THE SCIENTIFIC REVOLUTION

A Unit of Study for Grades 7–10

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Table of Contents

Teacher's Background

I. Unit Overview

The purpose of this Unit is for the student to explore the advances in scientific knowledge made in Europe in the mid-sixteenth to mid-seventeenth centuries. These advances, beginning with Copernicus, radically changed man's basic notions of the very structure of the universe, in which he was no longer the center. The Copernican vision replaced the Ptolemaic notion of an earth-centered universe with a new "solar system" which had the sun at its center. As this idea gained ground, its supporters like Galileo developed a new method to prove its validity which rejected all unsubstantiated authority, and instead used careful observation and mathematical reasoning. With the help of this method it now seemed possible to understand the very laws which governed the physical world.

The unit, based on primary sources, introduces students to the contributions of the key scientists of the Scientific Revolution and to their basic discoveries and inventions, using illustrations and short excerpts from their works. **Lesson One** compares the ancient earth-centered universe of Ptolemy with the new sun-centered solar system of Copernicus. **Lesson Two** deals with the invention of the telescope, and how Galileo's telescopic observations not only verified the Copernican theory, but also had grave social consequences for the scientist. **Lesson Three** focuses on the development of the Scientific Method by Francis Bacon and René Descartes. Students will see how empirical investigation became widespread, and how the dissemination of information was aided by the establishment of the English Royal Society in London and the French Academy of Sciences. **Lesson Four** expands the scientific domain from discoveries in astronomy and the social realm, to the world of the microscope, and its expansion of human consciousness to the miniature world previously unavailable.

The changes wrought by the Scientific Revolution of the mid-sixteenth and seventeenth centuries will introduce students to the historical beginnings of our modern scientific age. During this time, "natural philosophy" became "science". Fundamental issues such as the difference between belief and mathematical proof will be discussed, as well as the social consequences of attempting to replace a long-established authority with a new one. This unit also shows the practical application of these new ideas, with the inventions which followed naturally from their use. By following the development of scientific advances, students will be able to trace the dissemination of these ideas, seeing how governments aided research and facilitated communication between scientists by establishing and funding scientific organizations. This unit is crucial for students to be able to understand how reliance on long-established but unsubstantiated authority gave way to the scientific method.

Based on empirical evidence through observation and experimentation, the scientific method was used to predict the outcome of theoretical work, and achieved practical success in medicine and technology. As Galileo scholar Stillman Drake has written, "The truly influential and pervasive aspects of modern science are not its facts at all, but rather its method of inquiry and its criterion of truth."[1] This unit provides a critical historical link between the age of faith and the age of reason for students. This new, rational approach to learning had far-reaching consequences for society and religion, and created the basis for our modern world.

[1] Stillman Drake, *Discoveries and Opinions of Galileo* (New York: Doubleday, Anchor Books, 1957), p. 3.

II. Unit Context

This unit should come after covering the Protestant Reformation and the fragmenting of a Europe unified by the Catholic Church. The students should also have covered the changes introduced by the humanistic thought of the Renaissance, which would have included a discussion of the re-discovery of the Greek and Latin thinkers of antiquity. This unit on the Scientific Revolution would be followed logically by a lesson on the Age of the Enlightenment, coupled with the development of the Absolutist State.

III. Correlation to National Standards for World History

IV. Unit Objectives

1. To understand the radical difference between the notion of a sun-centered and an earth-centered universe, and the far-reaching implications of such a fundamental shift in thinking.

2. To comprehend the difference between gaining knowledge based on accepted authority and gaining knowledge through rational thinking and empirical proof.

3. To discern the social consequences of challenging existing doctrines with new ideas.

4. To learn about the Scientific Method and how to apply it to problem-solving.

5. To see the role envisioned for science in helping society to advance and make progress.

6. To understand the impact of the scientific approach upon European society and culture.

V. Introduction to the Scientific Revolution

The startling mathematical calculations first published in 1543 by Nicolaus Copernicus in his *Concerning the Revolutions of the Celestial Spheres*, showed the earth as a moving planet. This challenged the long-accepted belief of a motionless earth at the center of the universe, which had been described by the astronomer Ptolemy nearly 1400 years earlier at Alexandria, Egypt. Copernicus went on to posit the revolutionary notion that the sun, rather than the earth, was at the center of a "solar system," around which all spheres revolve. A debate began between the supporters of the traditional, Aristotelian-Ptolemaic world-view, and the proponents of the Copernican system.

Galileo then made telescopic discoveries, further validating this Copernican vision of the universe, which he discussed both in his *Starry Messenger* of 1610, and in his masterwork, *Dialogue on the Two Great World Systems* of 1632. Meanwhile, Johannes Kepler developed his three laws of planetary motion in 1609 and 1619, which he based on the findings of his mentor, the Danish astronomer Tycho Brahe. Kepler proved mathematically that Copernicus' findings were true, and was the first astronomer to say so openly. Later, the foundation of the principle of gravitation was developed by Sir Isaac Newton in his comprehensive laws of physics, which ordered the physical world into a cohesive and orderly system.

The reliance on strict observation and mathematical proofs to check the validity of a hypothesis was a fundamentally new idea which replaced the philosophical ideas of Aristotle, upon which the study of natural science had been based. These scientific advances, based on the process of observation, generalization and then experimentation, whose outcome could be predicted, gave birth to many basic discoveries and technological inventions which aided and ultimately changed methods of investigation.

To allow the precise observation and measurement demanded by the new scientific method, scientists and inventors came up with many of the basic tools which were necessary for research. These included the microscope, in principle first discovered in 1590 by a Dutch spectacle maker named Zacharias Janssen, and later, the science of microbiology actually developed by Anton Van Leeuwenhoek. In 1593, the thermometer was invented by Galileo, and then improved upon by Gabriel Fahrenheit in the mid-1600s. The telescope, first devised in 1608 by a Dutch optician named Hans Lippershey, was then built a year later by Galileo. With it he was able to see not only the craters on the moon, but also the rings of Saturn and four of the satellites of Jupiter. As he wrote in his *Starry Messenger* in 1610, this view of the imperfection on the surface of the moon shattered all medieval notions of the perfection of the celestial orbs, and threatened the authority of the Church, which then subjected Galileo to the threat of excommunication and virtual house arrest for the rest of his life.

Another instrument, the barometer, was invented in 1643 by Evangelista Torricelli, who had been a pupil of Galileo. The barometer measured the pressure of air, and its accuracy was later proven by Blaise Pascal. The fifth important advance came with the invention of the air pump, which was a basic device for moving liquids and gases. All of these inventions were critical for aiding scientific research.

Equally important in propelling scientific research forward were the men who believed in this new method of investigation, and spread their views in their writing. One of the most important advocates of science was a contemporary of Galileo, the English aristocrat Francis Bacon, (1561–1626) who became Chancellor of England in 1618. In his *Instauratio Magna* (Great Beginning) of 1605–1620, he wrote of the limitations of the existing systems of understanding in their inability to predict. He called for a new direction in learning, using experimentation as a way of investigation. In his *New Atlantis*, published in 1627, Bacon even envisioned a utopian society where science would become the savior of the human race. Later, his vision of scientific organization was made real by the establishment of the English Royal Society in London in 1660, followed by the French Academy of Sciences in 1666.

The writings of the French mathematician René Descartes (1596–1650), who began his *Discourse on Method* (1637) with the statement "I think, therefore I am *Cogito ergo sum*)," also stimulated interest in this new, optimistic notion of man's rational abilities. Buoyed with enthusiasm for predictability in scientific research, European governments subsidized more extensive investigation in the hopes of discoveries and inventions which would be of practical application in the areas of medicine, technology, and economic prosperity.

The culminating genius of the Scientific Revolution was the English physicist, Sir Isaac Newton (1642–1727). In 1687, after years of calculations built in part on the work of Galileo and Kepler in planetary and terrestrial motion, Newton published his *Mathematical Principles of Natural Philosophy*, or *Principia*, as it is often known. In this work of creative synthesis, Newton found a way to bring Kepler and Galileo together, showing that the same laws governed both the terrestrial and celestial realms. He gave mathematical proofs that all motion could be calculated and measured, and represented by a universal mathematical formula. The force which held the universe together was his "universal gravitation," a concept which remained unchallenged for two hundred years. It has been for this century to push past the universality of this concept, discovering its limits in subatomic structures and in the vast outer reaches of the physical universe.

You may wish to introduce the study of the Scientific Revolution by providing students with the names of individuals who are mentioned in this unit, a chronological chart of the Scientific Revolution, and a map locating the place of birth of each of these scientists (**Student Handouts 1-3**, pp. 13–15). As students investigate the lives and work of prominent scientists of the period you may also have them locate on the map where they made their important scientific discoveries or published their findings.

VI. Lesson Plans

1. Ptolemy and Copernicus
2. Galileo and His Telescope
3. Bacon and Descartes
4. The Development of the Microscope

Lesson One
Ptolemy and Copernicus

A. Objectives

1. To understand the ancient Ptolemaic view of the universe, with the earth at the center.
2. To see how different Copernicus' "solar system" is from Ptolemy's.
3. To draw conclusions about these two models of the universe.

B. Historical Background Notes

In 1543, the Polish priest and astronomer Nicholas Copernicus (1473-1543) posthumously published his book *Concerning the Revolutions of Celestial Spheres*, in which he presented a revolutionary new model of the very structure of the universe, with the sun at its center. His ideas, based on mathematical calculations, rejected the ancient view of Ptolemy, which had placed the earth at the center.

Ptolemy's model, dating from the Hellenistic period at Alexandria, Egypt in ca. 150 A.D., had been the view which had been taught by religious leaders. Copernicus' new model threatened the established doctrine of these Church writers, who understood the Bible as supporting the Ptolemaic notion (Joshua commanded the sun to stand still: i.e. it had to be in motion around the Earth). Leaders from both the Roman Catholic and the Protestant church condemned this new idea as false. It would be up to Kepler and Galileo to prove Copernicus correct by using the new invention of the telescope and logical analysis of empirical evidence.

C. Lesson Activities

Activity One

1. Introduce the lesson by leading a discussion on basic physical assumptions; in other words what things class members just take for granted about reality. (For example, that the earth is round; that the sun will come up in the morning; that if they roll a ball really hard, it will continue rolling until something stops it, etc.).

2. Divide the Class into Group A and Group B, giving Group A **Illustration 1**, *Ptolemy's Classical Model of the Universe*, (dating from 150 A.D.) and Group B, **Illustration 2**, *Copernicus' New Model*, (first introduced in 1543).

3. Have each group "read" their assigned model and appoint a notetaker to make a list of what they see in the drawing.

4. Bring the class back together and have group leaders present each document, listing the main points on the board, as a basis for class discussion on the differences in the two models.

Discussion Questions

a. What do these drawings represent?

b. What is the most important difference between the two?

c. What does Ptolemy's model contain that is absent from Copernicus'?

d. How might a change this drastic make people feel about their world, and their place in it?

e. How would your ideas have to change if you believed in Copernicus' idea?

f. How do you think that Copernicus could have come up with such a different model of the Universe?

g. How do you think the people of the sixteenth century would react to his idea of the universe?

E. Vocabulary

geocentric heliocentric

F. Pronunciation Key

Ptolemy (TAHL-EH-ME) Copernicus (KO-PAIR-NEE-KUS)

G. Evaluating the Lesson

Informal evaluation of group lists and class discussion.

Copernicus honored on an Hungarian stamp.

Men of the Scientific Revolution

Nicolas Copernicus (1473–1543)

Tycho Brahe (1546–1601)

Francis Bacon (1561–1626)

Galileo Galilei (1564–1642)

Hans Lippershey (ca. 1570–ca. 1619)

Johannes Kepler (1571–1630)

Francesco Stelluti (1577–ca. 1652)

Zacharias Jansen (1580–1638)

René Descartes (1596–1650)

Evangelista Torricelli (1608–1647)

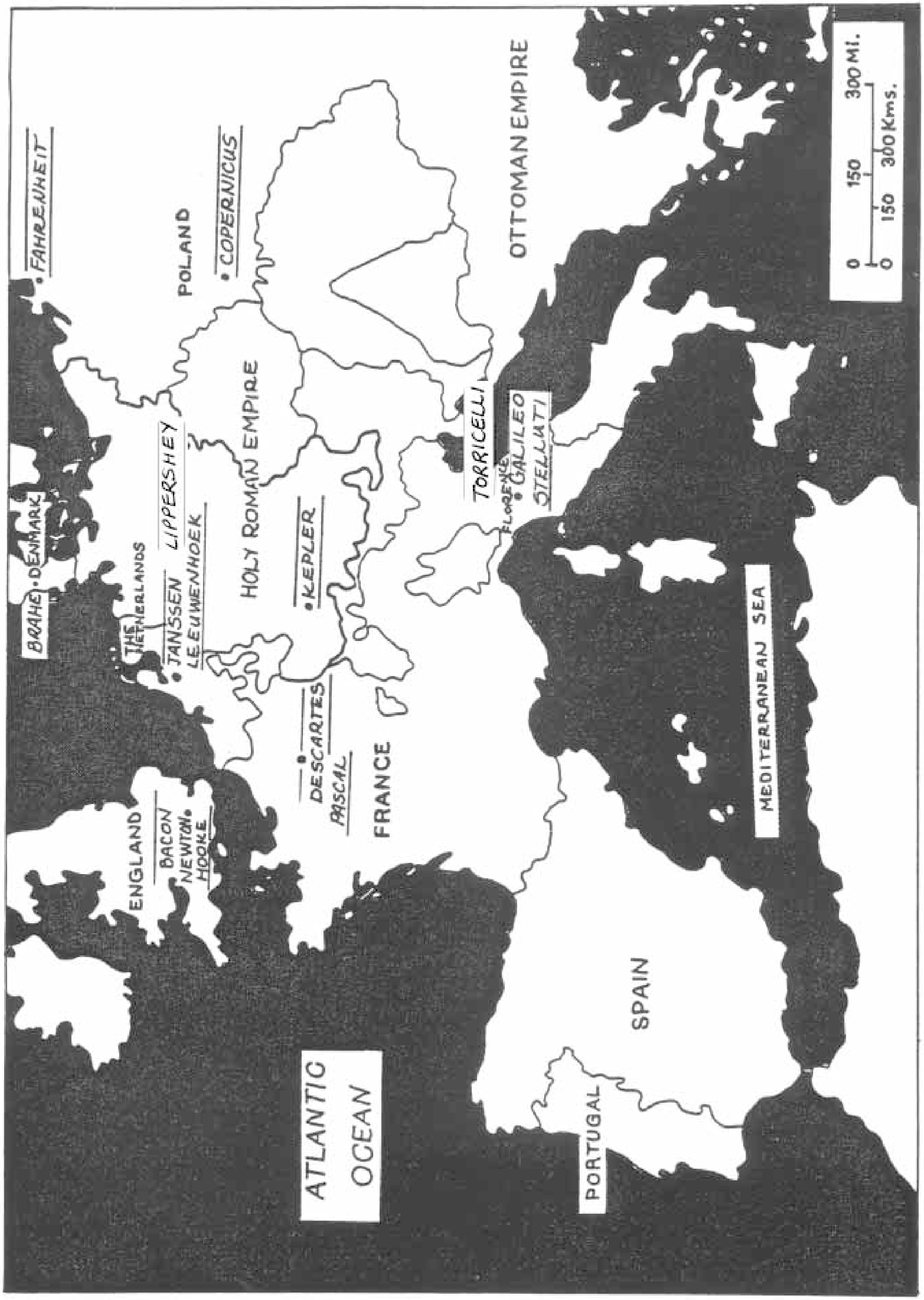
Blaise Pascal (1623–1662)

Anton Van Leeuwenhoek (1632–1723)

Robert Hooke (1635–1703)

Isaac Newton (1642–1727)

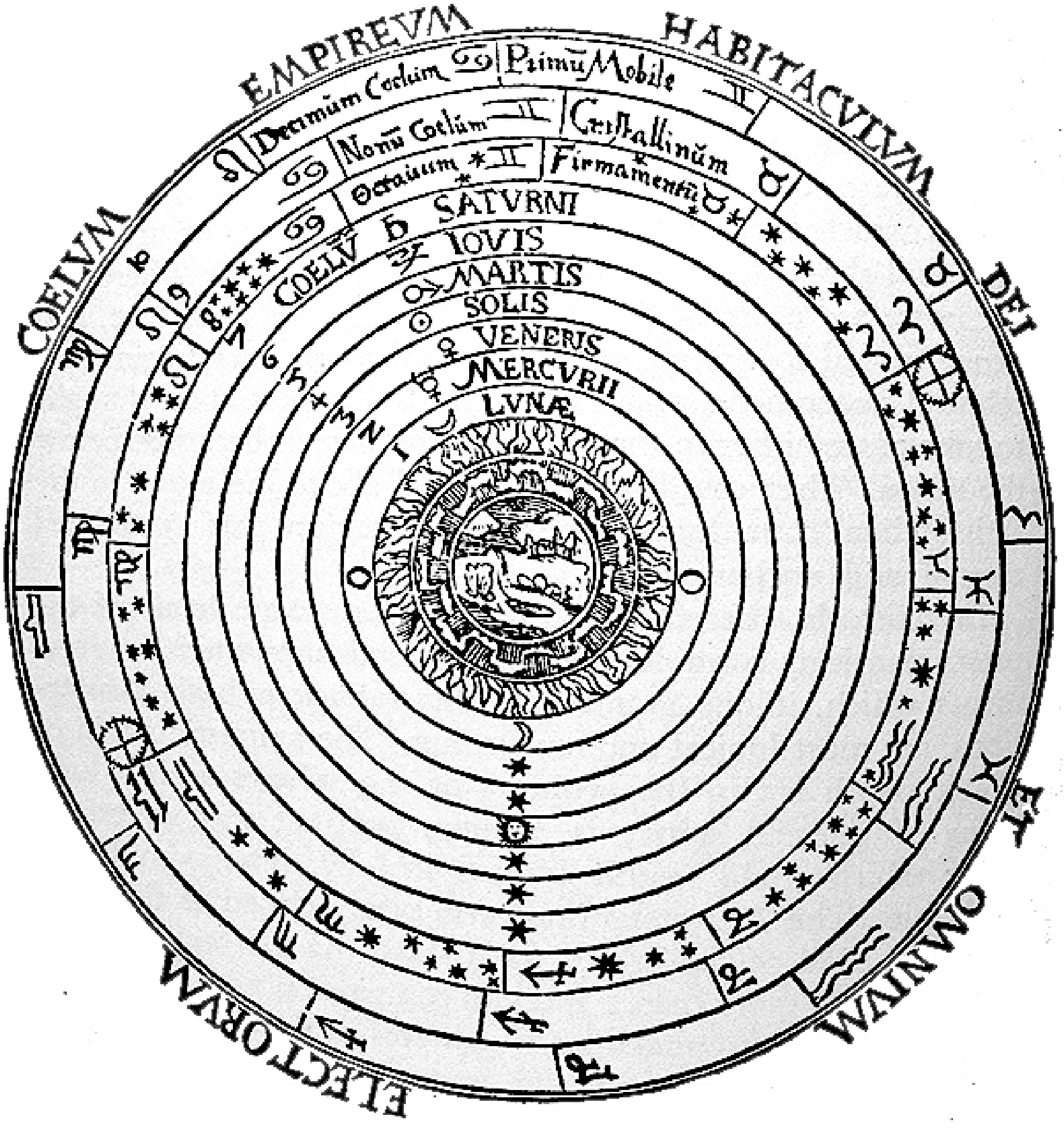
Gabriel Fahrenheit (1686–1736)


FAHRENHEIT
POLAND
COPERNICUS
OTTOMAN EMPIRE
BRAHE
DENMARK
THE NETHERLANDS
LIPPERSHEY
JANSSEN
LEEUWENHOEK
HOLY ROMAN EMPIRE
KEPLER
TORRICELLI
FLORENCE
GALILEO
STELLUTI
ENGLAND
BACON
NEWTON
HOOKE
DESCARTES
PASCAL
FRANCE
MEDITERRANEAN SEA
SPAIN
PORTUGAL
ATLANTIC OCEAN
0 150 300 MI.
0 150 300 Kms.

Scientific Revolution: A Chronological Table

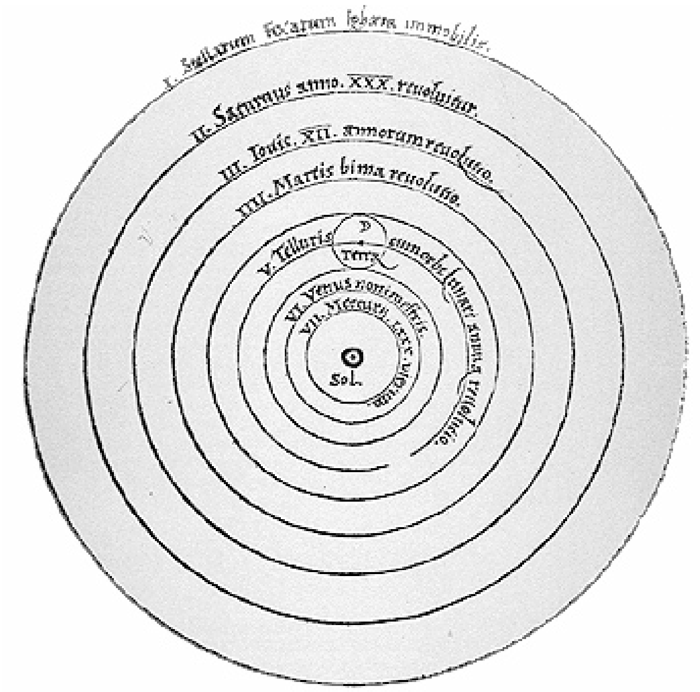
1543	Copernicus writes *On the Revolutions of the Heavenly Spheres*
1590	Zacharias Janssen invents **microscope**
1593	Galileo invents **thermometer**
1605–20	Francis Bacon writes *Instauratio Magna* (Great Beginning)
1608	Hans Lippershey invents **telescope**
1609–19	Johannes Kepler publishes *Three Laws of Planetary Motion*
1610	Galileo writes *Starry Messenger*
1613	Galileo writes *History and Demonstration Concerning Sun Spots*
1625	Francesco Stelluti publishes *Microscopic Studies of Honeybee*
1627	Bacon writes *New Atlantis*
1632	Galileo writes masterwork, *Dialogue on the Two Great World Systems*
1633	Trial of Galileo
1637	René Descartes writes *Discourse on Method*
1643	Evangelista Torricelli (student of Galileo's) invents **barometer**
1660	English Royal Society established
1665	Robert Hooke publishes *Micrographia*
1666	French Academy of Sciences established
1687	Sir Isaac Newton publishes *Principia*

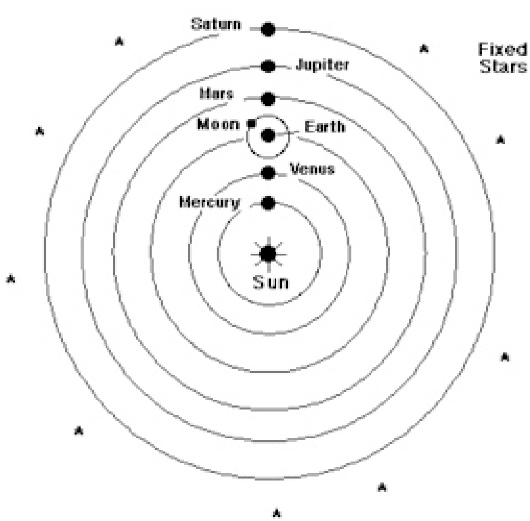
PTOLEMY'S CLASSICAL MODEL OF THE UNIVERSE CA. 150 A.D.



Albert Van Helden and Elizabeth Burr, *Galileo Project*. Houston, TX: Rice University, 1996. http://es.rice.edu/ES/humsoc/Galileo/

Copernican Model of the Universe ca. 1543 A.D.





Albert Van Helden and Elizabeth Burr, *Galileo Project*. Houston, TX: Rice University, 1996. http://es.rice.edu/ES/humsoc/Galileo/