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The Scientific Revolution

The Scientific Revolution was a multifaceted social and intellectual event that impacted and indeed changed the way we look towards science forever after. The Scientific Revolution of the late sixteenth, seventeenth, and eighteenth centuries was unparalleled among contemporary scholarly movements. Its impact is comparable to that made by the thinkers of Ancient Greece because, like them, the men and women responsible for the Scientific Revolution, changed not only ideas but also the method by which ideas are formulated. The Renaissance and the Reformation, for all their importance, were mostly rooted in traditional patterns of thought. They could be understood without reordering the concepts that had saturated Western thinking for more than two thousand years. The development of modern science, in many ways was the result of these earlier movements. These scientist asked questions that were different, from those that had been asked before, and by so doing so they created a whole new way of looking at the universe. Modern science and the scientific method with which it is associated with may be the one body of European ideas that has had a transforming effect on virtually every non-Western culture.

Many historians start the date of the Scientific Revolution to death of Copernicus. On his deathbed in 1543, Nicholas Copernicus received the first published copy of his book, De revolutionibus orbium coelestium (On the Revolutions of the Heavenly Spheres). In this influential work, and his now famous diagram, Copernicus put forward a sun centered or heliocentric model of the solar system with a moving earth rotating once a day on its own axis and orbiting the sun once a year. (The Columbia Electronic Encyclopedia 6th ed., 2007) In 1543, every culture in Europe placed the earth instead at the center of its cosmology. In breaking so radically with the teachings of Ptolemy, Aristotle, and The Bible, Copernicus rediscovered astronomical wisdom lost in antiquity, and turned away from the biblical tradition to see the truth that was hidden in heavens above. Although the innovators of the sixteenth and seventeenth centuries were interested in nearly everything, they achieved their greatest breakthroughs in realms of astronomy and physics. Though the Copernican theory, was by no means universally accepted, it became their starting point were others began to think "outside the box" and question the ideas accepted for centuries prior. Copernicus had brought the established cosmology into question, but his system remained mathematically complex and virtually incomprehensible as a description of physical reality. A more plausible model of the cosmos was devised by Johannes Kepler (1571–1630). Kepler thought that the universe was organized on geometrical principles. He wanted to believe in circular orbits, yet came to the finding that planetary orbits had to be elliptical. This solution, which proved to be correct, was not generally accepted until long after his death.

Meanwhile, Galileo Galilei (1564–1642) rejected the theory of elliptical orbits but provided important evidence that the planets rotated around the Sun. Galileo was perhaps the first thinker to use something like the modern scientific method. Galileo, a careful observer, tried to verify his hypotheses through experiment. Galileo using a perfected version of the telescope, that he had built himself, pointed this telescope up upon the heavens. The results changed the world. His discovery of the moons of Jupiter and the phases of Venus seemed to support the Copernican theory. His improvement of the telescope, his astronomical discoveries, and his research on motion and falling bodies brought him international recognition and places him in an enduring place in the history of science. Galileo’s career as a Renaissance scientist, reflects the deep changes in the social character of science and the emergence of the scientist in the sixteenth and seventeenth centuries. Galileo's infamous trial and recantation of Copernicus's heliocentric model for the solar system at the hands of the Holy Catholic Inquisition "is a notorious chapter in relations between faith and reason, which contributed to the slowly emerging recognition of the value of intellectual freedom." (McClenan III & Dorn, 2006, p. 223)

Copernicus theory led up to the work of Tycho Brahe (1546–1601) and René Descartes (1596–1650). Their theories of the working and mysteries of the universe tried to explain Copernicus's work, yet none understood and none could compare to the most influential figure of the Scientific Revolution, and perhaps science altogether this figure was Sir Isaac Newton. Isaac Newton (1642–1727) so dominates the intellectual landscape of the late seventeenth and early eighteenth centuries that his life and works changed the way we look at the universe. (McClenan III & Dorn, 2006, p. 249). Newton owes his rise to the rise of the scientific societies in England. These "institutions facilitated the growth of science in contemporary England, notably, the Royal College of Physicians (1518), Gresham College (a new institute with salaried professors founded in 1598, and, later in the seventeenth century, the Royal Society of London (1662) and the Royal Observatory at Greenwich (1675). Royal funding for new scientific chairs at Oxford (geometry-astronomy in 1619 and natural philosophy in 1621, and later at Cambridge (1663) likewise helps explain the flourishing of English science in the later seventeenth century." (McClenan III & Dorn, 2006, p. 248) , Sir Isaac Newton, was a fellow and later head of the Royal Society of England. To earlier discoveries in mechanics and astronomy he added many of his own and combined them in a single system for describing the workings of the universe. Unknown to the rest of the world, in 1666 Newton was in fact the world’s leading mathematician and was as knowledgeable as anyone about science or natural philosophy (new or old). He thought about gravity and calculated in a rough way the effects of gravity extending to the moon. Using prisms, he investigated light and colors, discovered new phenomena, and toyed with new explanations. He also gained his fundamental insight into the calculus by seeing a relation between tangents to curves and areas under curves the system is based on the concept of gravitation and uses a new branch of mathematics, calculus, that he invented for the purpose. All of this was set forth in his, Philosophical Principles of Natural Philosophy (1687), the publication of which marked the beginning of the modern period of mechanics and astronomy. Newton also discovered that white light can be separated into a spectrum of colors, and he theorized that light is composed of tiny particles, or corpuscles, whose behavior can be described by the laws of mechanics. In his now famous experiment, he passed a beam of light through a prism to create a spectrum. Refracting portions of that spectrum through a second prism failed to produce another spectrum or other changes, thus demonstrating to his satisfaction that colors are properties of light and not produced by refraction.

Yet the best was yet to come, because in August of 1684 Edmond Halley traveled to Cambridge to ask Isaac Newton a question. Halley visited the reclusive Newton and asked him about the motion of a planet orbiting the sun, Newton immediately replied that the shape of the orbit would be an ellipse and that he had calculated it. After fumbling through his papers, Newton promised the awestruck Halley that he would send him the calculation. Three months later Halley received a nine-page manuscript, "On the Motion of Orbiting Bodies," that outlined the basic principles of celestial mechanics. Everyone who saw it immediately recognized the significance of Newton's latest work. (Oxley, 2005) Halley shepherded the great work through the press. The Philosophiae Naturalis Principia Mathematica or Principia appeared in 1687. The

Principia is a highly mathematical or, better, geometrical text, and Newton begins it with definitions and axioms. He defines his terms for mass and force and states his historic three laws of motion: 1) his inertial law that bodies in motion remain at rest or in straight-line motion unless acted upon by an outside force. 2) That force is measured by change in motion, and 3) that for every action there is an equal and opposite reaction. In Principia he introduces his ideas about absolute space and time; and also shows that Galileo's law of falling bodies (that all objects fall at the same rate) follows as a consequence of his, Newton's, laws. Newton also presents a clear picture of a heliocentric solar system where orbiting bodies obey Kepler's three laws. In particular, he provides reliable observational data coupling Kepler's third law with the motions of the moon around the earth, the planets around the sun, and satellites around Jupiter and Saturn, respectively. Geo-centrism (that heavenly bodies revolve around the Earth) is shown to be absurd and inconsistent with the known facts. Using Kepler's third law and Book I of the Principia, Newton then proposes that the forces holding the world's planets and moons in their orbits are attracting forces and, in particular, "that the Moon gravitates towards the Earth." In an elegant bit of calculation Newton, using Galileo's law of falling bodies, demonstrated conclusively that the force responsible for the fall of bodies at the surface of the earth, the earth's gravity, is the very same force holding the moon in its orbit and that gravity varies inversely as the square of the distance from the center of the earth. In proving this one exquisite case Newton united the heavens and the earth and closed the door on now out of date cosmological debates going back to Copernicus and Aristotle.

The Royal Society (1662) and the Paris Academy of Sciences (1666) were the flagships of an organizational revolution of the seventeenth century. They created a new institutional base for science and scientists, and they ushered in a new age of academies characteristic of organized science in the following century. Major national academies of science subsequently arose in Prussia, Russia, and Sweden, and the model of a state academy or society of science spread throughout Europe and to its colonies around the world. Scientific academies and societies coordinated a variety of scientific activities on several levels: they offered paid positions, sponsored prizes and expeditions, maintained a publishing program, superintended expeditions and surveys, and rendered a diversity of special functions in the service of the state and society. These institutions, incorporating a broad array of scientific interests dominated organized science until the coming of specialized scientific societies and a renewed scientific vitality in universities in the nineteenth century. Growing out of Renaissance and courtly precedents, these new learned societies of the seventeenth and eighteenth centuries were creations of nation-states and ruling governments. These state supported scientific societies possessed a more permanent character than their Renaissance cousins, in that they received official charters from government powers incorporating them as legal institutions and permanent corporations. Given the increasing separation of government operations from royal households, official state scientific societies became detached from court activity and integrated into government bureaucracies. Society members tended to act less as scientific courtiers and more as expert functionaries in the service of the state. The state academies and societies were also institutions specifically concerned with the natural sciences; they were not subservient to other missions, they largely governed themselves, and, unlike universities, they did no teaching. The growth and maturation of state academies and societies of science in the eighteenth century provide impressive evidence of the greater social assimilation of science after the Scientific Revolution. (McClenan III & Dorn, 2006, p. 255)

Scientific views would also triumph in medicine, but the process by which they did so was not as straight forward as it had been in physics. Physicians moved from mechanism to magic and back again through the course of the sixteenth century. The works of the ancient Greek anatomist Galen had long been known through Arabic commentaries and translations. Galen's views were mechanistic in the sense that he was careful to relate the form of organs to their function and had little use for magic or for alchemical cures. The recovery and translation of original Galenic texts by the humanists popularized his teachings, and by the early sixteenth century his influence dominated academic medicine. In response, a Swiss physician and alchemist who called himself Paracelsus (1493–1541) launched a frontal attack on the entire medical establishment. Declaring that "wise women" and barbers cured more patients than all of the Galenists put together, he proposed a medical philosophy based upon natural magic and alchemy. All natural phenomena were chemical interactions between the four elements (earth, wind, water, and fire) and what he called the three principles: sulfur, mercury, and salt, which were the combustible, gaseous, and solid components of matter. Because people believed that the human body was a microcosm of the universe and because diseases were produced by chemical forces acting upon particular organs of the body, sickness could be cured by chemical antidotes. The war between the Galenists and the Paracelsians raged throughout the mid-sixteenth century. In the end, the Galenists won. Their theories, though virtually useless for the treatment of disease, produced new insights while those of Paracelsus did not. Andreas Vesalius (1514–64) was shocked to discover that Galen's dissections had been carried out primarily on animals. Using Galenic principles, he retraced the master's steps using human cadavers and in 1543 published his <u>De humani corporis fabrica</u> (<u>On the Structure of the Human Body</u>). Though not without error, it was a vast improvement over earlier anatomy texts and a work of art in its own right that inspired others to correct and improve his work. The long debate over the circulation of the blood, culminating in William Harvey's explanation of 1628 was also a Galenist enterprise that owed little or nothing to the chemical tradition. William Harvey (1578–1657) is best known as the physician who first described the circulation of the blood, yet he was no more consistent in his application of scientific method than most of his contemporaries. Old modes of thinking had survived along with the new. In his description of conception he reverts to inadequate observation, metaphorical language, philosophical idealism, and sheer male vanity. By the time microscopes were invented in Holland at the beginning of the seventeenth century, the anatomists had seized the initiative. The new device strengthened their position by allowing for the examination of small structures such as capillaries. Blood corpuscles were described for the first time and bacteria were identified, though a full-fledged germ theory would not be verified until the nineteenth century. These discoveries made sustaining the ancient metaphor of the human body as a microcosm of the universe even more difficult. The body was beginning to look more like a machine within a machine. (Hause & Maltby, 2004, pp. 297-8)

The new beliefs of the seventeenth and eighteenth centuries strengthened the claim that science should be useful and applied for the betterment of civilization. Yet the connections between science and technology in the period of the Scientific Revolution were not yet clear. Inventions like the printing press, cannons, and the gunned ship had an impact on the period, yet their development proceeded without the applications of science or natural philosophy. With the exception of cartography(the art of map making), no technological application or development from science produced a significant economic, medical, or military impact in the early modern period. Until the Industrial Revolution, European science and technology remained the largely separate enterprises, intellectually and sociologically, as they had been since antiquity. The creation and importance of the telescope and microscope and their impact on optics, astronomy, and medicine seem to be the exception. Yet in general, science and technology did not interact strongly in the era of the Scientific Revolution. In areas where scientific insights had realistic significance, natural philosophers and scientists were ignored in favor of engineers, builders, architects, craftsmen, and others with practical empirical experience. Indeed, contemporary technology seems to have had a greater effect on science than the other way around. The modern alliance between science and technology did not appear during the Scientific Revolution. Not until the end of the eighteenth and the beginning of the nineteenth century did science and technology begin to bear substantial fruit with the invention of the steam engine by James Watt in 1781, and the commencement of the Industrial Revolution.

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