CHAPTER 34

Scientific inventions helped humans better understand the world around them.

The Scientific Revolution

34.1 Introduction

In the last chapter, you read about the Age of Exploration. You learned that voyages of discovery changed how Europeans saw the world. Now you will learn about another major shift in thinking, the **Scientific Revolution**.

Between 1500 and 1700, modern science emerged as a new way of gaining knowledge about the natural world. Before this time, Europeans relied on two main sources for their understanding of nature. One was the Bible. The other was the work of classical thinkers, especially the philosopher Aristotle.

During the Scientific Revolution, scientists challenged traditional teachings about nature. They asked fresh questions, and they answered them in new ways. Inventions like the telescope showed them a universe no one had imagined before. Careful observation also revealed errors in accepted ideas about the physical world.

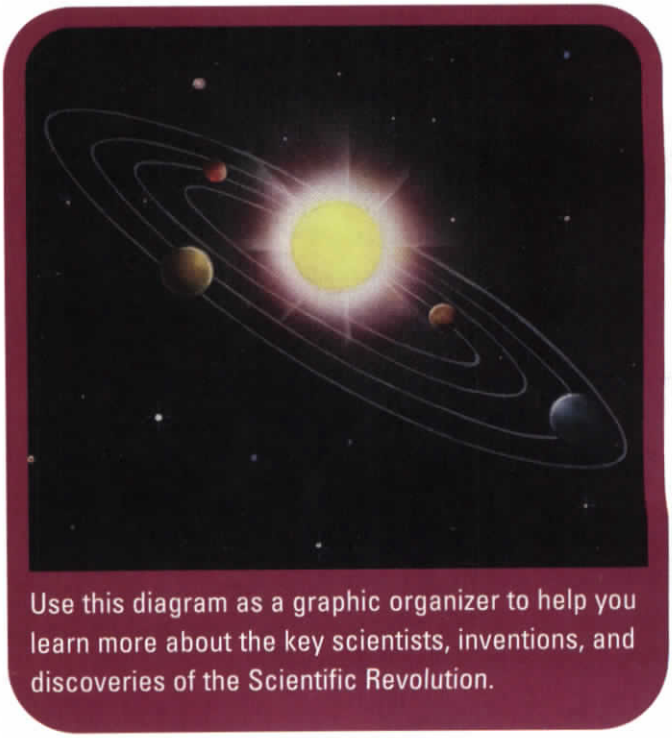
A good example is Aristotle's description of falling objects. Aristotle had said that heavier objects fall to the ground faster than lighter ones. This idea seemed logical, but the Italian scientist Galileo Galilei questioned it.

According to his first biographer, one day Galileo performed a demonstration in the city of Pisa, where he was teaching. He dropped two balls of different weights from the city's famous Leaning Tower.

The results shocked the watching crowd of students and professors. They expected the heavier ball to land first. Instead, the two balls landed at the same time.

Galileo's demonstration is an example of the **scientific method**. As you will learn, the scientific method uses both logic and observation to help people find out how the natural world works.

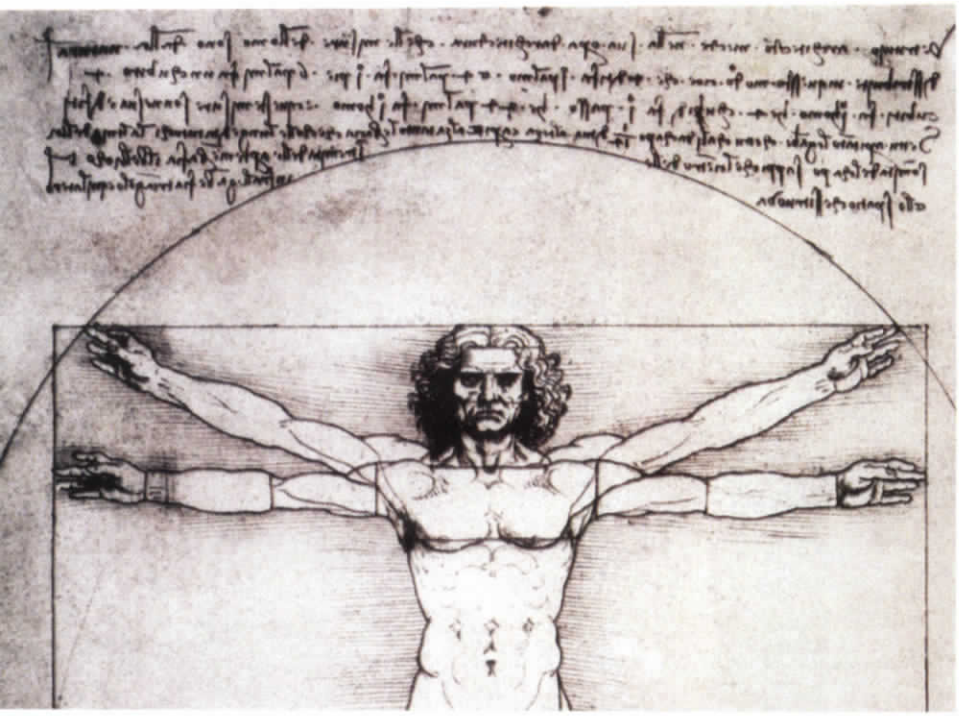
The work of thinkers like Galileo gave birth to modern science. In this chapter, you will first learn about the roots of the Scientific Revolution. Then you'll meet some of the key **scientists** of this period. You'll find out about their major **discoveries** and **inventions**. You'll also learn how their work gave rise to the scientific method.



Use this diagram as a graphic organizer to help you learn more about the key scientists, inventions, and discoveries of the Scientific Revolution.

34.2 Roots of the Scientific Revolution

Humans have asked questions about nature since ancient times. What was different about the Scientific Revolution of the 16th and 17th centuries? And what factors helped to bring it about?



Humanist studies from the Renaissance influenced later scientific discoveries. Da Vinci's drawing *Vitruvian Man* (detail) is a famous study of the human body from this period.

During the Middle Ages, two major sources guided most Europeans' thinking about the natural world. The first was the Bible. For Christians, the Bible was the word of God. Whatever the Bible seemed to say about nature, then, must be true.

The second source was the teachings of Aristotle. This Greek philosopher had written about nature in the 300s B.C.E. In the late Middle Ages, thinkers like Thomas Aquinas combined Aristotle's thinking with Christian faith. The result was a view of the world that seemed to be a satisfying whole.

During the Renaissance, many thinkers began to question this worldview. As you have learned, Renaissance scholars rediscovered more of the culture of ancient Greece and Rome. A number of ancient texts came to Europe by way of Muslim lands, where they had been preserved during the Middle Ages. Arab, Christian, and Jewish scholars in the Muslim world translated many classical works. They also made advances of their own in such fields as medicine, astronomy, and mathematics.

rationalism belief in reason and logic as the primary source of knowledge

From the works of these scholars, Europeans learned about a greater variety of ideas than just those of Aristotle. Many thinkers were influenced by Greek **rationalism**. This was the belief that reason (logical thought) could be used to discover basic truths about the world. Renaissance thinkers also observed nature for themselves. You may remember how Vesalius cut up corpses to test ancient ideas about the body. Trust in reason and observation became a key part of modern science.

The voyages of explorers also helped spur the growth of science. For instance, in the second century C.E., Ptolemy had stated that there were only three continents: Europe, Africa, and Asia. Explorers who visited the Americas proved that he was wrong. Such discoveries encouraged Europeans to question traditional teachings.

Gradually, scientists developed a new method for probing nature's mysteries. As you will see, their work led to many dramatic discoveries.

34.3 Copernicus and Kepler: A New View of the Universe

The Scientific Revolution began with the work of Polish astronomer Nicolaus Copernicus. You met Copernicus when you read about the Renaissance. Let's see how his work led to a new view of the universe.

For almost 2,000 years, most people believed that Earth was the center of the universe. According to this **geocentric** theory, the sun, stars, and planets traveled around a motionless Earth.

Aristotle had taught this theory. The Bible seemed to support it as well. For example, in one Bible story God stops the sun from moving across the sky. The geocentric theory also seemed to make sense. After all, the sun and stars do look like they travel around Earth.

Aristotle had also taught that all heavenly bodies move in circles. Unfortunately, this belief made it hard to explain the observed movements of planets such as Mars and Jupiter. In the second century C.E., Ptolemy created a complicated theory to account for these observations.

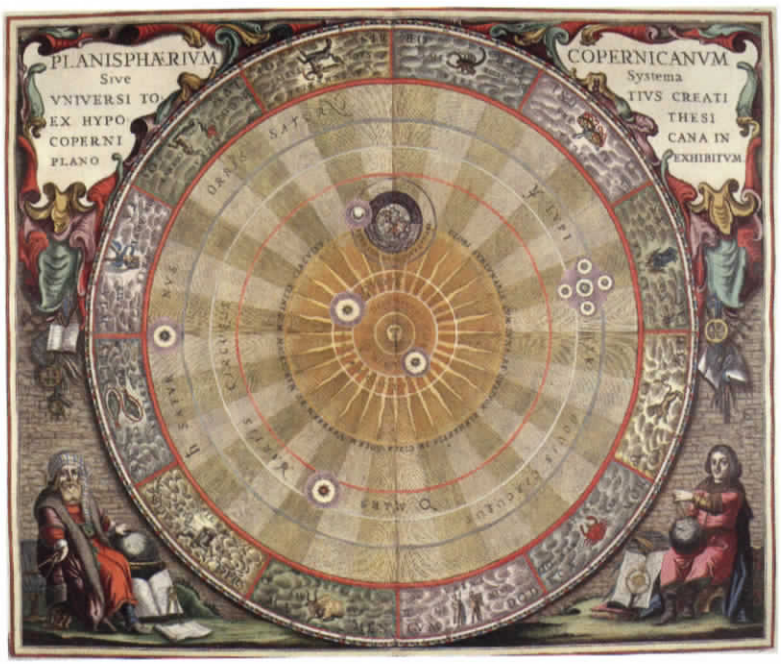
Both ancient and medieval writers, including Muslim scientists, pointed out problems with Ptolemy's theory. In the early 1500s, Copernicus tackled these problems. Using observations and mathematics, he proposed a very different idea. His **heliocentric** theory put the sun at the center of the universe. Earth and the other planets, he said, traveled in circles around the sun. Earth also turned on its own axis every 24 hours. This turning explained why heavenly objects seemed to move across the sky.

Like Ptolemy, Copernicus had trouble predicting the movement of planets with perfect accuracy. Still, he thought his theory was simpler and more satisfying than Ptolemy's. In 1543, he published a book describing his idea. The book convinced very few people. Some church officials and scientists attacked it.

Then, in the early 1600s, German scientist Johannes Kepler improved on Copernicus's theory. After studying detailed records of planetary observations, Kepler figured out that the **orbits** (paths) of the planets were ellipses (ovals), not circles. With this insight, he wrote precise mathematical laws describing the movements of the planets around the sun.

Kepler's laws agreed beautifully with actual observations. This agreement was evidence that the Copernican theory was correct. Once the theory took hold, people would never see the universe in the same way again.

geocentric having Earth at the center (*Geo* is Greek for "Earth.")
heliocentric having the sun at the center (*Helios* is Greek for "sun.")
orbit the path that one heavenly body (such as a planet) follows around another (such as the sun)



Copernicus's heliocentric theory put the sun at the center of the universe. Before this, people thought all planets revolved around Earth.

34.4 Galileo and the Copernican Theory

Galileo lived at the same time as Johannes Kepler. Galileo explored many questions. He was especially interested in problems of motion. As you have read, he disproved Aristotle's theory that heavy objects fall faster than lighter ones. He made other discoveries about motion as well. For example, he used mathematics to describe the paths of **projectiles**.

projectile an object that is fired or launched, such as a cannonball

Galileo's biggest impact came when he turned his curiosity to the heavens. What he learned made him a champion of the Copernican theory.

Galileo's Discoveries In 1609, Galileo was teaching in Padua, Italy, when he heard about an invention from the Netherlands: the telescope. The telescope used glass lenses to make distant objects appear much closer.

Galileo decided to build his own telescope. He figured out how telescopes worked. He learned how to grind glass. Soon he was building more and more powerful telescopes.

That fall, Galileo began studying the heavens through a telescope. He saw things no one had seen before. He saw that the moon's surface was rough and uneven. He discovered four moons revolving around the planet Jupiter.

Galileo also observed the planet Venus. To the naked eye, Venus looks like a bright star. Galileo saw something new. You know from looking at the moon that it goes through phases. It takes on what appear to be different shapes, from a thin sliver to the full moon. With his telescope, Galileo could see that Venus also passed through phases. Sometimes it was brightly lit. At other times it was partially dark.

Galileo's work with telescopes helped him discover new information about the planets that supported Copernicus's theories about the universe.

Galileo's discoveries contradicted the traditional view of the universe. For example, Aristotle had taught that the moon was perfectly smooth. Galileo saw that it wasn't. Aristotle had said that Earth was the only center of motion in the universe. Galileo saw moons going around Jupiter. Aristotle believed that Venus and other planets traveled around Earth. Galileo realized that the phases of Venus meant that it was traveling around the sun. As seen from Earth, sometimes only part of Venus was lit by the sun.

Galileo already believed in the Copernican theory of the universe. What he saw through his telescope only convinced him more.

Galileo was brought before the Inquisition, Rome's court, because his new beliefs were unacceptable to the church. Church officials demanded that he agree that Earth is at the center of the universe.

Conflict with the Church Galileo's discoveries led him into a bitter conflict with the Catholic Church. Church leaders saw the Copernican theory as both wrong and dangerous. To them, the idea that Earth was the center of the universe was part of an entire system of belief approved by the church. Church officials feared that attacks on the geocentric theory could lead people to doubt the church's teachings. In 1616, the church warned Galileo not to teach the Copernican theory.

Galileo refused to be silenced. In 1632, he published a book called *Dialogue on the Two Chief World Systems*. The book described an imaginary conversation about the theories of Ptolemy and Copernicus. Galileo did not openly take sides, but the book was really a clever argument for the Copernican theory. The character who upheld the geocentric theory was portrayed as foolish. The one who believed the heliocentric theory was logical and convincing.

Galileo's *Dialogue* caused an uproar. In 1633, the pope called Galileo to Rome to face the church court known as the Inquisition.

At Galileo's trial, church leaders accused him of heresy. They demanded that he confess his error. At first Galileo resisted. In the end, the court forced him to swear that the geocentric theory was true. He was forbidden to write again about the Copernican theory.

Galileo's Influence The church's opposition could not stop the spread of Galileo's ideas. Scientists all over Europe read his witty *Dialogue*. The book helped convert many people to the Copernican theory. The Inquisition ordered the burning of the *Dialogue*.

Galileo's studies of motion also advanced the Scientific Revolution. Like Kepler, he used observation and mathematics to solve scientific problems. Galileo's theory of motion described how objects moved on Earth. Kepler's laws described the movements of the planets. The next scientist you will meet united these ideas in a single great theory.

34.5 Isaac Newton and the Law of Gravity

Isaac Newton was born in 1642, the same year Galileo died. Newton became a brilliant scientist and mathematician. His greatest discovery was the law of gravity.

In later life, Newton told a story about his discovery. He was trying to figure out what kept the moon traveling in its orbit around Earth. Since the moon was in motion, why didn't it fly off into space in a straight line? Then Newton saw an apple fall from a tree. He wondered if the same force that pulled the apple to the ground was tugging on the moon. The difference was that the moon was far away, and Newton reasoned that the force was weaker there. It was just strong enough to bend the moon's motion into a nearly circular path around Earth.

Inspiration for new ideas and discoveries often comes when the ordinary is seen in a new way. Isaac Newton gained insight into the laws of nature after observing an apple fall to the ground.

This was Newton's great insight. A single force explained a falling apple on Earth and the movements of heavenly bodies as well. Newton called this force *gravity*.

Newton stated the law of gravity in a simple formula. All physical objects, he said, had a force of attraction between them. The strength of the force depended on the **masses** of the objects and the distance between them. For example, the moon and Earth tugged on each other. At a certain point in space, these "tugs" canceled each other out. The result was that the moon was trapped in its orbit around Earth. In contrast, an apple had a small mass and was very close to Earth, so gravity dragged it to the ground.

mass the amount of matter in an object

In 1687, Newton published a book known as the *Principia* (Principles). The book presented the law of gravity. It also described three laws of motion. Newton's laws provided a physical explanation for what earlier scientists had discovered. For example, others had shown that the planets moved around the sun. Newton's laws explained why. Just as gravity kept the moon traveling around Earth, it kept the planets traveling around the sun.

Newton's laws dramatically changed people's picture of the universe. Many people began to see the universe as a beautifully designed machine. Some compared it to a well-built clock. The same mathematical laws applied everywhere. All people had to do was discover them.

34.6 The Scientific Method

A key outcome of the Scientific Revolution was the development of the scientific method. Two philosophers who influenced this development were Francis Bacon and Rene Descartes.

Francis Bacon was born in England in 1561. Bacon distrusted much of the traditional learning of the Middle Ages. He said people could gain knowledge only if they rid their minds of false beliefs. He outlined a method of scientific investigation that depended on close observation.

Rene Descartes was born in France in 1596. Descartes prized logic and mathematics. To gain knowledge that was certain, he said, people should doubt every statement until logic proved it to be true. Descartes also saw the physical universe as obeying universal mathematical laws.

These ideas helped create a new approach to science. Over time, scientists developed this approach into the scientific method.

The scientific method combines logic, mathematics, and observation. It has five basic steps:

1. The scientist states a question or problem.
2. The scientist forms a **hypothesis,** or assumption, about the problem.
3. The scientist designs and conducts an experiment to test the hypothesis.
4. The scientist measures the **data,** or information, produced by the experiment and records the results.
5. The scientist analyzes the data to determine whether the hypothesis is correct.

Galileo's demonstration with falling objects shows how this method works. Galileo wondered whether objects of different weights fall at the same speed. He formed a hypothesis that they did. Then he designed and conducted an experiment. He dropped a heavy and a light ball from a tower and saw that they landed at the same time. This result showed that his hypothesis was correct.

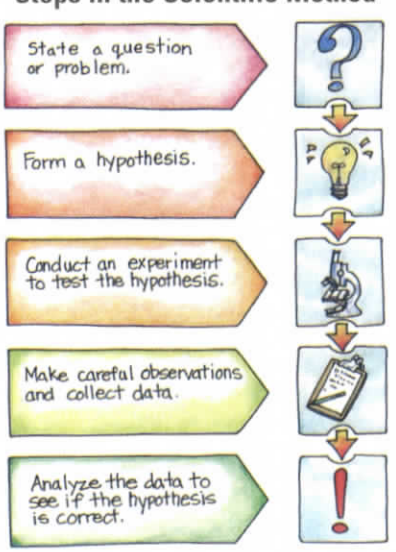
Scientists still use this basic method today. An advantage of the method is that any trained scientist can repeat what another has done. In this way, scientists can test others' ideas for themselves.

In one way, the spread of the scientific method marked a break with the past. Fewer and fewer people looked to traditional authorities for the answers to scientific problems. But that did not mean they discarded all their old beliefs. For example, thinkers such as Descartes and Newton were deeply religious. For many, science was a way to better understand the world God had made.

Galileo tested his hypotheses about gravity by dropping two different-size balls from the top of the Leaning Tower of Pisa.

hypothesis an idea or assumption to be tested in an experiment
data facts or information

Steps in the Scientific Method



Antonie van Leeuwenhoek observed microorganisms through microscopes that he designed.

34.7 Key Inventions

The Scientific Revolution spurred the invention of new tools for studying nature. These tools helped scientists discover new facts and measure data more accurately.

One example of such a tool is the telescope, which makes distant objects seem closer. A similar invention was the **microscope,** which makes small objects appear much larger.

The microscope was invented by Dutch lens makers in the late 1500s. In the mid 1600s, the Dutchman Antonie van Leeuwenhoek designed his own powerful microscopes. He became the first person to see bacteria. Leeuwenhoek was amazed to find a tiny world of living things. He exclaimed, "All the people living in our United Netherlands are not so many as the living animals that I carry in my own mouth this very day!"

Another important tool was the **barometer**. A barometer measures changes in the pressure of the atmosphere. Evangelista Torricelli invented the barometer in the 1640s. Torricelli filled a glass tube with a heavy liquid called *mercury*. Then he placed the tube upside down in a dish.

Over the next few days, Torricelli watched the tube. He saw that the height of the mercury did not stay the same. The column of mercury moved up and down as the pressure in the atmosphere changed. The barometer soon proved to be a valuable tool in studying and predicting the weather.

microscope an instrument that uses lenses to make small objects appear larger

barometer an instrument used for measuring changes in the pressure of the atmosphere

thermometer an instrument used for measuring temperature

Galileo likely made the first **thermometer**. In the early 1700s, a German scientist, Daniel Gabriel Fahrenheit, made thermometers more accurate. He put mercury in a glass tube. As the mercury grew warmer, it expanded and rose up the tube. The height of the mercury provided a measure of temperature. Fahrenheit also designed a new temperature scale. In the United States, we still measure temperature using Fahrenheit degrees.

With new tools and the scientific method, scientists made rapid advances in their understanding of nature. Their work had many practical results, such as the invention of the steam engine. As new technologies developed, Europeans used them to become the commercial and industrial leaders of the world. Science is one of the most powerful forces shaping our world today.

34.8 Chapter Summary

In this chapter, you learned about the Scientific Revolution. This movement marked a major shift in the way people thought about the natural world.

Several factors contributed to the Scientific Revolution. Renaissance thinkers questioned traditional learning and observed nature for themselves. Translations of classical texts exposed scholars to new ideas. Discoveries by explorers showed that accepted ideas could be wrong.

The Scientific Revolution began when Copernicus proposed the daring idea that Earth and the other planets traveled around the sun. Kepler built on this work by correctly describing the planets' orbits. Galileo's discoveries supported the Copernican theory.

Newton took all this work a giant step forward. His law of gravity explained why planets orbited the sun. Newton also showed that the same laws applied everywhere in the known universe.

The ideas of Bacon and Descartes helped to shape the scientific method, which proved to be a powerful way of testing ideas about nature. New tools like the microscope and the thermometer also aided scientific progress.

Europeans were dazzled by rapid advances in science. Many were inspired to take a similar approach to problems of human life and society. You'll learn about these thinkers in the next chapter.

Today's high-powered microscopes are based on the first designs from the 1600s. Scientific research would not be possible without such inventions.