# 1 The Scientific Revolution

**MAIN IDEA**

In the mid-1500s, scientists began to question accepted beliefs and make new theories based on experimentation.

**WHY IT MATTERS NOW**

Scientists' questioning led to the development of the scientific method still in use today.

**TERMS & NAMES**

- Scientific Revolution
- Nicolaus Copernicus
- heliocentric theory
- Johannes Kepler
- Galileo Galilei
- scientific method
- Francis Bacon
- René Descartes
- Isaac Newton

**SETTING THE STAGE** The Renaissance inspired a spirit of curiosity in many fields. Scholars began to question ideas that had been accepted for hundreds of years. During the Reformation, religious leaders challenged accepted ways of thinking about God and salvation. While the Reformation was taking place, another revolution in European thought was also occurring. It challenged how people viewed their place in the universe.

## The Roots of Modern Science

Before 1500, scholars generally decided what was true or false by referring to an ancient Greek or Roman author or to the Bible. Whatever Aristotle said about the material world was true unless the Bible said otherwise. Few European scholars questioned the scientific ideas of the ancient thinkers or the church by carefully observing nature for themselves.

**The Medieval View** During the Middle Ages, most scholars believed that the earth was an unmoving object located at the center of the universe. According to that belief, the moon, the sun, and the planets all moved in perfectly circular paths around the earth. Beyond the planets lay a sphere of fixed stars, with heaven still farther beyond. Common sense seemed to support this view. After all, the sun appeared to be moving around the earth as it rose in the morning and set in the evening.

This earth-centered view of the universe, called the geocentric theory, was supported by more than just common sense. The idea came from Aristotle, the Greek philosopher of the fourth century B.C. The Greek astronomer Ptolemy expanded the theory in the second century A.D. In addition, Christianity taught that God had deliberately placed earth at the center of the universe. Earth was thus a special place on which the great drama of life took place.

THINK THROUGH HISTORY
**A. Analyzing Issues** Why did most people believe the geocentric theory?

This drawing from an astrology text of 1531 shows the signs of the zodiac moving around the earth. It is based on Ptolemy's system, with the earth at the center.

**A New Way of Thinking** Beginning in the mid-1500s, a few scholars published works that challenged the ideas of the ancient thinkers and the church. As these scholars replaced old assumptions with new theories, they launched a change in European thought that historians call the Scientific Revolution. The **Scientific Revolution** was a new way of thinking about the natural world. That way was based upon careful observation and a willingness to question accepted beliefs.

A combination of discoveries and circumstances led to the Scientific Revolution and helped spread its impact. By the late Middle Ages, European scholars had translated many works by Muslim scholars. These scholars had compiled a storehouse of ancient and current scientific knowledge. Based on this knowledge, medieval universities added scientific courses in astronomy, physics, and mathematics.

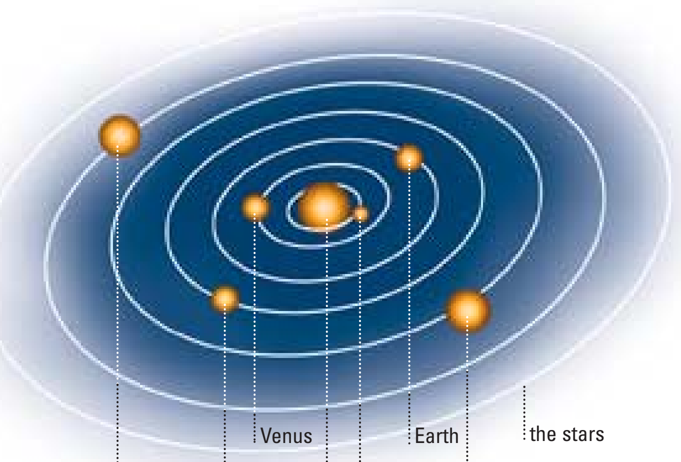
During the Renaissance, scholars uncovered many classical manuscripts. They found that the ancient authorities often did not agree with each other. Moreover, European explorers traveled to Africa, Asia, and the Americas. Such lands were inhabited by peoples and animals previously unknown in Europe. These discoveries opened Europeans to the possibility that there were new truths to be found. The invention of the printing press during this period helped spread challenging ideas—both old and new—more widely among Europe's thinkers.

The age of European exploration also fueled a great deal of scientific research, especially in astronomy and mathematics. Navigators needed better instruments and geographic measurements, for example, to determine their location in the open sea. As scientists began to look more closely at the world around them, they made observations that did not match the ancient beliefs. They found they had reached the limit of the classical world's knowledge. Yet, they still needed to know more.

## A Revolutionary Model of the Universe

The first major challenge to accepted scientific thinking came in the field of astronomy. The Scientific Revolution started when a small group of scholars began to question the geocentric theory.

This model shows how Copernicus saw the planets revolving around the sun—in perfect circles.




**The Heliocentric Theory** Although backed by authority and common sense, the geocentric theory did not accurately explain the movements of the sun, moon, and planets. This problem troubled a Polish cleric and astronomer named **Nicolaus Copernicus** (koh·PUR·nuh·kuhs). In the early 1500s, Copernicus became interested in an old Greek idea that the sun stood at the center of the universe. After studying planetary movements for more than 25 years, Copernicus reasoned that indeed, the stars, the earth, and the other planets revolved around the sun.

THINK THROUGH HISTORY
**B. Clarifying** How did Copernicus arrive at the heliocentric theory?

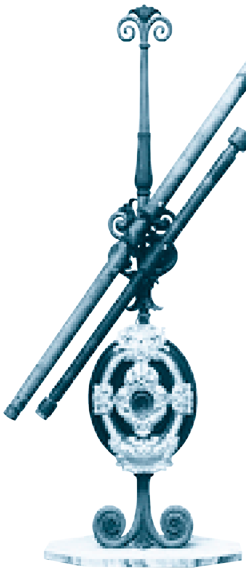
Copernicus's **heliocentric,** or sun-centered, **theory** still did not completely explain why the planets orbited the way they did. He also knew that most scholars and clergy would reject his theory because it contradicted their religious views. Fearing ridicule or persecution, Copernicus did not publish his findings until 1543, the last year of his life. He received a copy of his book, *On the Revolutions of the Heavenly Bodies,* on his deathbed.

While revolutionary, Copernicus's book caused little stir at first. Over the next century and a half, other scientists built on the foundations he had laid. A Danish astronomer, Tycho Brahe (TEE·koh brah), carefully recorded the movements of the planets for many years. Brahe produced mountains of accurate data based on his observations. However, it was left to his followers to make mathematical sense of them.

After Brahe's death in 1601, his assistant, a brilliant mathematician named **Johannes Kepler,** continued his work. After studying Brahe's data, Kepler concluded that certain mathematical laws govern planetary motion. One of these laws showed that the planets revolve around the sun in elliptical orbits instead of circles, as was previously thought. Kepler's laws showed that Copernicus's basic ideas were true. They demonstrated mathematically that the planets revolve around the sun.

THINK THROUGH HISTORY
**C. Recognizing Effects** How did Kepler's findings support the heliocentric theory?

**Galileo's Discoveries** In 1581, a 17-year-old Italian student named **Galileo Galilei** sat in a cathedral closely watching a chandelier swing on its chain. Aristotle had said that a pendulum swings at a slower rhythm as it approaches its resting place. Using his beating pulse, Galileo carefully timed the chandelier's swings. Aristotle's idea was wrong. Instead, each swing of the pendulum took exactly the same amount of time. Galileo had discovered the law of the pendulum.



Galileo used this telescope to observe the moon. He saw that the moon's surface is rough, not smooth as others thought.

In another study, Galileo found that a falling object accelerates at a fixed and predictable rate. Galileo also tested Aristotle's theory that heavy objects fall faster than lighter ones. According to legend, he dropped stones of different weights from the Leaning Tower of Pisa. He then calculated how fast each fell. Contrary to Aristotle's assumption, the objects fell at the same speed.

Later, Galileo learned that a Dutch lens maker had built an instrument that could enlarge far-off objects. Without seeing this device, Galileo successfully built his own telescope. After making some improvements, Galileo used his telescope to study the heavens in 1609.

Then in 1610, he published a series of newsletters called *Starry Messenger,* which described his astonishing observations. Galileo announced that Jupiter had four moons and that the sun had dark spots. He also noted that the earth's moon had a rough and uneven surface. His description of the moon's surface shattered Aristotle's theory that the moon and stars were made of a pure and perfect substance. Galileo's observations, as well as his laws of motion, also clearly supported the theories of Copernicus.

**Conflict with the Church** Galileo's findings frightened both Catholic and Protestant leaders because they went against church teaching and authority. If people believed the church could be wrong about this, they could question other church teachings as well.

In 1616, the Catholic Church warned Galileo not to defend the ideas of Copernicus. Although Galileo remained publicly silent, he continued his studies. Then, in 1632, he published *Dialogue Concerning the Two Chief World Systems.* This book presented the ideas of both Copernicus and Ptolemy, but it clearly showed that Galileo supported the Copernican theory. The pope angrily summoned Galileo to Rome to stand trial before the Inquisition.

Galileo stood before the court in 1633. Under the threat of torture, he knelt before the cardinals and read aloud a signed confession. In it, he agreed that the ideas of Copernicus were false.

**A VOICE FROM THE PAST**

With sincere heart and unpretended faith I abjure, curse, and detest the aforesaid errors and heresies [of Copernicus] and also every other error . . . contrary to the Holy Church, and I swear that in the future I will never again say or assert . . . anything that might cause a similar suspicion toward me.

GALILEO GALILEI, quoted in *The Discoverers*

**CONNECT *to* TODAY**

**The Vatican Clears Galileo**

In 1992, Pope John Paul II officially acknowledged that Galileo was correct in asserting that the earth revolves around the sun. His pronouncement came after a 13-year study of Galileo's case by a Vatican science panel.

The panel concluded that church leaders were clearly wrong to condemn Galileo but that they had acted in good faith. They were working within the knowledge of their time, the panel said. Therefore, they could not see how Galileo's discoveries could go along with their interpretation of the Bible.

Galileo was never again a free man. He lived under house arrest and died in 1642 at his villa near Florence. However, his books and ideas still spread all over Europe.

## The Scientific Method

The revolution in scientific thinking that Copernicus, Kepler, and Galileo began eventually developed into a new approach to science called the scientific method. The **scientific method** is a logical procedure for gathering and testing ideas. It begins with a problem or question arising from an observation. Scientists next form a hypothesis, or unproved assumption. The hypothesis is then tested in an experiment or on the basis of data. In the final step, scientists analyze and interpret their data to reach a new conclusion. That conclusion either confirms or disproves the hypothesis.

The scientific method did not develop overnight. The work of two important thinkers of the 1600s, Francis Bacon and René Descartes, helped to advance the new approach.

**Francis Bacon,** an English politician and writer, had a passionate interest in science. He believed that by better understanding the world, scientists would generate practical knowledge that would improve people's lives. In his writings, Bacon attacked medieval

## Major Steps in the Scientific Revolution

- **1520**
- **1543** Copernicus publishes heliocentric theory. Vesalius publishes human anatomy textbook.
- **1570**
- **1572** Brahe discovers nova, or bright new star, which contradicts Aristotle's idea that universe is unchanging.
- **1590** Janssen invents microscope.
- **1609** Kepler publishes first two laws of planetary motion.
- **1610** Galileo publishes *Starry Messenger.*
- **1620** Bacon's book *Novum Organum (New Instrument)* encourages experimental method.

This microscope dates from the 17th century.

Nicolaus Copernicus began the Scientific Revolution with his heliocentric theory.

scholars for relying too heavily on the conclusions of Aristotle and other ancient thinkers. He also criticized the way in which both Aristotle and medieval scholars arrived at their conclusions. They had reasoned from abstract theories. Instead, he urged scientists to experiment. Scientists, he wrote, should observe the world and gather information about it first. Then they should draw conclusions from that information. This approach is called empiricism, or the experimental method.

In France, **René Descartes** (day·KAHRT) also took a keen interest in science. He developed analytical geometry, which linked algebra and geometry. This provided an important new tool for scientific research.

Like Bacon, Descartes believed that scientists needed to reject old assumptions and teachings. As a mathematician, however, his approach to gaining knowledge differed from Bacon's. Rather than using experimentation, Descartes relied on mathematics and logic. He believed that everything should be doubted until proved by reason. The only thing he knew for certain was that he existed—because, as he wrote, "I think, therefore I am." From this starting point, he followed a train of strict reasoning to arrive at other basic truths.

THINK THROUGH HISTORY
**D. Contrasting** How did Descartes's approach to science differ from Bacon's?

Modern scientific methods are based on the ideas of Bacon and Descartes. Scientists have shown that observation and experimentation, together with general laws that can be expressed mathematically, can lead people to a better understanding of the natural world.

### Changing Idea: Scientific Method

**Old Science**
Scholars generally relied on ancient authorities, church teachings, common sense, and reasoning to explain the physical world.

**New Science**
In time, scholars began to use observation, experimentation, and scientific reasoning to gather knowledge and draw conclusions about the physical world.

## Newton Explains the Law of Gravity

By the mid-1600s, the accomplishments of Copernicus, Kepler, and Galileo had shattered the old views of astronomy and physics. Later, the great English scientist **Isaac Newton** helped to bring together their breakthroughs under a single theory of motion.

Newton studied mathematics and physics at Cambridge University. By the time he was 24, Newton was certain that all physical objects were affected equally by the same forces. Kepler had worked out laws for a planet's motion around the sun. Galileo had studied the motion of pendulums. Newton's great discovery was that the same force ruled the motions of the planets, the pendulum, and all matter on earth and in space.

**1620** **1670** **1720**

**1628** Harvey reveals how human heart functions.

**1633** Galileo faces Inquisition for support of Copernicus's theory.

**1637** Descartes's book *Discourse on Method* sets forth his scientific method of reasoning from the basis of doubt.

**1643** Torricelli invents barometer.

**1660** England establishes Royal Society to support scientific study.

**1662** Boyle discovers mathematical relationship between the pressure and volume of gases, known as Boyle's law.

**1666** France establishes Academy of Sciences.

**1674** Leeuwenhoek observes bacteria through microscope.

**1687** Newton publishes law of gravity.

**1714** Fahrenheit invents mercury thermometer.

**Isaac Newton's law of gravity explained how the same physical laws governed motion both on the earth and in the heavens.**

He disproved the idea of Aristotle that one set of physical laws governed earth and another set governed the rest of the universe.

The key idea that linked motion in the heavens with motion on the earth was the law of universal gravitation. According to this law, every object in the universe attracts every other object. The degree of attraction depends on the mass of the objects and the distance between them.

THINK THROUGH HISTORY
**E. Clarifying** Why was the law of gravitation important?

In 1687, Newton published his ideas in a work called *Mathematical Principles of Natural Philosophy*—one of the most important scientific books ever written. The universe he described was like a giant clock. Its parts all worked together perfectly in ways that could be expressed mathematically. Newton believed that God was the creator of this orderly universe, the clockmaker who had set everything in motion.

## The Scientific Revolution Spreads

After astronomers explored the secrets of the universe, other scientists began to study the secrets of nature on earth. Careful observation and the use of the scientific method eventually became important in many different fields.

**Scientific Instruments** Scientists developed new tools and instruments to make the precise observations that the scientific method demanded. The first microscope was invented by a Dutch maker of eyeglasses, Zacharias Janssen (YAHN•suhn), in 1590. In the 1670s, a Dutch drapery merchant and amateur scientist named Anton van Leeuwenhoek (LAY•vuhn•HUK) used a microscope to observe bacteria swimming in tooth scrapings. He also saw red blood cells for the first time. His examination of grubs, maggots, and other such organisms showed that they did not come to life spontaneously, as was previously thought. Rather, they were immature insects.

In 1643, one of Galileo's students, Evangelista Torricelli (TAWR•uh•CHEHL•ee), developed the first mercury barometer, a tool for measuring atmospheric pressure and predicting weather. In 1714, the Dutch physicist Gabriel Fahrenheit (FAR•uhn•HYT) made the first thermometer to use mercury in glass. Fahrenheit's thermometer showed water freezing at 32°. A Swedish astronomer, Anders Celsius (SEHL•see•uhs), created another scale for the mercury thermometer in 1742. Celsius's scale showed freezing at 0°.

**Medicine and the Human Body** During the Middle Ages, European doctors had accepted as fact the writings of an ancient Greek physician named Galen. However, Galen had never dissected the body of a human being. Instead, he had studied the anatomy of pigs and other animals. Galen assumed that human anatomy was much the same. Galen's assumptions were proved wrong by Andreas Vesalius, a Flemish physician. Vesalius dissected human corpses (despite disapproval of this practice) and published his observations. His book, *On the Fabric of the Human Body* (1543), was filled with detailed drawings of human organs, bones, and muscle.

An English doctor named William Harvey continued Vesalius's work in anatomy. In 1628, he published *On the Motion of the Heart and Blood in Animals,* which showed that the heart acted as a pump to circulate blood throughout the body. He also described the function of blood vessels.

In the late 1700s, British physician Edward Jenner introduced a vaccine to prevent smallpox. Inoculation using live smallpox germs had been practiced in Asia for centuries. While beneficial, this technique was also dangerous. Jenner discovered that inoculation with germs from a cattle disease called cowpox gave permanent protection from smallpox for humans. Because cowpox was a much milder disease, the risks for this form of inoculation were much lower. Jenner used cowpox to produce the world's first vaccination.

**Vocabulary**
**inoculation:** injecting a germ into a person's body so as to create an immunity to the disease.

**Discoveries in Chemistry** Robert Boyle pioneered the use of the scientific method in chemistry. He is considered the founder of modern chemistry. In a book called *The Sceptical Chymist* (1661), Boyle challenged Aristotle's idea that the physical world consisted of four elements—earth, air, fire, and water. Instead, Boyle proposed that matter was made up of smaller primary particles that joined together in different ways. Boyle's most famous contribution to chemistry is Boyle's law. This law explains how the volume, temperature, and pressure of gas affect each other.

Another chemist, Joseph Priestley, separated one pure gas from air in 1774. He noticed how good he felt after breathing this special air and watched how alert two mice were while breathing it. Wrote Priestley, "Who can tell but that, in time, this pure air may become a fashionable article of luxury? Hitherto only two mice and I have had the privilege of breathing it." Meanwhile, in France, Antoine Lavoisier (lah·vwah·ZYAY) was performing similar experiments. In 1779, Lavoisier named the newly discovered gas oxygen.

Other scholars and philosophers applied a scientific approach to other areas of life. Believing themselves to be orderly, rational, and industrious, they thought of themselves as enlightened. They would become the leaders of a new intellectual and social movement called the Enlightenment.

## Daily *Life*

### Smallpox Inoculations

In the 1600s and 1700s, few words raised as much dread as *smallpox.* This contagious disease killed many infants and young children and left others horribly scarred.

In the early 1700s, an English writer named Lady Mary Wortley Montagu observed women in Turkey deliberately inoculating their young children against smallpox. They did this by breaking the skin and applying some liquid taken from the sore of a victim.

Children who were inoculated caught smallpox, but they had a good chance of getting only a mild case. This protected them from ever having the disease again.

Lady Montagu bravely had her son inoculated. She brought the procedure back to Britain, and from there it spread all over Europe.

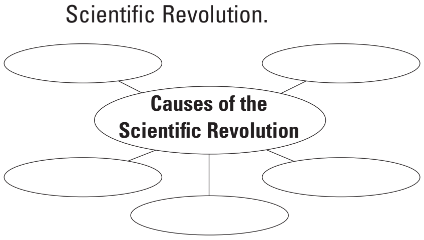
## Section 1 Assessment

**1. TERMS & NAMES**

*Identify*
- Scientific Revolution
- Nicolaus Copernicus
- heliocentric theory
- Johannes Kepler
- Galileo Galilei
- scientific method
- Francis Bacon
- René Descartes
- Isaac Newton

**2. TAKING NOTES**

Use a web diagram such as the one below to show the events and circumstances that led to the Scientific Revolution.




**3. DRAWING CONCLUSIONS**

"If I have seen farther than others," said Newton, "it is because I have stood on the shoulders of giants." Who were the giants to whom Newton was referring? Could this be said of any scientific accomplishment? Explain.

**4. THEME ACTIVITY**

**Science & Technology** Working in groups of three or four, create a Scientific Revolution Discovery Board. Use these categories: Astronomy, Science, Medicine, Chemistry, Biology. Include important people, ideas, accomplishments.