NAME _____ DATE _____ CLASS _____

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The Enlightenment and Revolutions, 1550–1800

Lesson 1 The Scientific Revolution

ESSENTIAL QUESTIONS

Why do new ideas often spark change? How do new ways of thinking affect the way people respond to their surroundings?

Reading HELPDESK

Academic Vocabulary

philosopher a person who seeks wisdom or enlightenment; a scholar or a thinker

sphere in ancient astronomy, any of the concentric, revolving, spherical transparent shells in which the stars, sun, planets, and moon are set

Content Vocabulary

geocentric Earth-centered; a system of planetary motion in which the sun, moon, and other planets revolve around the Earth

heliocentric sun-centered; the system of the universe in which the Earth and planets revolve around the sun

universal law of gravitation one of Newton's three rules of motion; it explains that planetary bodies continue in elliptical orbits around the sun because every object in the universe is attracted to every other object by a force called gravity.

rationalism a system of thought expounded by René Descartes based on the belief that reason is the chief source of knowledge

scientific method a systematic procedure for collecting and analyzing evidence that was crucial to the evolution of science in the modern world

inductive reasoning the doctrine that scientists should proceed from the particular to the general by making systematic observations and carefully organized experiments to test hypotheses or theories, a process that will lead to correct general principles

empiricism the theory that says knowledge is achieved through observation

TAKING NOTES: *Summarizing*

ACTIVITY Use a table like this one to list the contributions of Copernicus, Kepler, Galileo, and Newton to a new concept of the universe.

Copernicus	
Kepler	
Galileo	
Newton	

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IT MATTERS BECAUSE

Of all the changes that occurred in Europe during the sixteenth and seventeenth centuries, the one that most influenced the world was the Scientific Revolution. The Scientific Revolution did not just bring major scientific and technical changes. It also changed how Europeans looked at themselves and their world.

Causes of the Scientific Revolution

Guiding Question *What developments were the foundation of the Scientific Revolution?*

In the Middle Ages, many educated Europeans took great interest in the world around them. However, these "natural philosophers"—the name for medieval scientists—did not observe the natural world. Instead, they relied on a few ancient authorities for their scientific knowledge. They especially relied on the teachings of Aristotle, the ancient Greek thinker (384–322 B.C.). Aristotle had developed basic ideas about science. During the fifteenth and sixteenth centuries, changes occurred that caused the natural philosophers to abandon their old ways of viewing the world.

At the time of the Renaissance, some works by the ancient writers were rediscovered. Renaissance humanists, scholars who studied the classics (Greek and Roman texts), had mastered Greek as well as Latin. These language skills allowed them to read newly discovered works by the ancient Greek writers Archimedes and Plato. The works made it clear that some ancient thinkers had disagreed with Aristotle and with other authorities whose ideas were accepted during the Middle Ages.

Other developments also encouraged new ways of thinking. Careful observation and accurate measurements were required to solve technical problems. For example, people at the time needed to know the amount of weight that ships could hold. The search for answers to practical questions like that helped to encourage scientific study. The invention of new instruments, such as the telescope and microscope, made fresh scientific discoveries possible. Above all, the printing press helped spread new ideas quickly and easily.

Mathematics played a key role in the scientific achievements of the sixteenth and seventeenth centuries. During the Renaissance, the ancient mathematicians had been rediscovered, so a new interest in mathematics developed. Mathematics was also seen as the key to new developments in navigation, military science, and geography.

Renaissance thinkers also believed that mathematics was the key to understanding the nature of things in the universe. Nicolaus Copernicus, Johannes Kepler, Galileo Galilei, and Isaac Newton were all great mathematicians who believed that the secrets of nature were written in the language of mathematics. They studied the ideas of the ancient mathematicians. Then these intellectuals sometimes abandoned the old ideas and developed new theories. Their theories became the foundation of the Scientific Revolution.

Reading Progress Check

Drawing Conclusions Why might new inventions such as the telescope and microscope change the way people saw the world?

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Scientific Breakthroughs

Guiding Question *What role did scientific breakthroughs play during the Scientific Revolution? What obstacles did participants in the Scientific Revolution face?*

During the Scientific Revolution there were discoveries in astronomy. These discoveries led to a new idea of the universe. Breakthroughs advanced medical knowledge. A new field called chemistry also started at this time.

The Ptolemaic System

Ptolemy lived in the A.D. 100s. He was the greatest astronomer of antiquity. **Philosophers** of the Middle Ages used the ideas of Ptolemy and those of Aristotle and Christianity to create a model of the universe. The model was later called the Ptolemaic (tah•luh•MAY•ihk) system. This system is **geocentric** because it places Earth at the center of the universe.

In the Ptolemaic system, the universe is seen as a series of concentric **spheres**. *Concentric* means that one sphere is inside the next, which is inside the next, and so on. Earth is fixed, or motionless, at the center of these spheres (round objects). The heavenly bodies are pure orbs, or spheres, of light. They are inside the crystal-like, transparent spheres that rotate, or turn, around Earth. The moon is in the first sphere, Mercury in the second, Venus in the third, and the sun in the fourth. The rotation of the spheres makes these heavenly bodies rotate around Earth and move in relation to one another.

The tenth sphere in the Ptolemaic system is the "prime mover." This sphere moves itself and gives motion to the other spheres. Heaven is beyond the tenth sphere and is where God lives. Therefore, in the Ptolemaic system, God was at one end of the universe, and humans were at the center.

Copernicus and Kepler

Nicolaus Copernicus was a Polish mathematician. In May 1543 Copernicus published *On the Revolutions of the Heavenly Spheres*. He argued that the planets revolved, or turned, around the sun and that the sun, not Earth, was at the center of the universe. He also stated that the moon revolved around Earth. Copernicus thought that his **heliocentric**, or sun-centered, idea about the universe was more accurate than the Ptolemaic system was. Copernicus explained that it only looked as if the sun moved around Earth. It appeared this way because of Earth's rotation on its axis and its journey around the sun.

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Johannes Kepler was a German mathematician. He took the next step in destroying the Ptolemaic system. Kepler used detailed astronomical data to arrive at his laws of how planets move. Kepler confirmed that the sun was at the center of the universe. Kepler also stated that some of the ideas of Copernicus were wrong. He showed that the planets' orbits around the sun were elliptical, or egg-shaped, and not in the shape of a circle. Kepler also showed that the sun was toward the end of this ellipse instead of at the center. This finding was known as Kepler's First Law. It also contradicted the idea of crystal-like spheres, which was important in the Ptolemaic system.

Galileo's Discoveries

Scientists could now think in terms of planets revolving around the sun in elliptical orbits. Important questions still had no answers, however. What are the planets made of? How does one explain motion in the universe? An Italian scientist answered the first question.

Galileo Galilei taught mathematics. He was the first European to make regular observations using a telescope. With this tool, Galileo made a remarkable series of discoveries. He found mountains on Earth's moon, four moons revolving around Jupiter, and sunspots.

Galileo's observations seemed to destroy yet another idea in the Ptolemaic system. Heavenly bodies had been seen as pure orbs, or spheres, of light. They now appeared to be made of material substance, just as Earth was.

Galileo's discoveries were published in *The Starry Messenger* in 1610. They did more to make Europeans aware of the new view of the universe than did the works of Copernicus and Kepler. Galileo gained fame, but he also found himself under questioning from the Catholic Church. The Church ordered him to stop his defense of the Copernican system, which challenged the Church's traditional view of the universe. In the Copernican view, humans were no longer at the center of the universe, and God was no longer in a specific place.

By the 1630s and 1640s, most astronomers had accepted the heliocentric model of the universe, even in the face of the Church's opposition. However, motion in the universe had not been explained. The ideas of Copernicus, Kepler, and Galileo were not yet tied together. An Englishman named Isaac Newton would make this connection. Newton is considered the greatest genius of the Scientific Revolution.

Newton's View of the Universe

Isaac Newton was born in 1642. He attended Cambridge University and later became a professor of mathematics there. His major work was *Mathematical Principles of Natural Philosophy*. This work is known simply as the *Principia*, which is a shortened form of its Latin title.

In his *Principia*, Newton defined the three laws of motion that govern, or control, planets, as well as objects on Earth. The **universal law of gravitation** was a key to his whole argument. This law explains why the planets continue their elliptical orbits around the sun. The law states that every object in the universe is attracted to every other object by a force called gravity. This law, which is stated in mathematical terms, could also be proved with mathematics to explain all motion in the universe.

At the same time, Newton's ideas created a new picture of the universe. In this picture, the physical world and everything in it were like a giant machine that worked according to natural laws. Newton's world-machine idea was a central part of the modern worldview until the twentieth century. At that time, Albert Einstein's concept of relativity would give a new picture of the universe.

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Breakthroughs in Medicine and Chemistry

Galen was a Greek physician in the A.D. 100s. His ideas dominated medicine in the Late Middle Ages. Galen relied on animal, rather than human, dissection to describe human anatomy. For that reason, Galen's ideas about the human body were wrong in many instances.

A revolution in medicine began in the sixteenth century. During this time, Andreas Vesalius and William Harvey added to the understanding of human anatomy. Vesalius dissected human bodies at the University of Padua, in Italy. By doing this he accurately described the organs and general structure of the human body. Harvey showed that Galen was wrong to say that the liver was where blood circulation began. Harvey showed that the heart was the beginning point for the circulation of blood. He also proved that the same blood flows through the veins and arteries and makes a complete circuit through the body.

The French scientist Blaise Pascal experimented with how liquids behaved under pressure. This led him to the principle known as Pascal's Law. He applied this principle to the development of tools such as the syringe and the hydraulic press.

Robert Boyle was one of the first scientists to conduct controlled experiments in chemistry. His work on the properties of gases led to Boyle's Law. This law states that the volume of a gas varies with the pressure put on it. Antoine Lavoisier was considered the founder of modern chemistry. In the eighteenth century, he invented a system for naming chemical elements that is still used today.

Women's Contributions

At the time of the Scientific Revolution, scholarship was thought of as men's work. Yet, women also contributed to the Scientific Revolution. Margaret Cavendish, a philosopher, and Maria Winkelmann, an astronomer, helped advance science through their work.

Margaret Cavendish was one of the most important female scientists of the seventeenth century. She came from an English aristocratic family and was taught at home. Cavendish studied music, dancing, reading, and needlework. These subjects were considered suitable for a proper education for girls. As a result, she was not formally educated in the sciences. However, Cavendish wrote a number of works on scientific matters, including *Observations Upon Experimental Philosophy*. In it, she criticized the idea that humans, through science, can control nature.

Cavendish published under her own name at a time when many female writers had to publish anonymously. Her contribution to philosophy is widely recognized today. In her own time, however, many intellectuals did not take her work seriously.

In Germany, many of the women who were involved in science were astronomers. These women had received the opportunity to become astronomers from working in family observatories where their fathers or husbands trained them. Between 1650 and 1710, women made up 14 percent of all German astronomers.

The most famous of the female astronomers in Germany was Maria Winkelmann. She received training in astronomy from a self-taught astronomer. When she married Gottfried Kirch, Prussia's most important astronomer, she became his assistant and began to practice astronomy.

Winkelmann made some original contributions to astronomy, including the discovery of a comet. When her husband died, Winkelmann applied for a position as assistant astronomer at the Berlin Academy. She was highly qualified, but she had no university degree—and she was a woman. As a result, she was not given the job. Members of the Berlin Academy feared that they would set a bad example by hiring a woman.

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Reading Progress Check

Speculating Why might changes in the way people saw the universe change the questions they asked about the natural world?

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Connections to Today

Women in Science

The important position of women in the sciences today can be traced back to the Enlightenment's ideas about human equality and natural rights. The careers of Enlightenment-era women like Margaret Cavendish and the astronomer Caroline Herschell (1750–1848), who was a pioneer in the study of nebulae and star clusters, gained acceptance for the female scientists who would follow them. For example, half of the engineers operating the Large Hadron Collider, a powerful particle accelerator, are women.

Philosophy and Reason

Guiding Question *How did the Scientific Revolution change people's worldview?*

The Scientific Revolution led to new ideas about the universe. These new ideas strongly influenced the Western view of humankind.

Descartes and Rationalism

The work of the seventeenth-century French philosopher René Descartes (day•KAHRT) strongly influenced modern thought. He brought the perspective, or point of view, of philosophy to the study of the natural sciences. Descartes began by thinking and writing about the doubt and uncertainty that seemed to be everywhere in the confusion of the seventeenth century. He ended with a philosophy that dominated Western thought until the twentieth century.

The starting point for this philosophy was doubt, or questioning the truth of things. Descartes's most famous work was *Discourse on Method,* written in 1637. In this work, Descartes decided to set aside all that he had learned and to begin again. One fact seemed to him to be beyond doubt—his own existence.

Descartes emphasized the importance of his own mind. He said that he would accept only those things that his reason said were true. His first principle was "I think, therefore I am." Descartes used this first principle and his reason to arrive at a second principle. He argued that we cannot doubt the mind, but we can doubt the body and the material world. Therefore, the mind and the material world, including the body, must be completely different.

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From this idea came the principle of the separation of mind and matter (and of mind and body). Descartes's idea that mind and matter were completely separate allowed scientists to view matter as dead or inert. That is, matter was something that was totally separated from the mind. It could be investigated, or studied, independently by reason. Descartes has been rightly called the father of modern **rationalism**. Rationalism is based on the belief that reason is the main source of knowledge.

Bacon and the Scientific Method

People became concerned about how they could best understand the physical world during the Scientific Revolution. The result was the creation of the **scientific method**. The scientific method is a series of steps for collecting and analyzing evidence. It was important to the development of science in the modern world.

The person who developed the scientific method was not a scientist. Francis Bacon was an English philosopher with very little background in science. Bacon believed that scientists should not rely on the ideas of ancient authorities. Instead, they should learn about nature by using of **inductive reasoning**. This kind of reasoning means going from the particular, or the specific, to the general. Bacon also practiced the theory of **empiricism**. This theory says knowledge is achieved through observation. Empiricism, together with experimentation and inductive reasoning would lead to a greater understanding of the natural world.

With inductive reasoning, the "particular" means specific examples. For example, a scientist might make one thousand observations of how pinecones are produced. Each observation is a particular or specific example. Then the scientist might move on to the "general," or a general statement about all pinecones or the trees that produce them.

Before using this type of reasoning, scientists try to free their minds. They get rid of opinions that might stop them from finding or recognizing the truth. Then they use detailed facts and work with them to identify general principles. From observing events in nature, scientists propose hypotheses, or possible explanations, for the events. Then they use carefully planned observations and carefully organized experiments to test the hypotheses. The system helps lead to correct general principles.

Bacon was clear about what he believed his scientific method could accomplish. He said that the real goal of the sciences is to bring new discoveries and new power to human life. He was much more concerned with practical matters than pure science. Bacon wanted science to benefit industry, agriculture, and trade. He wanted to lay a foundation to produce things that are useful to humans.

How would this "human power" be used? Bacon believed it could be used to "conquer nature in action." The control and domination of nature became an important concern of science and the technology that accompanied it.

Reading Progress Check

Describing What did Bacon believe was the purpose of the scientific method?

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