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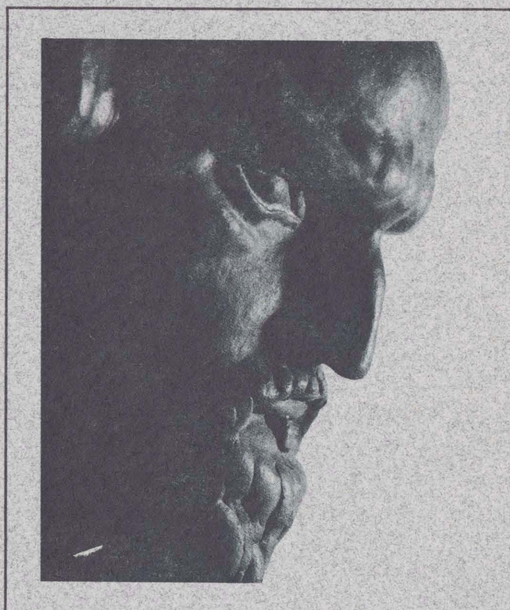

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On the Shoulders of Giants: The Progress of Science in the Seventeenth Century

BY ERICH M. HARTH

To give an account of the scientific revolution of the seventeenth century is like ploughing the sea. Every fact, taken up and examined, only brings up more, equally significant and wondrous facts in a seemingly inexhaustible flood. I can do no more than pick a few samples and attempt through them to convey the unique spirit of that epoch.

Events in the sixteenth century set the stage for what was about to happen. The studies of Vesalius (*De humani corporis fabrica*, 1543) represented the first hard look at human anatomy and dispelled much of what had been taught by Galen many centuries earlier. Paracelsus similarly inveighed against Galenic doctrine and became the forerunner of modern pharmacology. Though himself a mystic, he poked fun at many superstitions. The most profound change was brought about by the publication in 1543 of *De revolutionibus orbium coelestium*, in which Copernicus set forth his daring concept of a moving earth that was a planet among other planets, rather than the center of the universe. This notion was contrary to Aristotelian concepts, but, more significantly, challenged the then accepted church doctrine of a unique and central earth. Near the close of the sixteenth century Tycho Brahe performed his painstaking astronomical measurements that were to become the foundation of Kepler's laws of planetary motion.*

But sixteenth-century science was almost wholly in the mystical tradition, based on the tenets of Christian dogma, on the one hand, and the occult tradition known as neo-Platonism, on the other. Neo-Platonists, or hermetics, as they were called, claimed as the source of their philosophy the legendary figure of Hermes Trismegistus. Their mysticism did not disappear in the seventeenth century; indeed, it held

*The George Arents Research Library has in its collections a number of the early titles mentioned by Professor Harth. For holdings of seventeenth-century works, the reader may refer to the catalogue which follows this essay.

a powerful sway over some of the most prominent figures in science from Kepler to Newton. But we see now, along with neo-Platonism and the traditional 'organic' interpretation of nature, the rise of a new and powerful approach, *mechanism*, whose most eloquent early spokesman was Galileo. Also, we see the rebirth of the ancient concept of *atomism*, represented by such names as the German physician and chemist Daniel Sennert (*Notes on Physics*, 1636), Pierre Gassendi (*Observations on the Tenth Book of Diogenes Laertius*, 1649), René Descartes (*Principia Philosophiae*, 1644), Robert Boyle (*The Skeptical Chemist*, 1661, and *Origin of Forms and Qualities*, 1666), and, of course, Isaac Newton. But often the mechanistic-atomistic outlook was coupled with the mysticism inherited from the past. In the seventeenth century only a handful of scientists and some philosophers such as Hobbes, Locke, and Spinoza proclaimed the kind of pure mechanism that was to become popular in eighteenth-century enlightenment.

The seventeenth century begins with a tragedy. In Rome, on 19 February 1600, Giordano Bruno, at the age of fifty-two, tried and convicted of heresies by the Inquisition, was burned at the stake in the Piazza Campo de' Fiori. The shock of that example was not soon to be forgotten. Thirty-three years later Galileo was called before the Inquisition because of his Copernican views. One of his accusers was Cardinal Bellarmine, who had also participated in the trial of Giordano Bruno.

Sixteen hundred was also the year in which William Gilbert published *De magnete*, considered the first significant English contribution to science. In it Gilbert described his experiments with lodestones and magnetized needles, and hypothesized that the entire earth was one gigantic lodestone. As Paracelsus before him, Gilbert laced his writings with passionate attacks on occultism. But he was himself very much under the influence of both neo-Platonism and scholasticism.

The same is true of Johann Kepler (1571-1630). His first published work, *Mysterium Cosmographicum*, is a turgid piece of mysticism, in which he derives the orbital radii of the planets from the geometry of the five perfect solids. His later and more significant *Astronomia Nova* (1609) and *Harmonice Mundi* (1619) incorporate the astronomical observations of Brahe and brilliantly deduce from them the celebrated three laws of planetary motion. The first of these announces that planets move in ellipses, not circles — as radical a departure from Aristotelian dogma as the heliocentric view of Copernicus. These later works, too,

Galileo presented both the Ptolemaic theory of the geo-centered universe and the Copernican heliocentric theory of the organization of the solar system in a series of dialogues. But the argument was presented in such a way that the Ptolemaic theory was ridiculed. Publication of this book resulted in Galileo's trial by the Inquisition in 1633.

Galileo Galilei, *Dialogo*. Florence, 1632.

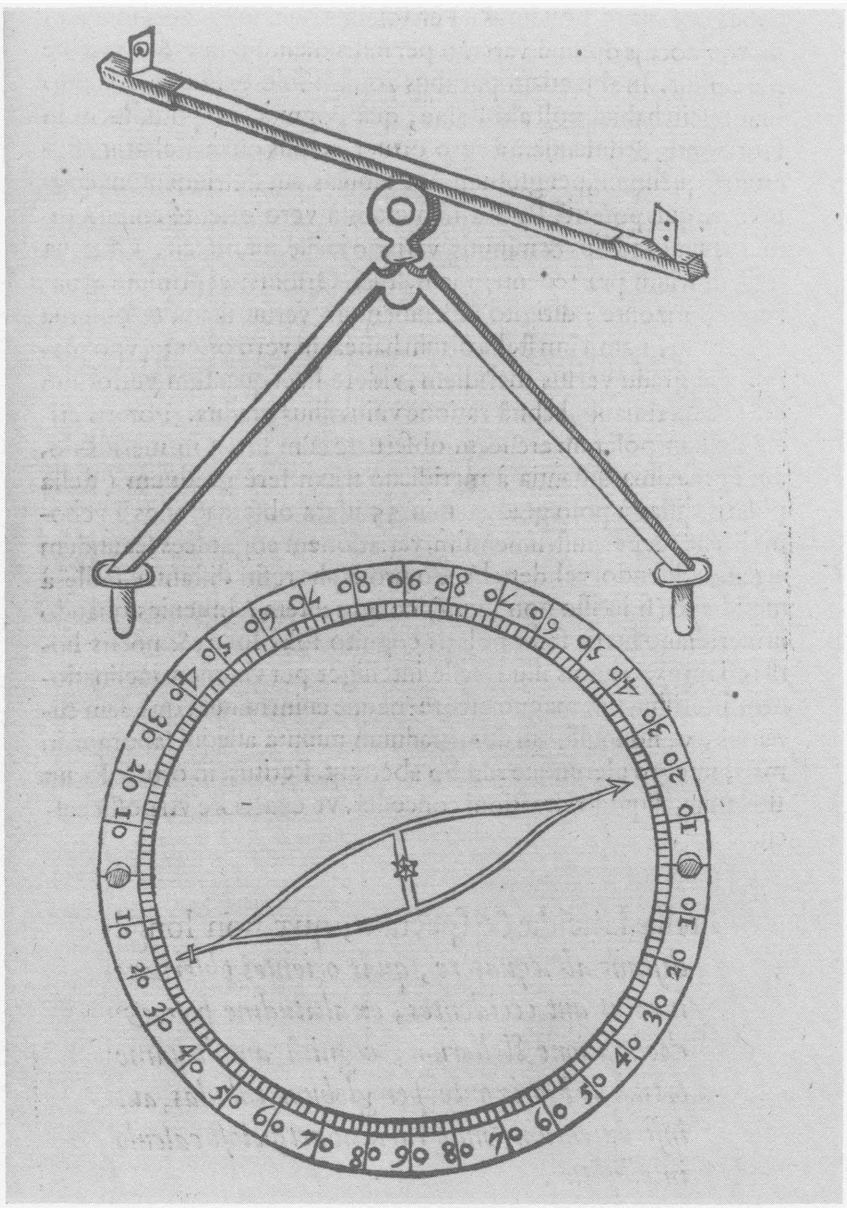
are full of mystical references and show as yet no sign of a mechanistic interpretation. It was perhaps that feature which was responsible for Galileo's almost total indifference to Kepler's work. Galileo, the ardent champion of the heliocentric system, continued to believe that all heavenly bodies move in circles, or perhaps epicycles, as Ptolemy had supposed.

Galileo was launched almost by accident into his research on astronomy. Having come across the newly invented telescope, he turned the instrument skyward and there discovered a number of facts that convinced him of the wrongness of Aristotle's geocentric view and the belief that spherical perfection pertains to everything beyond the terrestrial orb. In his *Messenger from the Stars* (1610), he describes the mountains and valleys on the moon, refuting once and for all the notion that the smudges seen with the unaided eye are but the 'mark of Cain' caused by viewing the polished sphere with imperfect eyes from the imperfect earth. With his telescope he discovered four moons of Jupiter forming another planetary system; and in observing the phases of Venus, he demonstrated irrefutable proof for the heliocentric system.

But powerful arguments were brought forth against this notion. If the earth is moving through space, wouldn't we and everything on its surface slide off and be left behind? The problem is embodied in a contemporary cartoon showing a cannon firing straight up and the caption asking "Retombera t'il?" (Will it fall back?). The Aristotelian answer would be: "No, the cannonball would land somewhere else if the earth were moving while the cannonball was going through the air".

This problem pinpoints a fundamental property of all material bodies that was not clearly appreciated until Newton: inertia. Galileo's answer was only partly correct. The motion of earth, he states, cannot be felt because we are taking part in it. He presents his argument with the clarity and persuasiveness that are his hallmark:

> The goods with which a ship is laden leaving Venice, pass by Corfu, by Crete, by Cyprus and go to Aleppo. Venice, Corfu, Crete, etc. stand still and do not move with the ship; but as to the sacks, boxes, and bundles with which the boat is laden and with respect to the ship itself, the motion from Venice to Syria is as nothing, and in no way alters their relation among themselves. This is so because it is common to all of them and



Instrument designed by Gilbert to determine the variation of a mariner's compass at sea, from his great work on the magnet, which was considered the first significant example of the experimental method.
William Gilbert, *De Magnete*. London, 1600.

all share equally in it. If, from the cargo in a ship, a sack were lifted from a chest one single inch, this alone would be more of a movement for it than the two-thousand–mile journey made by all of them together.

The quote above is taken from Galileo's second major work, the *Dialogue Concerning the Two Chief World Systems*, which was published in Florence in 1632. Albert Einstein stated in a foreword to a modern edition that Galileo here addresses "educated men of his age in such clear and impressive language as to overcome the anthropocentric and mythical thinking of his contemporaries and to lead them back to an objective and causal attitude toward the cosmos, an attitude which had become lost to humanity with the decline of Greek culture".

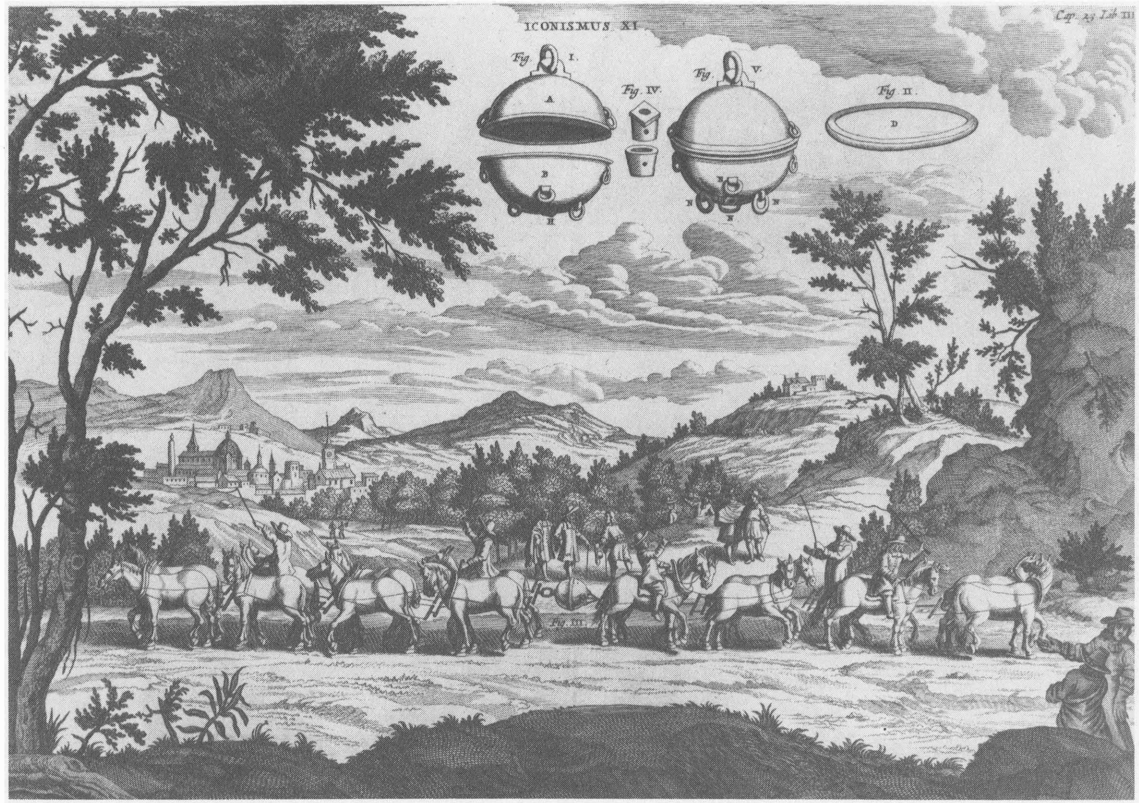
But Galileo's statement regarding our inability to sense the earth's motion is more a statement of fact rather than a recognition of the principle of inertia. In that, it is not very different from Giordano Bruno's description some fifty years earlier of motion in a moving frame of reference. This passage is taken from the Third Dialogue of Bruno's *Ash Wednesday Supper* (*La cena de le Ceneri*, 1584):

> [If] someone who is inside the ship would throw a stone straight up, it would return to the bottom along the same line, however far the ship moved, provided it was not subject to any pitch and roll.

Although Galileo's advocacy of the Copernican world systems might seem persuasive to us, it was either not persuasive enough or perhaps too much so to some of his contemporaries. The church hierarchy might have tolerated a 'philosophical argument' for a moving earth, but not an unequivocal statement to that effect.

Pronounced guilty of "holding as true the false doctrine taught by some that the sun is the center of the world and immovable and that the earth moves", Galileo appeared to be a man broken in spirit. He was made, for the remainder of his life, a virtual prisoner at his small country estate in Arcetri. He was then already seventy years old.

Five years later, however, he published his monumental *Dialogue and Mathematical Demonstrations Concerning Two New Sciences*. The work is without question his most significant contribution, since it represents nothing less than the foundation of the science of physics.



By placing two hemispheres tightly together and then evacuating the air using a pump he had devised, von Guericke demonstrated that the force of atmospheric pressure was so great that teams of horses could not pull the hemispheres apart. Otto von Guericke, *Experimenta Nova*. Amsterdam, 1672.

It is a masterpiece of precision and lucidity. Evidently unable to publish in Italy, Galileo gave a copy of the manuscript to the Count of Noailles to "give evidence that my silence was not to be interpreted as complete idleness". It was printed by the Elzeviers in Leiden in 1638.

If setting an example had been the object in the Church's condemnation of Galileo, it had clearly achieved its purpose. Younger than Galileo by some thirty years, René Descartes was about to publish a major scientific work expounding a heliocentric and mechanistic universe, when he heard about Galileo's trial. The book was to have had the ambitious title *Le Monde*, but it never saw print, except for a posthumous edition (Paris, 1664) of fragments of the work. In a letter to Mersenne, Descartes explains:

> This has so strongly affected me that I have almost resolved to burn all my manuscript, or at least to show it to no one . . . on no account will I publish anything that contains a word that might displease the church.

His fear of censure by the authorities might explain Descartes' often expressed piety, which stands in strange contrast to his thoroughly mechanistic approach to nature. The world is a machine, the human body is a machine. But there is also a soul and free will. His dualism, which is the assertion of reality of the body and the mind, is one of the most precarious structures ever erected by a philosopher. Yet it has had remarkable durability. It is still held by a few scientists today.

Isaac Newton was born in 1642, the year Galileo died. It was, in retrospect, the ideal time for him to be born, because the second half of the seventeenth century was a time of the most intense and rewarding scientific activity all over Europe. Newton's unique genius made him easily the most successful and universally venerated scientist. He stood, in his own words, "on the shoulders of giants", and he was surrounded and in close communication with a galaxy of geniuses. His own contribution to physics was so profound and lasting that he has been compared with some of the founders of great religions. His mechanics has been the foundation of physics ever since the publication of his *Principia* (1687) and his law of universal gravitation made physics truly a cosmic science.

He was not completely unchallenged, however. His invention of the calculus led to a protracted controversy with Leibnitz over priorities,

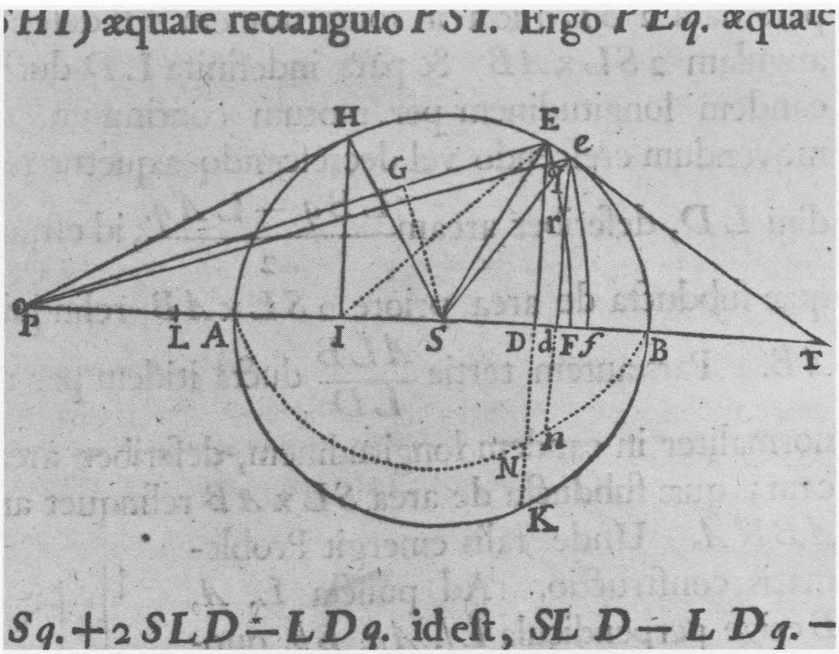


Illustration from Newton's *Principia*, the first great scientific synthesis, in which Newton formulated the Three Laws of Motion. In this book, considered the climax of the scientific revolution, the mechanism of the universe was explained through mathematical analysis. Isaac Newton, *Principia Mathematica*. London, 1687.

while his corpuscular theory of light conflicted with that of his contemporary, Christian Huygens.

Science—not only physics and astronomy, but also chemistry, biology, physiology, anatomy, geology, and oceanography—was now flourishing on all fronts. Scientific societies and national academies were founded all over Europe. The Académie des Sciences in France received the royal charter from Louis XIV in 1666. The Royal Society of London was founded in 1660 and began publishing its famous *Transactions* in 1665, which are to this day a major outlet for scientific information.

The scientific enterprise had become international. The Dutch physicist Huygens, a member of the Royal Society of London as well as the Académie des Sciences, was proud to correspond in six languages with fellow scientists in other countries. "The world is my country", he once stated, and "to promote science is my religion".

The few decades since the beginning of the century had brought about enormous changes. A repetition of the tragedy of Giordano Bruno seems almost unthinkable in the enlightened latter half of the 1600s. But the spirit of the Middle Ages had not yet died completely. Isaac Newton, who gave us a rigid system of mechanics, also spent much time in his laboratory at Cambridge in the pursuit of occult dreams: the philosopher's stone, the elixir of life, changing base metals into gold. Besides the *Principia* he also left behind numerous notes on alchemy. Perhaps we should not be too surprised at this paradox, because that period only mirrors our own. It is instructive to ponder how impressed Newton would be if he were to witness the state of today's science and technology, and how our superstitions might still get a chuckle from that sixteenth-century mystic, Paracelsus.