**Scientific Advances in the Middle Ages: These are the scientific developments <u>prior to the Scientific Revolution of the 16th and 17th centuries.</u>**

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| Optics | Hasan Ibn al-Haytham is known as the "father of optics." He was the first to determine that vision occurs when light reflects from an object and passes to one's eye and that vision occurs in the brain, not the eyes. He also was one of the first to vary experimental conditions (known as variables). Al-Haytham also published the first (almost completely accurate) drawing of the anatomical eye and how it functioned. Roger Bacon used his al-Haytham's work in the 1200s to write about the use of lenses to correct vision. Scholar Hunayn ibn Ishaq wrote "Book of the Ten Treatises of the Eye" in the 1200s, detailing not only the anatomy of the eye, but also various diseases of the eye and treatments. |
| Circulatory system | Al-Razi, (tenth century), Ibn al-Nafis (thirteenth century), and Ibn alQuff (thirteenth century) documented circulation of the blood. Al-Nafis described how blood circulated between the ventricles and described the anatomy of the lungs. He was also one of the first physicians to believe that the brain, not the heart, was responsible for thinking and sensation. |
| Experimentation | Al-Haytham is considered the "world's first true scientist," using experiments in his optics studies. He also emphasized using skepticism (critical thinking) and empiricism (the idea that knowledge comes mainly from sensory experiences, like sight, touch, taste, etc). In the 1200s, English philosopher Roger Bacon began describing the process of observation, hypothesis, experimentation, and verification, keeping detailed records of his experiments so they could be repeated and independently tested by others. |
| Mathematics | Al-Khwarzami is considered the founder of algebra, revolutionizing quadratic and linear equations in the 800s. Omar Khayyam laid the foundations of analytic geometry by finding the geometric solution of the cubic equation. Al-Tusi developed the concept of a mathematical function. Al-Jayyani developed the law of sines for calculating the sides of triangles, and Frenchman Nicole Oresme invented coordinate geometry. Italian mathematician Fibonnaci introduced the Hindu-Arabic numeral system (0-9) to Europe, showing how it could be applied to bookkeeping and accounting in addition to other mathematical calculations. . |
| Physics | French philosopher Jean Buridan questioned Aristotle's ideas on motion and built on the ideas of 6th century philosopher John Philoponus and 11th century philosopher Avicenna. He proposed a theory of impetus, a precursor to Newton's inertia (objects in motion stay in motion until impeded by another force). English scholar Thomas Bradwardine formulated the speed mean theorem:*a body moving with constant velocity travels distance and time equal to an accelerated body whose velocity is half the final speed of the accelerated body*. This preceded Galieloe's "Law of Falling Bodies" by over 200 years. |
| Astronomy | In the 900s, Al-Sufi published his *Book of fixed Stars,* which first referenced the Andromeda Galaxy, the closest galaxy to our galaxy. Al-Tusi invented a concept that replaced Ptolemy's account for the motion and speed of the planets. And in *Livre du ciel et du monde* (1377) Nicole Oresme opposed the theory of a stationary Earth as proposed by Aristotle and instead proposed the rotation of the Earth on an axis some 200 years before Copernicus. Da Vinci also claimed that "the earth is not at the center of the sun's orbit." |
| Medicine | Muslim scholars used specific substances to destroy microbes. Al-Razi (tenth century) used mercurial compounds as antiseptics. During the Black Death of the 14th century, some European cities developed the concept of quarantine to prevent the spread of the plague. Al-Zahrawi was a tenth century Arab physician sometimes referred to as the "Father of surgery." He performed mastectomies to treat breast cancer as well as the first thyroidectomy. The French surgeon Ambroise Pare (sixteenth century) is noted as the "father of scientific surgery" partly for using sutures to tie off arteries and prevent bleeding out. The physician and philosopher Ibn-Sina (Avicenna) wrote a medical encyclopedia with all of the knowledge that Muslim medicine had accumulated. This book was used throughout Europe until the 1600s. Al-Razi studied the nervous system and made the connection between nerves and pain. He also suggested the possibility of an immune system. Finally, Leonardo da Vinci did extensive work drawing detailed anatomies of the human body during the Renaissance. He was the first to define liver cirrhosis and he claimed that the heart defined the circulatory system. |

## Now compare the above developments to the major achievements of the Scientific Revolution listed below:

## Copernicus

Nicolaus Copernicus was a Polish astronomer known as the father of modern astronomy. He was the first modern European scientist to propose that Earth and other planets revolve around the sun, or the **Heliocentric Theory** of the universe. Prior to the publication of his major astronomical work, “Six Books Concerning the Revolutions of the Heavenly Orbs,” in 1543, European astronomers argued that Earth lay at the center of the universe, the view also held by most ancient philosophers and biblical writers. In addition to correctly postulating the order of the known planets, including Earth, from the sun, and estimating their orbital periods relatively accurately, Copernicus argued that Earth turned daily on its axis and that gradual shifts of this axis accounted for the changing seasons.

Sometime between 1508 and 1514, Nicolaus Copernicus wrote a short astronomical treatise commonly called the *Commentariolus,* or “Little Commentary,” which laid the basis for his heliocentric (sun-centered) system. The work was not published in his lifetime. In the treatise, he correctly postulated the order of the known planets, including Earth, from the sun, and estimated their orbital periods relatively accurately.

For Copernicus, his heliocentric theory was by no means a watershed [critical turning point], for it created as many problems as it solved. For instance, heavy objects were always assumed to fall to the ground because Earth was the center of the universe. Why would they do so in a sun-centered system? He retained the ancient belief that circles governed the heavens, but his evidence showed that even in a sun-centered universe the planets and stars did not revolve around the sun in circular orbits. Because of these problems and others, Copernicus delayed publication of his major astronomical work, *De revolutionibus orbium coelestium libri vi,* or “Six Books Concerning the Revolutions of the Heavenly Orbs,” nearly all his life. Copernicus nonetheless came to be seen as the initiator of the Scientific Revolution.

## After Copernicus: Brahe & Kepler

Over the next century and a half, other scientists built on the foundations he had laid. A Danish astronomer, Tycho Brahe, 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.

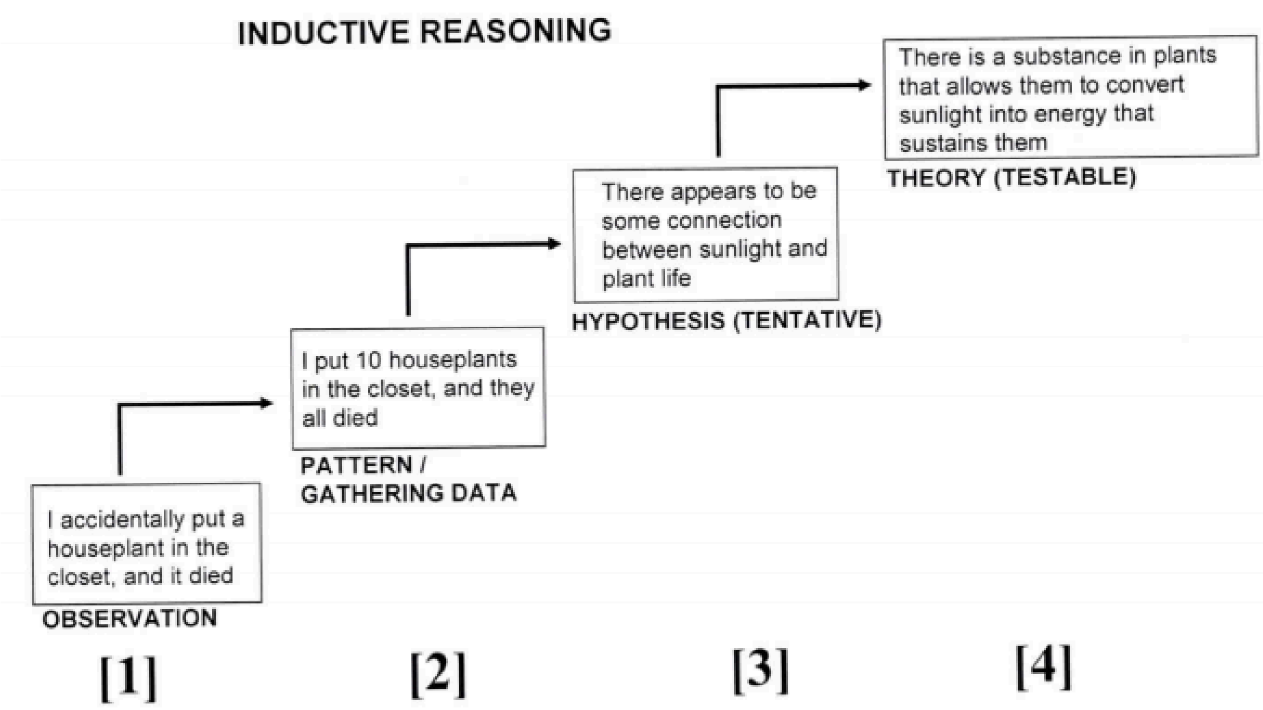
**Francis Bacon**

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 statesman 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 scholars for relying too heavily on the conclusions of Aristotle and other ancient thinkers. Instead of reasoning from abstract theories, he urged scientists to experiment and then draw conclusions. This approach is called **empiricism**, or the experimental method.

Deductive Reasoning (Aristotle): theory→ observation→ conclusion


Inductive Reasoning (Bacon): knowledge based on observation/experiment, not predetermined theory.



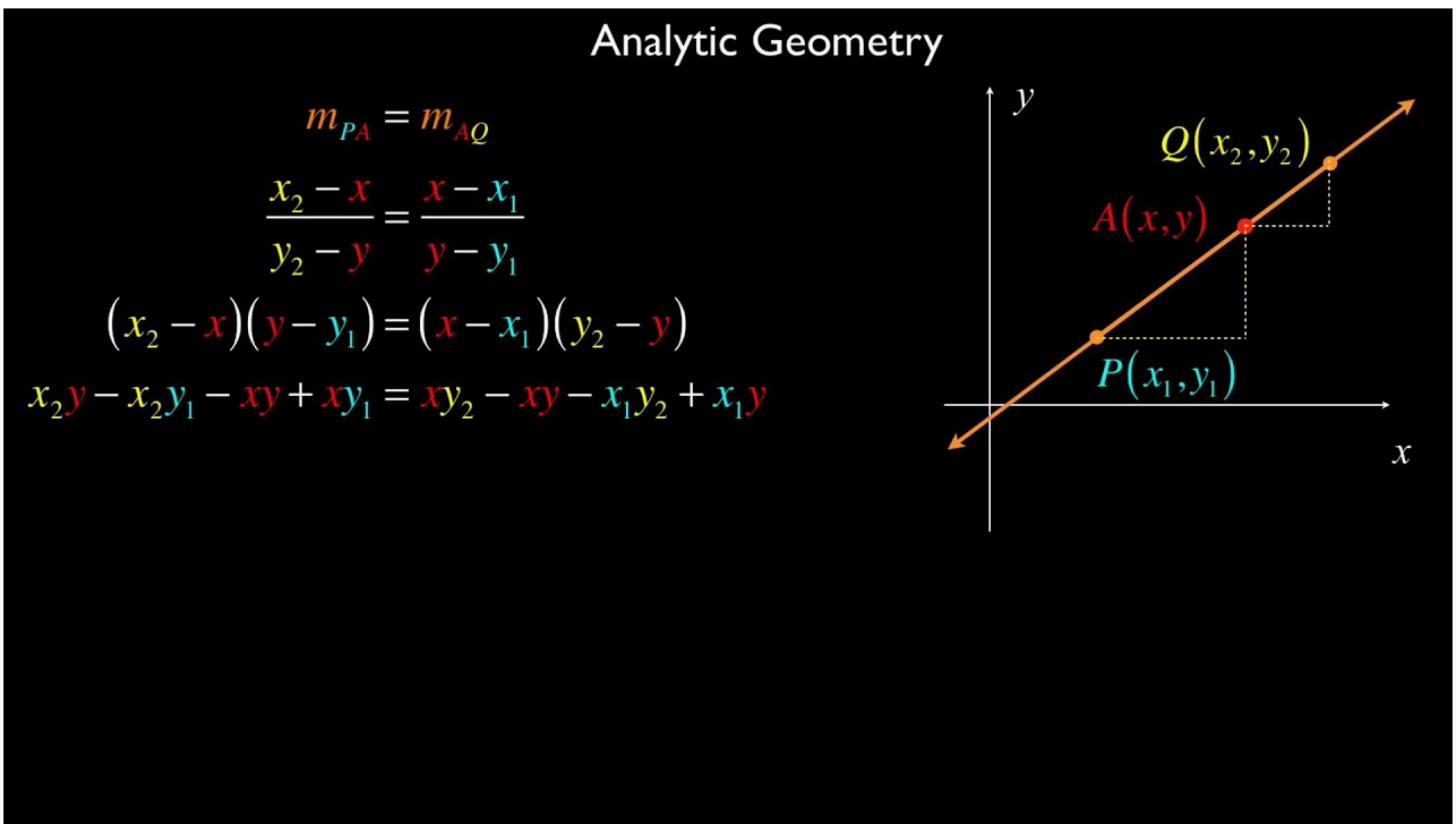
**Rene Descartes**

In France, René Descartes 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, he approached gaining knowledge differently than Bacon. Rather than using experimentation, Descartes relied on mathematics and logic. He developed the Cartesian coordinate system, which allowed geometric shapes to be expressed in algebraic equations. He is known as the father of analytic geometry.

Descartes also believed that everything should be doubted until proven by reason. In *Discourse on Methods,* Descartes attempted to create a fundamental set of principles that one could know as true without any doubt. 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 in a system known as Dualism: there are two kinds of reality. The first is "thinking substance" such as mind, emotions, feelings, spirit, etc.

The second reality is extended substance: things outside the body like trees, animals, nature, etc. Extended substances could be measured and quantified and explained with formulas and equations. Descartes emphasized the limitations of using the senses (smell, taste, etc) and instead asserted that using the mind—thinking and deduction—was the only way to truly know.



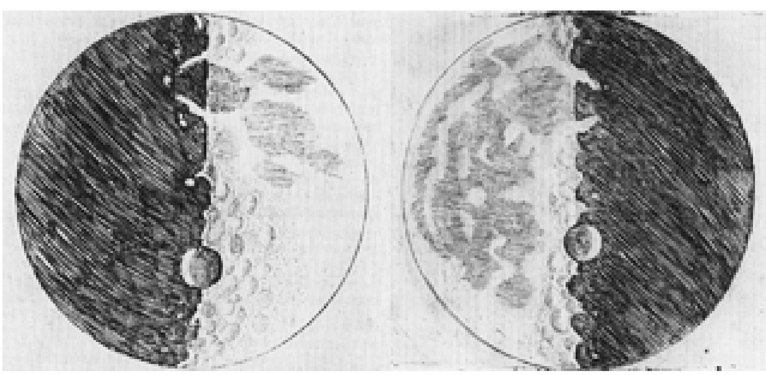
Galileo Galilei

In 1592, Galileo moved to become mathematics professor at the University of Padua, a position he held until 1610. During this time he worked on a variety of experiments, including the speed at which different objects fall, mechanics and pendulums. Experimenting with balls of different sizes and weights, he rolled them down ramps with various inclinations. His experiments revealed that all of the balls boasted the same acceleration independent of their mass, paving the way for Newton's law of inertia. He also demonstrated that objects thrown in the air travel along a parabola.

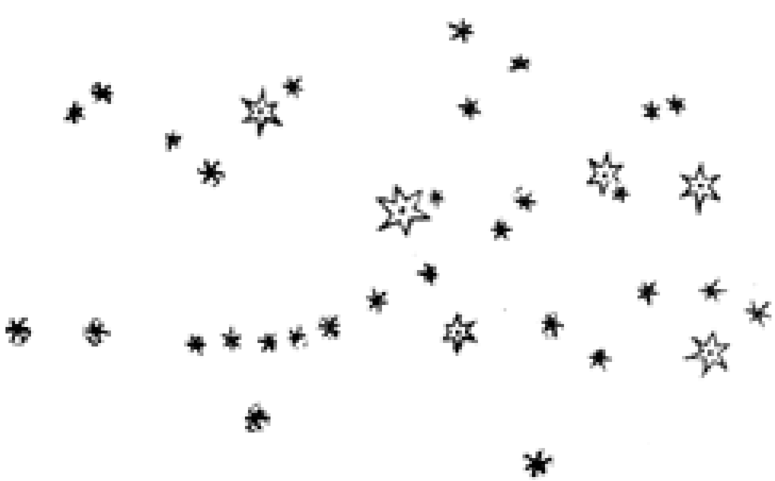
At the same time, Galileo worked with pendulums. In his life, accurate timekeeping was virtually nonexistent. However, Galileo observed that the steady motion of a pendulum could improve time keeping, and near the end of his lifetime, he designed the first pendulum clock.

In 1609, Galileo heard about the invention of the telescope in Holland. Without having seen an example, he constructed an improved version that could magnify six times more than existing telescopes. Using his telescope, Galileo discovered mountains and valleys on the surface of the moon, sunspots, the rings of Saturn, the four largest moons of the planet Jupiter and the phases of the planet Venus. These findings undermined the beliefs of Aristotle and the Church that the cosmos were perfect and unblemished.

Perhaps most importantly, Galileo's discoveries provided proof for Copernicus' Heliocentric Theory. Twice Galileo was condemned for heresy for promoting these views, and the Inquisition sentenced him to house arrest and forced him to withdraw support for Copernicus' theory. Although he was now going blind he continued to write. In 1638, his 'Discourses Concerning Two New Sciences' was published with Galileo's ideas on the laws of motion and the principles of mechanics. Galileo died in his home in 1642.



Galileo's drawings of the phases of the moon.



Galileo's drawing of stars in the Milky Way, which were not visible to the naked eye.

Physics/Math

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 26, he was certain that all physical objects were affected equally by the same forces, and he came up with the theory of gravitation: the same force ruled motion of the planets and all matter on earth and in space. 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. Newton also invented a new branch of mathematics: calculus.

In 1687, Newton published his ideas in a work called *The Mathematical Principles of Natural Philosophy*. It was 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. This belief would come to be known as Deism.

Newton's Three Laws of Motion:

1. An object will remain in a state of inertia unless acted upon by force
2. The relationship between acceleration and applied force is F=ma
3. For every action there is an equal and opposite reaction

**The Revolution Spreads**

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 examined red blood cells for the first time.

In 1643, one of Galileo's students, Evangelista Torricelli, developed the first mercury barometer, a tool for measuring atmospheric pressure and predicting weather. In 1714, the German physicist Gabriel Fahrenheit made the first thermometer to use mercury in glass. Fahrenheit's thermometer showed water freezing at 32°. A Swedish astronomer, Anders Celsius, created another scale for the mercury thermometer in 1742. Celsius's scale showed freezing at 0°

## Advances in Medicine

At the time there were a host of received notions and prejudices, especially against work on human cadavers, that prevented large-scale experimentation. Instead, most doctors continued to rely on the work of the Greek physician Galen, who in the second century CE had elaborated on the Aristotelian idea of the four “humors” that supposedly governed health: blood, phlegm, yellow bile, and black bile. According to that theory, illness was the result of an overabundance of one humor and a lack of another - hence the centuries-old practice of bleeding someone who was ill in hope of reducing the "excess" blood.

While belief in humors continued to hold sway in the absence of more compelling theories, important advances did occur in anatomy. The Italian doctor Andreas Vesalius published a work on anatomy based on cadavers. Vesalius dissected human corpses and published his observations. His book, *On the Structure of the Human Body* (1543), was filled with detailed drawings of human organs, bones, and muscle. In the 17th century, another doctor, William Harvey, conclusively demonstrated that blood flows through the body by being pumped by the heart, not emanating out of the liver as had been believed before. Shortly after his death, other doctors used a new invention, the microscope, to detect the capillaries that connect arteries to other tissues.

Many medical advances would not have been possible without Renaissance-era advances in other fields. Renaissance artistic techniques made precise, accurate anatomical drawings possible, and print ensured that works on medicine could be distributed across Europe rapidly after their initial publication.

Unfortunately for the health of humankind, the new understanding of anatomy did not lead to an understanding of contagion. The Dutch scientist Antonie Van Leeuwenhoek (1632-1723) invented the microscope, and in the 1670s he was able to identify what were later referred to as bacteria. Unfortunately, he did not deduce that bacteria were responsible for illness; it would take until the 1860s with the French doctor and scientist Louis Pasteur for definitive proof of the relationship between germs and sickness to be established.

However, 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 could also be 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.

## 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. The notions of reason and order, which spurred so many breakthroughs in science, soon moved into other fields of life. Philosophers and scholars across Europe began to rethink long-held beliefs about the human condition, most notably the rights and liberties of ordinary citizens. These thinkers helped to usher in a movement that challenged the age-old relationship between a government and its people, and eventually changed forever the political landscape in numerous societies.