16 – The Scientific Revolution: The 1600s

As the Renaissance encouraged scholars to think for themselves, explorers expanded geographical and cultural views of the world, astronomers observed phenomena that did not fit conventional models, and the authority of the Catholic Church suffered from the splintering of the Reformation. Europeans began to think about their world in new ways, eventually adopting a scientific and mathematical view of the universe. This marked the beginning of a more modern intellectual mindset that manifested itself not only in new discoveries and inventions but also in the intellectual revolution that led to a more secular view of the world.

KEY TERMS

alchemy
Aristotelian philosophy
astrology
Cartesian dualism
cosmology
deductive method
empiricism
geocentric conception
heliocentric model of the universe
Hermeticism
inductive method
Principia Mathematica
Ptolemaic (geocentric) model of the universe
querelles des femmes
rationalism
Royal Academy of the Sciences
Royal Society
scholasticism
scientific method
Scientific Revolution
world machine

KEY CONCEPTS

- Scientific societies promoted the new scientific concept of the natural world, attracting the attention-and patronage-of governments that hoped to use this new knowledge.
- Science became a part of the high culture of Europe during the seventeenth century, with Europe's wealthy, educated elites eager to exploit the practical applications of science to their own advantage in trade and industry.
- The transition to a new world view proved to be a difficult process for some to accept. Threatened by scientific discoveries that contradicted centuries-old church teachings, Protestant and Catholic church leaders tried unsuccessfully to silence the spread of new scientific ideas, as the trial of Galileo demonstrates.
- The Scientific Revolution ushered in a transformation in intellectual thought that revolutionized the concept of the universe and man's place in it, challenging traditional views of the world and marking a fundamental break with the old intellectual order.

For a full discussion of the Scientific Revolution, see *Western Civilization*, 8th and 9th editions, Chapter 16.

Origins of the Scientific Revolution

Although medieval scholars had studied the natural world and employed mathematical and scientific thinking in many ways, the Catholic Church forced them to stay within the boundaries of the old order, the conception of the world laid out by thinkers, such as Aristotle, Galen, and Ptolemy. Several factors led sixteenth-and seventeenth-century thinkers to challenge accepted beliefs and eventually spurred them to embrace a more modern scientific model.

First, Renaissance scholars read more of the classical works in the original Greek and realized that even during classical times, other scholars and writers had challenged the great authorities of the old order. Building on the intellectual curiosity of the Renaissance, humanist scholars put away their fear of retribution from Church authorities and asked questions about the world. They were particularly influenced by Plato's insistence that an understanding of mathematics is essential for an understanding of the universe, as well as by the rediscovery of the mathematical works of ancient scholars.

AP Tip

Remember that the Scientific Revolution had far-reaching consequences. For example, Renaissance artists applied the principles of science and mathematics to their art, even dissecting bodies to understand anatomy, a practice deemed unacceptable by the Church.

Second, the age of exploration had created a demand for new technology, so explorers and merchants began to turn to science to solve practical problems and design equipment, such as better navigational tools. With the invention of the printing press around 1450, the scientific community in Europe began to come together; having read the same published works, scientists – for example, Galileo and Kepler – often corresponded with one another. As a result, scientists began to build on each other's observations and theories, and the speed of scientific advancement accelerated.

Finally, Renaissance Hermeticism held that the universe was the embodiment of God's creation and that humans, as creations of God, could understand the universe's direct nature for beneficial purposes. Hermeticism combined alchemy and astrology and used mathematical magic to unlock the secrets of the universe, so most believed that only an intellectual elite could use it. It was not the magic, but Hermeticism's interest in controlling nature, that was significant. For famous scientists, such as Copernicus, Kepler, Galileo, and Newton, Hermetic magic served as an intellectual springboard.

Advances in Astronomy

Many notable achievements of the Scientific Revolution came in the field of astronomy. Traditionally accepted views of the universe were based on the geocentric model, in which Earth, made up of earth, air, fire, and water, was the fixed center of the universe, surrounded by revolving concentric spheres.

AP Tip

The traditional model of the universe based its assumptions on the ideas of Ptolemy and Aristotle, promoting Ptolemy's geocentric belief and Aristotle's concept that circular motion was perfectly shaped and appropriate for heavenly bodies.

The Church clung tightly to this view because it implied that man was the center of God's universe. However, sixteenth-century astronomers realized that their observations did not fit this model; they tried to modify it to make it both acceptable to the Church and consistent with the physical evidence they witnessed.

Copernicus

In 1543, Polish astronomer and mathematician Nicolaus Copernicus's book *On the Revolutions of the Heavenly Spheres* was published-it rocked the scientific community. Advancing a heliocentric, or sun-centered, model of the universe, it challenged Aristotle's work and the Church's view of man's place in the universe and man's relationship to God. At first the Catholic Church ignored his theory, but Protestant reformers quickly denounced it. As Copernicus's ideas gained more attention from astronomers, the Catholic Church joined in the denunciations.

Brahe

Tycho Brahe, a Danish astronomer and the imperial mathematician for Holy Roman Emperor Rudolf II, gathered detailed records of observations over some twenty years. He rejected the geocentric model, but he did not fully agree with the Copernican model, either. Brahe advocated a two-part model: all heavenly bodies revolve around the sun except for Earth and its moon, and the sun and all of its planetary bodies revolve around Earth.

Kepler

Johannes Kepler, a German astrologer, astronomer, and mathematician, worked with Brahe and eventually succeeded him as an imperial mathematician to Rudolf II. Inheriting Brahe's observational data allowed Kepler to apply the data to his emerging ideas and eventually publish three laws of planetary motion. He proved mathematically that the sun is the center of the universe; that the planets have elliptical orbits and that the orbital speeds of planets vary depending on the distance of each planet from the sun; and that planets with smaller orbits revolve more slowly than those with larger orbits. Collectively, these affirmed heliocentrism and further refined the details of Copernican theory.

Gallleo

Galileo, a scientist and mathematician from Pisa, built an improved telescope and turned it to the heavens, discovering craters on the moon, the four largest moons of Jupiter, the existence of stars in the Milky Way, and sunspots. In his book *Starry Messenger* (1610), Galileo firmly advocated the Copernican model, which had been condemned by the Catholic Inquisition in Rome. In 1616, Galileo attracted his own attention from the Inquisition, which prohibited him from declaring Copernicanism fact. His book *Dialogue on the Two Chief World Systems: Ptolemaic and Copernican*, published in 1632, unequivocally supported Copernican theory and was immediately put on the Catholic Index of Prohibited Books. The Inquisition put Galileo on trial in 1633, found him guilty of violating his 1616 sentence, and put him under house arrest. Galileo spent his final years studying mechanics and motion and making discoveries about acceleration and inertia. His experience with the Catholic Church discouraged Italian scientists; soon after, England, France, and the Dutch Republic became the forefront for scientific innovation.

Newton

Sir Isaac Newton, English mathematician, alchemist, and scientist, invented calculus as a method for explaining infinitesimal changes in motion. He also discovered the three laws of motion, laid out in his most famous work, the *Principia Mathematica* (1687). Explaining the motion of the universe and demonstrating that the universe operated according to set principles that could be discovered through the use of human reason, Newton presented a mechanistic model of the universe, one in which the world was like a machine that operated according to natural scientific laws. A religious man, Newton believed that God created universal laws of motion and moved the heavenly bodies according to those laws; many later thinkers used his model to discount the need for divine intervention. Newton's worldview – the accepted worldview until Einstein's theory of relativity shattered it – suggested that if human reason could discover natural laws governing the physical universe, human reason might also discover natural laws governing fields such as politics and society. In stimulating investigation in those fields, Newton's worldview led to the Enlightenment.

Advances in Medicine and Chemistry

Like astronomy, medicine underwent revolutionary change in the sixteenth and seventeenth centuries. Medieval medicine had been based on the ideas of Galen, a second-century A.D. Greek physician who dissected animals to investigate human anatomy. His inaccurate model of human anatomy, paired with his inaccurate model of human physiology, critically impeded an understanding of disease, which Galen attributed to an imbalance of the four humors (blood, yellow bile, phlegm, and black bile). The commonplace practice of bloodletting is a product of Galen's postulation that treating the imbalance would cure the disease.

Leading the revolution in medicine, Paracelsus began with the premise that just as chemical reactions occur in the universe, they also occur within the human body. Paracelsus posited that disease results from chemical imbalances and can be cured by correcting the imbalances with chemical remedies. Vesalius concentrated on anatomy. Having dissected human bodies as a professor of surgery at the University of Padua, he assembled an illustrated handbook of human anatomy, *On the Fabric of the Human Body* (1543). Although he corrected many of Galen's anatomical errors, he still did not correctly explain the circulatory system. That fell to William Harvey, whose book *On the Motion of the Heart and Blood* (1628) showed the heart as the center of the circulatory system, pumping blood through a circuit of arteries and veins.

Chemistry emerged as a new field of study in the seventeenth century. Robert Boyle, among the first to use controlled experiments, theorized that pressure affects the volume of gases. Boyle also hypothesized that matter is composed of atoms. A century later, Antoine Lavoisier built on Boyle's model and formulated a modern system of naming elements.

Women in the Sciences

Prior to the Renaissance, the view that the proper role of a woman was to be a daughter, wife, and mother was so prevalent that women rarely received higher education unless they became nuns. However, Renaissance humanism permitted the education of some elite women.

Scientific education for women, unlike humanist education, came mostly from informal sources. Noblewomen learned of the sciences from their husbands, fathers, and brothers. Occasionally, they attended meetings of scientific societies with their male relatives or sat in as listeners at scientific discussions. A few privileged women made names for themselves in the sciences, but scientific societies in England and France did not admit any women as members until the twentieth century.

One such noblewoman was Margaret Cavendish, Duchess of Newcastle. In addition to poetry, essays, plays, popular fiction-even an early example of science fiction-she wrote six books on natural philosophy in which she criticized both rationalism and empiricism and questioned the scientific method.

French and English women in the sciences mainly came from aristocratic families. In Germany, the majority of women in the sciences had a craft production background. For example, Maria Merian was trained in illustration in her father's workshop. A serious entomologist, she traveled to Surinam in 1699 to study insects and plants. Her book, Metamorphosis of the Insects of Surinam, is notable for both her close observation and her excellent illustrations of the insect life.

Maria Winkelmann learned astronomy in a family observatory, trained by her father, her uncle, and a neighbor. She married Gottfried Kirch, a renowned German astronomer, and was his assistant at the Berlin Academy of Science observatory, where she discovered a comet. Although well qualified, she was denied the position of assistant astronomer at the observatory after her husband's death.

AP Tip

It is important to remember that only elite, privileged women received humanist learning. Most women in Europe were unaffected by Renaissance humanism and the Scientific Revolution.

In the age-old debate on the inherent nature of women, the traditional male view held that women were weak, irrational, and easily corruptible, and therefore not fit for higher education. In the sixteenth and seventeenth centuries, that view was challenged. Women argued that they possessed rational minds and should be allowed to participate in the scientific and intellectual revolutions of their age but that they needed an education-that education was the key to a broader understanding of the world and valuable participation in society. By the eighteenth century, however, women had lost ground in many traditionally female fields-for example, midwifery-when the occupations first were considered professions and then came to be dominated by men. Although a handful of women did have roles in the sciences, the Scientific Revolution generally promoted traditional beliefs about women. Some men, such as Benedict de Spinoza, even used the new sciences to further promote male superiority, claiming that women were naturally inferior beings.

The Scientific Method

As the accepted view of the universe changed and science became popularized, the Scientific Revolution spurred thinkers to question the very process of scientific inquiry and ask about the nature of man and how one could discover truth. Two of the most important such thinkers were Francis Bacon and Rene Descartes.

- Bacon (1561-1626), an English jurist and amateur scientist, proposed a revolutionary reorganization of the scientific process. In his book *Novum Organum*, Bacon asserted that misunderstandings – he called them idols – clouded human knowledge and needed to be eliminated in order to achieve intellectual certainty; scientists should reject the assumptions of previous thought and use the inductive method rather than the deductive method – in other words, gather evidence through observation, then proceed to make general hypotheses and axioms. Unlike Descartes, Bacon trusted his senses and believed that all human knowledge entered the mind through the perception of the senses. This made Bacon an empiricist, because he rejected as uncertain any assertion that could not be proven through experiments and observations.
- Descartes (1596-1650), a French philosopher and mathematician, founded modern rationalism, the belief that the basis of knowledge is human reason, not physical observation or experience. Descartes built his philosophy with the process of systematic doubt – he doubted everything, from the existence of the world around him to his own existence. An extreme rationalist, he concluded that he could not trust his senses and so discounted all knowledge he perceived with them. Eventually, he decided that the only thing he knew for sure was that he existed – doubting was the affirmation of his thinking and his existence. This led to his declaration "I think, therefore I am" in *Discourse on Method. Descartes* then postulated the existence of God as the creator of thinking things and of the world around him. He argued that the mind uses mathematics to help explain the world and could be trusted, while the senses could not. Descartes favored deductive thinking: using rational thought, one proceeds from general principles and axioms to specific and complex truths. A related principle, Cartesian dualism, holds that the mind and body are separate – the mind being a spiritual entity and the body a physical one. Thus, a mechanistic model of humanity emerged.

AP Tip

It is important to understand how thinkers built on one another's ideas. Newton eventually defined the modern scientific method, building on the ideas of both Bacon and Descartes. He combined the empiricism and inductive thinking of Bacon with the rationalism and deductive thinking of Descartes to create a method that began with observations and experiments, proceeded to general axioms, prompted new deductions based on the general concepts, and then tested the new deductions through more experimentation.

The Spread of Scientific Knowledge

Several vehicles for the dissemination of scientific ideas emerged during the seventeenth century. Scientific journals and societies dedicated to the study and advancement of science helped create a community of scientists. The public was interested, too.

Although the first scientific societies originated in Italy, the English Royal Society (founded in 1662) and the French Academy of the Sciences (1666) proved more important in the advancement of scientific research and ideas. Both grew from informal gatherings of scientists and received royal support-at first for investigating practical applications of science to industry and technology, but soon after for concentrating theoretical work. During the wars of Louis XIV, however, the French Academy worked with the Marquis de Louvois, the war minister, because the French government provided the Academy's members with generous monetary support and salaries. German states, copying the English and French models, also supported small scientific societies.

The publication of scientific journals further encouraged cooperation among scientists, allowing them to read the results of one another's experiments and build on shared ideas. In France, journals aimed at both practicing scientists and the educated public had a wider circulation than comparable English journals, which were generally only distributed to Royal Society members and other active scientists.

Several important factors led to the rapid acceptance of the usefulness of science. In the larger society, literate merchants and aristocrats saw that scientific applications could provide them with ways to make greater profits. Some political leaders used science to create stability in their nations. While some Puritan leaders wanted to pursue radical scientific changes, most aristocrats and political leaders pursued the application of science to the improvement of conditions in their nations, such as increasing crop yields or making trade more efficient. In using science to improve nations, the governing elite enhanced its own political power.

Science and Religion

As scientists began to make discoveries that called into question the traditional theological claims about the world and the universe, conflicts arose between science and religion. Galileo, whose ideas were victims of such disagreements, believed that such conflict was not inevitable; the Church should refrain from making decisions about the nature of the universe based on Biblical texts that could be interpreted in many different ways. The Church, however, clung to the traditional cosmology of the universe. The split between science and religion widened, even though many scientists were deeply religious and feared the effects would lead people to a rejection of their faith.

Two thinkers tried to bridge the divide:

- Benedict de Spinoza (1632-1677), a Dutch lens grinder and philosopher, advocated rationalism as a means to understanding. He believed that understanding of universal truths cannot be discovered adequately and completely by sense perceptions alone. Although he rejected Cartesian dualism, Spinoza agreed with many of the mathematical ideas of Descartes and read most of his works. A Jew excommunicated from his synagogue at the age of twenty-four and ostracized by Christian churches, Spinoza believed that God and nature are inseparable – that God is the universe. This philosophy, pantheism, is the subject of *Ethics Demonstrated in the Geometrical Manner.*
- Blaise Pascal (1623-1662) was a French mathematician and scientist. In *Pensées*, Pascal asserted that Christianity did not contradict reason and, in an explanation known as Pascal's wager, that the most reasonable action was to bet that God exists: if one were correct, he would go to heaven; if incorrect, he had lost nothing. According to Pascal, finite human reason cannot adequately comprehend an infinite universe and God, so only faith can bring a person close to God. Pascal hoped to bring together religion and science, but like many other seventeenth-century thinkers, his efforts failed, and philosophers became more secular in their thinking on the eve of the Enlightenment.

The Scientific Revolution of the sixteenth and seventeenth centuries turned medieval cosmology upside down and radically changed human perceptions concerning man, the universe, and God. The new science prompted a variety of reactions, ranging from outright hostility on the part of many organized churches to eager acceptance by scientists and those educated people who realized that science could be used to bring profits, stability, and practical improvements to the human condition. Most important, Newton's discovery of natural laws that govern the physical world prompted philosophers to search for natural laws that govern many aspects of society and politics, a trend that created great optimism and hope for the future and ushered in the Enlightenment.