualism (p. 493)
rationalism (p. 493)
scientific method (p. 494)
empiricism (p. 495)

Suggestions for Further Reading

GENERAL WORKS General surveys of the entire Scientific Revolution include **J. Henry, *The Scientific Revolution and the Origins of Modern Science*,** 2nd ed. (London, 2002), and **J. R. Jacob, *The Scientific Revolution: Aspirations and Achievements, 1500–1700*** (Atlantic Highlands, N.J., 1998). See also **P. Dear, *Revolutionizing the Sciences: European Knowledge and Its Ambitions, 1500–1700*** (Princeton, N.J., 2001). On the relationship of magic to the beginnings of the Scientific

Revolution, see the pioneering work by **F. Yates,** ***The Rosicrucian Enlightenment*** (London, 1975). On the relationship between Renaissance artists and the Scientific Revolution, see **P. H. Smith,** ***Body of the Artisan: Art and Experience in the Scientific Revolution*** (Chicago, 2006).

A REVOLUTION IN ASTRONOMY On the important figures of the revolution in astronomy, see **H. Margolis,** ***It Started with Copernicus: How Turning the World Inside Out Led to the Scientific Revolution*** (New York, 2002); **M. Sharratt,** ***Galileo: Decisive Innovator*** (Oxford, 1994); **S. Drake,** ***Galileo, Pioneer Scientist*** (Toronto, 1990); **M. Casper,** ***Johannes Kepler,*** trans. **C. D. Hellman** (London, 1959), the standard biography; **R. S. Westfall,** ***The Life of Isaac Newton*** (New York, 1993); and **P. Fara,** ***Newton: The Making of Genius*** (New York, 2004).

ADVANCES IN MEDICINE The worldview of Paracelsus can be examined in **P. Ball,** ***The Devil's Doctor: Paracelsus and the World of Renaissance Magic and Science*** (New York, 2006). The standard biography of Vesalius is **C. D. O'Malley,** ***Andreas Vesalius of Brussels, 1514–1564*** (Berkeley, Calif., 1964). The work of Harvey is discussed in **G. Whitteridge,** ***William Harvey and the Circulation of the Blood*** (London, 1971).

IMPACT OF SCIENCE The importance of Francis Bacon in the early development of science is underscored in **P. Zagorin,** ***Francis Bacon*** (Princeton, N.J., 1998). A good introduction to the work of Descartes can be found in **G. Radis-Lewis,** ***Descartes: A Biography*** (Ithaca, N.Y., 1998).

WOMEN AND SCIENCE On the subject of women and early modern science, see the comprehensive and highly informative work by **L. Schiebinger,** ***The Mind Has No Sex? Women in the Origins of Modern Science*** (Cambridge, Mass., 1989).

SCIENCE AND SOCIETY The social and political context for the triumph of science in the seventeenth and eighteenth centuries is examined in **M. C. Jacobs,** ***The Cultural Meaning of the Scientific Revolution*** (New York, 1988). On the relationship of science and industry, see **M. C. Jacobs,** ***Scientific Culture and the Making of the Industrial West*** (Oxford, 1997).

AP® REVIEW QUESTIONS FOR CHAPTER 16

1. All of the following contributed to the Scientific Revolution EXCEPT
   (A) Renaissance humanist thinking.
   (B) the development of new technology that aided in scientific discovery.
   (C) the influence of Classical thinkers like Ptolemy.
   (D) encouragement by the church to question God's power.
   (E) new advances in the field of mathematics.

2. In *On the Revolutions of the Heavenly Spheres,* Copernicus asserted that
   (A) the earth is at the center of the universe and all planets revolve around it.
   (B) the sun is at the center of universe and the planets move in concentric circles around it.
   (C) the heavens are at the center of the universe and the planets move around the heavens.
   (D) the sun is at the center of the universe and the planets move in elliptical orbits around it.
   (E) the earth is at the center of the universe and all planets move in conjunction with the moon.

3. The Dutch painting below

Louvre, Paris/© Giraudon/The Bridgeman Art Library

   (A) is an example of new scientific painting techniques.
   (B) embodies the Puritan ideal that science and God were not inherently at odds.
   (C) reflects an attempt to spread the knowledge of science to the New World.
   (D) was condemned by the Catholic Church because the church was in opposition to Dutch painters.
   (E) reflects mass popular culture and the response of the poorer classes to the subtleties of style.

4. When René Descartes wrote "I think, therefore I am," he did so to demonstrate the concept of
   (A) the power of the human mind.
   (B) deductive reasoning.
   (C) the new emerging agnostics.
   (D) inductive reasoning.
   (E) the humanists' ability to control the mind.

5. During the seventeenth century, European society generally saw women as
   (A) nurturers who were essential to the survival of the family.
   (B) deserving of limited education and some political freedoms.
   (C) worthy of being encouraged to participate in academic endeavors and venues such as royal societies.
   (D) valuable autonomous voices in community forums and church leadership meetings.
   (E) the superior sex because they had the ability to bring new life.

6. Margaret Cavendish wrote, "we have no power at all over natural causes and effects . . . for man is but a small part. . . . His powers are but particular actions of Nature, and he cannot have a supreme and absolute power."

   Which of the following best characterizes this statement?
   (A) Man can do all things.
   (B) God and man are equal.
   (C) Man is simply a part of a larger picture.
   (D) God can be understood and nature can be explained.
   (E) Man is limited in his mental abilities and therefore should not attempt to understand science.

7. When Pascal said, "Man is but a reed, the weakest in nature, but he is a thinking reed," he was trying to convey that
   (A) man needs God and that science is unnecessary within God's realm.
   (B) God was like a clockmaker; he created man and then allowed him to function as an individual needing little spiritual intervention.
   (C) man and nature are connected; as the two can work together, so can God and man combine reason and religion.
   (D) man is alone in the world and only through reason can he find his way.
   (E) man is merely a small piece of the universe and he must cooperate with his fellow men in order to live in the complex society that they have built.

8. The Catholic Church chose to denounce Galileo because
   (A) he posed a political threat to authorities like the pope.
   (B) the church leaders wanted to start their own scientific revolution.
   (C) he was a social leader that many of the peasants followed, and the church feared a peasant uprising.
   (D) the church leaders were convinced that Galileo's scientific ideas would cause people to leave the church or to embrace the new reform religions.
   (E) many of the leading scientists at the time had proved him wrong, and he had given an unconvincing explanation for the movement of the planets.

9. Galileo Galilei is NOT credited with which of the following?
   (A) discovering the laws of inertia
   (B) naming the moons of Jupiter
   (C) developing an optical lens to view the heavens
   (D) using a telescope to view the heavens
   (E) writing *The Starry Messenger*

10. During the seventeenth century, women often lost jobs as midwives to men because
   (A) men convinced pregnant women that their scientific expertise made them better suited than women to deliver children.
   (B) women chose to leave the profession to spend more time with their families.
   (C) women lost interest in the field of medicine and felt they were not able to perform their duties as well as men could.
   (D) the church decreed that women should not be involved in birth, as it was a holy experience that only learned men could attend.
   (E) pregnant women feared other women would harm their infants, and found solace in the presence of a man during childbirth.

11. Science impacted European society in that
   (A) it was offered up to the common man to actively engage in thoughtful conversations.
   (B) it was responsible for bringing the Protestant and Catholic churches together under a common mission to eradicate any new scientific discoveries.
   (C) it created a deeper divide between the educated elite and the uneducated common man.
   (D) monarchs attempted to stifle scientific progress because they believed it would decrease their power over the people.
   (E) women were given additional venues to seek an education and be seen as more equal within the society.

12. The scientific societies throughout Europe
   (A) were primarily based in Italy because the church led the way in associating science with religion.
   (B) were open to much of the public and became a valuable outlet for women to produce and highlight their new scientific work.
   (C) varied by country, with the governments of some states (like France) sponsoring societies, and other governments exerting little direct control over them.
   (D) primarily worked in isolation and failed to create any meaningful connections with other societies.
   (E) were primarily engaged in theory and failed to produce any meaningful accomplishments.

13. Which of the following is true of Benedict Spinoza's philosophical writings?
   (A) They were accepted by many, especially the Catholic Church, as he suggested that all are part of God's kingdom.
   (B) They caused him to be excommunicated by the Catholic Church and ostracized by many of his fellow scientists.
   (C) They caused him to be banned from all royal societies and many royal courts.
   (D) They proved him to be diametrically opposite in thought from Galileo and Pascal.
   (E) They proposed the rationalization of universal laws that are developed by God and that humans could formulate rational explanations about the world and nature.

14. All of the following arguments were used to explain the status of women EXCEPT
   (A) that women were content with their station and did not seek change.
   (B) that women were irrational and could not benefit from education.
   (C) that women's skulls were smaller than men's skulls, thereby proving natural male superiority.
   (D) that women were naturally more prone to sin or easily swayed.
   (E) that women were similar to sheep and needed the guidance of men to keep them from going astray.