Chapter 11: The Scientific Revolution

While the attention of Europe had been focused on politics and war, great changes were occurring in the realm of ideas. By the early seventeenth century, exciting new developments were under way in astronomy and the physical sciences.
The heliocentric (sun-centered) theory of the universe, which Copernicus proposed in the mid-sixteenth century, gradually won acceptance, replacing the old geocentric (earth-centered) theory, first developed in ancient times. While Sir Isaac Newton developed the law of universal gravitation, other scientists laid the foundations for the scientific study of anatomy and physiology, chemistry, biology, physics, and geology. The methodology of science was debated, and scientific societies were established to promote further research and the spread of the new knowledge. The Scientific Revolution ultimately brought radical changes to people's understanding of the entire physical universe.

The Background of the Scientific Revolution

In the sixteenth century, Europeans' understanding of the universe was based on the conclusions of the ancient Greek philosopher Aristotle (fourth century B.C.) and the Hellenistic astronomer and mathematician Claudius Ptolemy (second century A.D.). According to the ancient geocentric view of the universe, the earth stood motionless at the center of the universe, while the moon, sun, planets, and stars revolved around the earth in a series of circular orbits. These heavenly bodies were composed of a substance different from that of the earth, and they were weightless. This was what made it possible for them to revolve around the earth. As the ancients understood motion, no heavy body could move without a mover. Since the earth was heavy, and since there was no mover, it remained motionless.

Problems with the Ancient View of the Universe

Although the ancient view of the physical universe had been accepted by Western Europeans during the Middle Ages, there were obvious problems with the Ptolemaic system. The most troublesome problem was that the planets could be observed moving in evidently noncircular patterns around the earth. Sometimes the planets even appeared to be moving backward.
To make these patterns of movement compatible with the geocentric theory of Ptolemy, medieval astronomers introduced the concept of epicycles. According to this concept, the planets made a second revolution in an orbit that was tangential to their primary orbit around the earth. The concept of epicycles greatly complicated the geocentric theory. Nevertheless, it won acceptance since it provided a satisfactory explanation of the motion of the planets as that motion was observed by human beings. It also helped shore up both the geocentric theory and the Christian belief that the earth stood at the very center of the universe that God had created.

The Revolution in Astronomy

Nicolaus Copernicus and the Heliocentric Theory

In the sixteenth century, the Polish monk, mathematician, and astronomer Copernicus (1473-1543) presented the first serious challenge in many centuries to the geocentric theory. He hypothesized that the sun stood at the center of the universe and that the earth moved in a circular orbit around the sun. For some twenty-five years, he worked on the development of this heliocentric theory. In 1543, the year of his death, Copernicus's treatise, *On the Revolution of the Heavenly Spheres*, was published. Other scientists and both Protestant and Catholic churchmen denounced Copernicus's theory, charging that it was illogical, unbiblical, and un-Christian.

Tycho Brahe and Astronomical Discoveries

Brahe (1546-1601), a Danish astronomer, built Europe's most modem astronomical laboratory, where he and his associates collected a mass of accurate data about the stars and planets. These discoveries served to undermine the Ptolemaic view of the universe. Nevertheless, Brahe did not fully accept the heliocentric theory advanced by Copernicus, for he concluded that while the planets revolved around the sun, the earth remained stationary. Other astronomers, however, used the data collected by Brahe to support the view that the earth also circled around the sun.

Johannes Kepler and the Laws of Planetary Motion

Kepler (1571-1630), a German astronomer who had worked as Brahe's assistant, accepted the fundamental validity of the heliocentric theory. He proceeded to develop the three laws of planetary motion, publishing the first two in 1609and the third in 1619. According to the first law, the planets, including the earth, revolve around the sun in elliptical (rather than circular) orbits. The second law stated that the velocity of the planets varies according to their distance from the sun. A planet moves faster when it is closer to the sun than when it is farther away. The third law set forth a complex mathematical formula explaining the physical relationship among the moving planets.

Galileo Galilei and Proof of the Heliocentric Theory

Galileo (1564-1642), an Italian mathematician, astronomer, and physicist, set out to demonstrate the validity of the heliocentric theory. The telescope had recently been invented in the Netherlands, and Galileo was the first to use a telescope for astronomical observations. With his telescope, Galileo could actually see what others had hypothesized: that the planets revolve around the sun. He discovered the mountains of the moon, the moons of Jupiter, the rings around Saturn, and sunspots. What mattered most, however, was that he provided decisive support for the heliocentric theory.

In 1632, Galileo published his *Dialogue on Two Chief Systems of the World* and promptly got into trouble with the authorities of the Catholic Church. While Galileo was personally devout in his religious faith, he contended that the Bible was not a reliable authority on scientific matters. The Church was prepared to tolerate the heliocentric theory if it was advanced as a hypothesis, rather than as established fact. In 1633, the Roman Inquisition condemned Galileo's work and placed it on the *Index* of prohibited books. Galileo was compelled to recant, although he is said to have muttered, referring to the earth, "And yet it does move."

Confined to house arrest in a comfortable villa, Galileo continued his scientific work, concentrating on less controversial subjects. His study of falling bodies disproved Aristotle's contention that objects fall at varying speeds, depending on their weights. Galileo also developed the theory of the pendulum and discovered the principle of inertia.

Sir Isaac Newton and the Law of Universal Gravitation

The work of Copernicus, Kepler, and Galileo had left one great unanswered question: What is it that causes the planets, stars, and other heavenly bodies to move in an orderly fashion? Newton discovered the answer to this question.

The son of an English farmer, Newton's (1642-1727) genius won him early recognition, and he became a professor of mathematics at Cambridge University while he was still in his twenties. Working independently of one another, both Newton and Gottfried Wilhelm von Leibniz (1646-1716), a German philosopher and mathematician, discovered differential and integral calculus.

Newton shared the conviction of other scientists that the physical universe was governed by natural laws. His research convinced him that all of the heavenly bodies moved as they did because of the operation of the law of gravity. In his *Principia Mathematica* (1687), Newton set forth the law of universal gravitation, which provided a mathematical explanation of the operation of gravity everywhere in the universe.

Scientific Methodology and the Promotion of Science

Francis Bacon and the Inductive Method

Bacon(1561-1626), an English attorney and royal official, wrote extensively on history, ethics, and philosophy. While he was not a professional scientist, he did much to promote the inductive method of modem science. Bacon attacked the excessive reverence given to the work of ancient thinkers, including Aristotle. In particular, he challenged Aristotle's dependence on deductive reasoning.

Bacon insisted that valid conclusions about the physical universe could be reached only through the inductive method, which involves experimentation and the systematic collection and analysis of data. Generalizations can then be made on the basis of the collected and analyzed data. If scientists carefully examined the empirical evidence, he believed, they would develop new knowledge that would produce benefits for all of humanity. His major works include *The Advancement of Learning* (1605) and the *Novum Organum* (1620).

René Descartes and the Deductive Method

While Bacon emphasized the inductive method, based on experiment and observation, the Frenchman Descartes (1596-1650) promoted the deductive method, which involved reasoning out a general law from specific cases and then applying it broadly to cases that have not been specifically observed. Descartes set forth what came to be known as the Cartesian method in his Discourse on Method (1637).

Descartes began by doubting all authorities and all knowledge, both scientific and religious, until he was left with one thing he could not doubt: his own existence. "*Cogito, ergo sum*" ("I think, therefore I am"), he declared. He then proceeded to deduce the existence of God and the physical world.

Although the Cartesian method had a considerable influence on European thought, it was eventually replaced to a great extent by the inductive method.

A brilliant mathematician, Descartes developed analytical geometry.

Scientific Societies

As the interest in science mounted, scientific societies were organized in a number of countries to promote further research and the spread of scientific knowledge. Galileo was a member of the scientific society established in Rome in 1603; the Medici family sponsored the establishment of the Academy of Experiments in Florence in 1657. In England, the Royal Society for Improving Natural Knowledge was founded in 11662. Four years later, the French Academy of Science was established. The Berlin Academy was founded in 1701.

Other Sciences and Mathematics

The Scientific Revolution ultimately gave rise to most of the fields of modem science.

Anatomy and Physiology

Research in human anatomy (the study of the structure of the human body) and physiology (the study of its functions) served to undermine the teachings of the ancient Hellenistic physician and anatomist, Galen (c. A.D. 130-201), whose conclusions had been unquestioned for centuries.

Vesalius

Andreas Vesalius (15 14-1564), a Flemish-born professor of anatomy at the University of Padua in Italy, prepared the first textbook of human anatomy based on dissection, *The Structure of the Human Body* (1543).

Harvey

William Harvey (1578-1657), an English physician educated at Padua, did much to establish the foundations of modem medicine. He was the first to demonstrate the function of the heart and the circulation of the blood, publishing *On the Movement of the Heart and Blood in Animals* (1628).

Chemistry

Boyle

The title of the father of modem chemistry has been bestowed upon Robert Boyle (1627-1691), an Anglo-Irish chemist. He is most famous for Boyle's Law, which states that the volume of a gas under compression is inversely proportional to the amount of pressure. Boyle was the first to make a clear distinction between a chemical element and a chemical compound and to define clearly the nature of a chemical reaction.

Black

Joseph Black (1728-1799), a Scottish physician and chemist, proved that air was not a single element but instead consisted of several gasses.

Priestley and Lavoisier

In 1775, Joseph Priestley (1733-1804), an English Unitarian minister, published the results of his experiments isolating and identifying oxygen. A few years later, Antoine Lavoisier (1743-1794), a French chemist, demonstrated that water consisted of hydrogen and oxygen. He believed that water and other substances consisted of basic chemical elements, and he identified twenty-three of these elements. Lavoisier's book, *Elementary Treatise on Chemistry* (1789), contributed to the development of both organic and inorganic chemistry.

Biology

Although the study of biology had made some advances during the early stages of the Scientific Revolution, the systems of classification remained relatively primitive until the eighteenth century.

Linnaeus

Carolus Linnaeus (1707-1778), a Swedish botanist, developed a system for the classification of plants and animals by genus and species, which he presented in his *Systema Naturae* (1735). Linnaeus believed, however, that species remained constant, thus disregarding any concept of evolution. Linnaeus developed a botanical garden, and by the end of the eighteenth century, Europe boasted some 1600botanical gardens.

Buffon

The Count of Buffon (1707-1788), a French zoologist, made important contributions to the classification of animal life. His 44-volume natural history was published between 1749 and 1804. Europeans organized a number of zoos, with the one at Versailles becoming particularly famous.

Physics

Galileo's study of motion and the work of Newton, including his study of optics, promoted the development of physics as a modem science.

Gilbert

Important discoveries were gradually made in the field of electricity. In 1600, William Gilbert (c. 1540-1603), the court physician to Queen Elizabeth I and King James 1of England, described the presence of electric charges in many substances. His work won for him the title of the father of modem electricity.

Franklin and Volta

The experiments of Benjamin Franklin (17O6-1790) identified the presence of electricity in lightning, and he invented the lightning rod. The Italian Alessandro Volta (1745-1827), a professor of physics, invented the storage battery, which made it possible to harness electricity. The unit of electrical measurement called the volt is named for him.

Geology

Gilbert

William Gilbert was also one of the pioneers in the field of geology, the study of the origins, development, and structure of the earth. In *De magnete* (1600), a study of magnetism, Gilbert suggested that the earth operated like a huge magnet.

Hutton

James Hutton (1726-1797), a Scotsman, developed theories about the origins of the earth and published *The Theory of the Earth* (1795). He concluded that the surface of the earth had been undergoing gradual changes over the course of many thousands of years.

Mathematics

There were other achievements in mathematics in addition to Descartes's invention of analytical geometry and the development of the system of calculus by Newton and Leibniz.

Logarithms

In 1614, John Napier (1550-1617), a Scottish mathematician, published a table of logarithms that provided a simplified method for multiplying and dividing large numbers and for finding square roots.

The Slide Rule

Using Napier's principle of the logarithm, William Oughtred and Edmund Wingate independently invented the slide rule about 1630.

The Scientific Revolution not only produced a vast amount of specific knowledge about the nature of the physical universe, it also demonstrated that all of nature operates in accordance with natural laws, which human beings are capable of discovering. These new ideas about the physical universe led, in turn, to the Enlightenment, the dominant intellectual movement of the eighteenth century. Applying the methods of science to the study of human affairs, the thinkers of the Enlightenment developed new and radical ideas about the nature of human beings and the organization of government and society.