## Science

The scientific revolutions of the sixteenth and seventeenth centuries overturned millennia of knowledge since the ancient Greeks. Scientists of this era exposed subjects such as gravity, motion, optics, the Solar System, chemistry, fluids, and gases to careful scrutiny.

### Text

Humans have tried to understand nature since the dawn of history. Ancient civilizations such as the Babylonians and Egyptians examined regularities in the heavens to track the seasons. They also created a written mathematics for commerce and surveying. Such ancient science reached its pinnacle with the Greeks. Philosophers such as Aristotle (384 BC-322 BC), Euclid (c. 330 BC-c. 260 BC), and Plato (c. 428 BC-347 BC) imagined geometrical theories for the universe. Many of these ideas were collected in Euclid's book *Elements*, which influenced scientific thought for nearly two millennia.

European science languished during the war-torn and superstitious times of the Dark Ages, starting in around 500 AD. Fortunately the *Elements* and other Greek texts were retained in Arabic places of learning. Islamic scholars built on the ancient knowledge and introduced Hindu counting to science (our present number system). The ancient Greek science and Arabic mathematics reached Europe in the medieval period. By the sixteenth and seventeenth centuries European scientists were finding new laws for how the universe works. These discoveries began the Industrial Age and Scientific Enlightenment over the next few centuries.

### Understanding the solar system

The first major scientific discovery of the Renaissance era completely reshaped our view of the Cosmos and ultimately led to the laws of motion and gravity. Polish astronomer Nicolaus Copernicus (1473-1543) proposed that Earth and the other planets circle the Sun. This theory contradicted the two thousand year old view that Earth was the center of the Universe. Although Copernicus formed his theory between 1510 and 1514, he did not publish his ideas until just before his death. He probably worried about angering the Catholic Church, who banned his book *De revolutionibus coelestium* (Revolving celestial spheres) in 1616.

Copernicus's ideas were slow to take hold. Even the greatest practical astronomer of the age, Tycho Brahe (1546-1601) of Denmark, was highly skeptical of this Sun-centered theory. Scientists disliked the idea of an Earth moving and rotating through space. In addition the clergy thought the theory heretical because it contradicted Holy Scripture.

A few scientists were converted to Copernicus's view of the Universe. The most important of these was German astronomer Johannes Kepler (1571-1630), who succeeded Brahe in his academic post. While working through the astronomical tasks that Brahe had left, Kepler devised two laws of planetary motion. These laws gave a formula for the shape of each planet's orbit (an ellipse) and their rate of looping around the Sun.

He published these observations in his 1610 book *Astronomia nova* (New Astronomy), followed by a third law in 1619. Analysis of Kepler's mathematics later led to the laws of motion and gravity.

Newton's laws of motion and gravity

Since the Greek philosopher Aristotle, motion was seen as a restoration of a body's natural place in the universe. Stones are part of Earth and therefore fall, while air is part of the Heavens and rises.

Italian physicist Galileo Galilei (1564-1642) sought to replace this accepted view. Rather than relying on the ancient Greek method of pure thought, Galileo pioneered the use of measurement to investigate the physical world. In several ingenious experiments of rolling balls down planes he showed that the speed of a falling body does not depend on its weight. He also devised an equation for the distance the ball falls after a certain time. Throughout his scientific career Galileo supported Copernicus's planetary view, which eventually led him into trouble with the Church and house arrest.

All the pieces were now in place for the greatest scientist of the Renaissance era to propose one of the most insightful discoveries of all time. English physicist and mathematician Sir Isaac Newton (1642-1727) proposed three laws of motion and a law of gravity. These four simple laws described how any object in the universe moves, from Earthly objects such as apples and stones to Cosmic bodies like planets and comets. In particular he inferred from Kepler's principles an exact equation for the force of gravity. Newton's laws lasted until Albert Einstein's (1879-1955) theories in the early twentieth century. The differences between their theories are almost unnoticeable in most usual situations.

In addition to discovering the laws of motion and gravity Newton investigated virtually every scientific and mathematical subject known at that time. To calculate planetary motion he invented calculus, a branch of mathematics that underlies most modern scientific disciplines. He also discovered many basic principles in optics, fluids, and chemistry. Newton presented these insights in his great work *Philosophiae Naturalis Principia Mathematica* (Mathematical principles of natural philosophy), first published in 1687.

The laws of optics

Optics is the study of light and how it travels. Some basics facts were known since the Greek philosopher Euclid (c. 330 BC-c. 260 BC), such as how it reflects from a mirror. However the ancients were unsure about its other properties, even arguing whether it travels from our eyes to an object or the other way round. The expansion of science in the seventeenth century meant such basic questions were now answerable. Many leading figures wrote books on optics. These further helped science and technology through accurate telescopes, microscopes, and magnifying glasses.

An early book on the nature of light was Johannes Kepler's *Optics* (1604). This described many basic principles, such as how a lens creates an image and the laws of reflection and refraction (bending) of light. Another important contribution to the subject was French philosopher and mathematician René Descartes' (1596-1650) *Dioptics.* This book sparked a debate with another leading French intellectual Pierre de Fermat (1601-1665) over how scientists should investigate optics. Fermat argued for experiments, whereas Descartes supported pure reasoning. Fermat made clear his approach with two leading discoveries: light slows in a denser material, and always travels along the quickest path.

Another important seventeenth century debate concerned whether light consists of waves or particles. By considering light as a collection of "wavelets," Dutch physicist Christiaan Huygens (1629-1695) explained many optical phenomena. On the other hand, Sir Isaac Newton argued instead that light consists of many particles called "corpuscles." Scientists accepted Newton's views until the nineteenth century when several experiments appeared to confirm Huygen's wavelet idea. Yet twentieth century quantum physics later showed that light behaves like both waves and particles. Both scientists were therefore right in their own way.

From alchemy to chemistry

Arising from the ancient practice of metallurgy, Alchemy sought to transmute one natural form into another. Its practitioners examined problems such as turning lead into gold or finding the "elixir of youth." Although it now regarded as largely superstitious, some of its principles helped found the modern science of chemistry. Many leading scientists of the Renaissance period had an interest in alchemy. For example, Sir Isaac Newton wrote more than half a million words on the subject.

In the sixteenth century chemistry was still in its infancy. Chemistry books were highly superstitious such as German alchemist Andreas Libavius's (1560-1616) *Alchemia.* The subject gradually became more scientific during the seventeenth century. Flemish chemist Jan Baptista van Helmont (1579-1644) introduced the word "gas" into scientific language, from the ancient Greek *khaos* (chaos). A few years later the British chemist Robert Boyle (1627-1691) continued Helmont's investigations. In his manuscript *The Skeptical Chemist* (1661) Boyle criticized Aristotle's view that matter is a mixture of air, earth, fire, and water. He suggested instead a collection of tiny indivisible particles joined together into larger structures.

Toward the end of the Renaissance a new theory began to dominate chemistry. German chemist Georg Ernst Stahl (1660-1734) developed the idea of phlogiston to explain how matter can combust. Substances rich in phlogiston could burn to leave a "de-phlogistinated" residue. This theory appeared to explain how metals rust and react but had some strange predictions. For example, when metal rusts it becomes heavier, so phlogiston must have negative mass. The phlogiston theory was overturned about a century later after the discovery of oxygen.

Box: Newton's laws of motion

In one of the greatest ever insights Sir Isaac Newton simplified the movement of any object to just three laws. (I) A body moving at constant speed in a straight line will continue to do so unless acted on by a force. (II) This force then produces an acceleration equal to the force divided by the body's mass. (III) If one body causes a force on another, then an equal force is pushed back in reaction.

These laws laid the foundations for modern science. Just as Newton understood gravity as a force caused by mass, later scientists would similarly picture electricity and magnetism as another force. Newton's laws also led to theories of moving fluids and gases. Only in the early twentieth century did his ideas of the world finally be superseded by quantum theory and Einstein's relativity.

Box: The speed of light

The first accurate measurement of how fast light travels was, rather remarkably, achieved in the seventeenth century. In 1668 the Italian astronomer Giovanni Domenico Cassini (1625-1712) drew tables of when moons moved around Jupiter. A few years later the Dutch astronomer Ole Christensen Römer (1644-1710) noticed that these lunar cycles seemed early or late at particular times of the year. He suggested this is because we become closer to or farther from Jupiter as Earth orbits the Sun.

Römer used Cassini's figures to estimate 140,000 miles (225,000 km) per second for the speed of light. This value is impressively close to the 186,000 miles (300,000 km) per second known today.

Box: Robert Boyle

Born the son of the Irish Earl of Cork, Robert Boyle made many important discoveries in physics and chemistry. His physical insights mainly concerned the properties of gases. In the late 1650s he and Robert Hooke (1635-1703) showed that air is essential for transmitting sound, breathing, and combustion. He also discovered his famous "Boyle's law" of gases, which relates their pressure and volume.

Boyle's advances in chemistry were similarly impressive. He introduced the idea of acids and alkalis, and did many experiments to look at their properties. One of his main contributions to chemistry was his emphasis on careful experiments. Many of the techniques that he pioneered are still in use today. These include dyes that indicate the acidity of a solution and tests to detect certain metals from how they color flames.

Box: See also

Astronomy
Copernicus
Descartes
Galileo

Mathematics
Newton, Isaac
Technology