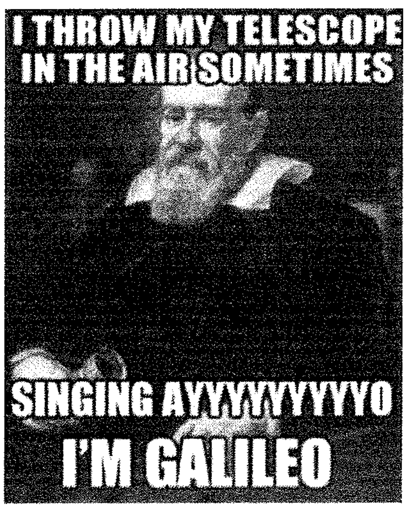
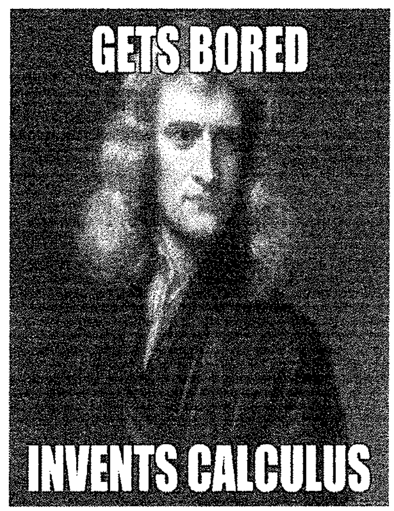
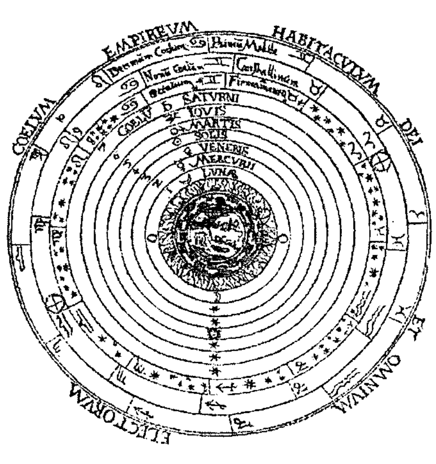
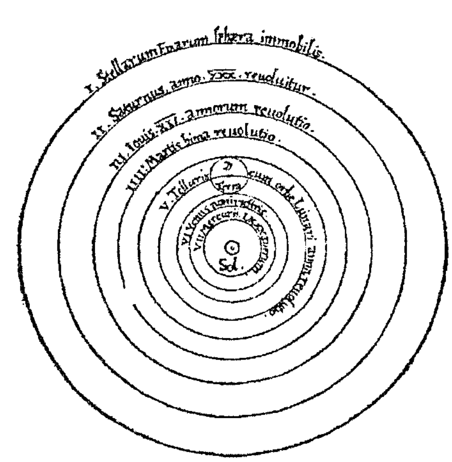
AP EURO READINGS
CHAPTER 16: TOWARD A NEW HEAVEN AND EARTH–
THE SCIENTIFIC REVOLUTION

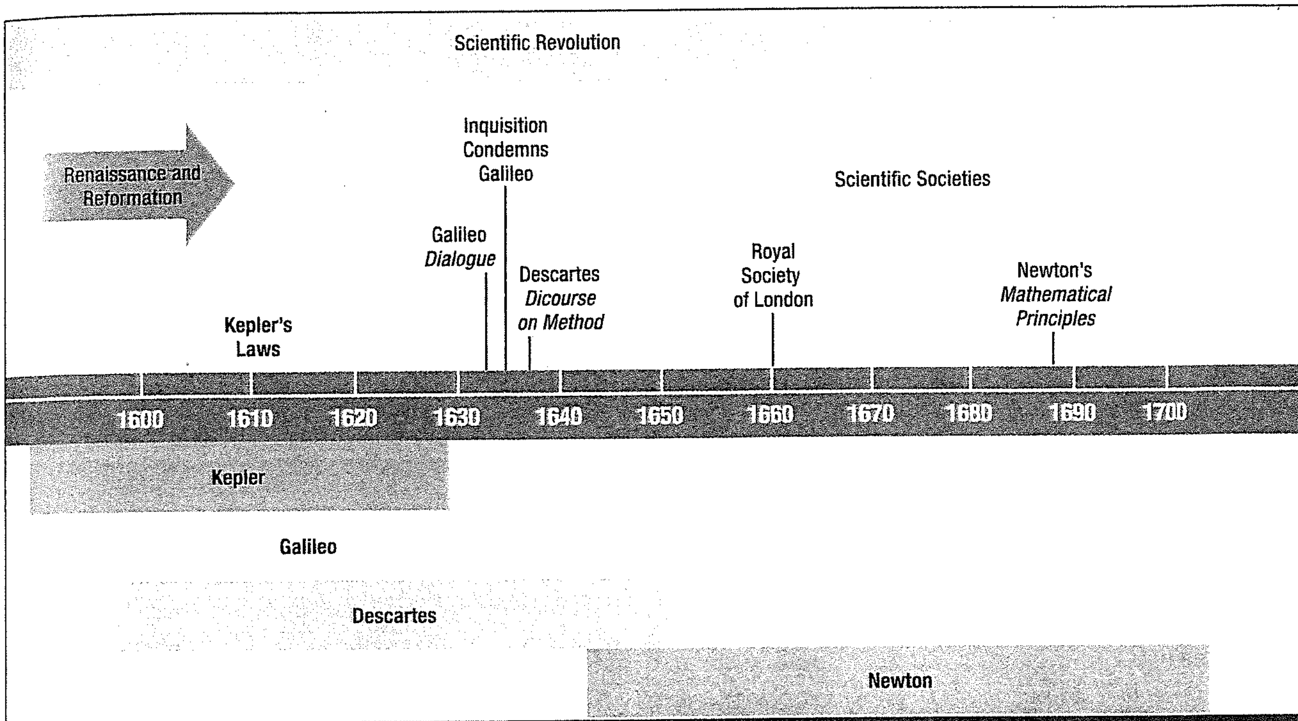
Table of Contents:











6 The Scientific Revolution

One of the most important intellectual revolutions in Western civilization occurred in the seventeenth century. Building on some sixteenth-century breakthroughs and a more deeply rooted interest in the workings of the natural world, a small elite of thinkers and scientists—Descartes, Galileo, Newton, Kepler, Bacon, and Boyle—established the foundations for the modern sciences of astronomy, mathematics, physics, and chemistry. Although at first their work was known to only a few, their ideas spread widely during the eighteenth century.

In the process of developing the modern sciences, these thinkers challenged the established conception of the universe as well as previous assumptions about knowledge. This ultimately successful challenge, now known as the Scientific Revolution, had a number of key elements. First, the view of the universe as being stable, fixed, and finite, with the earth at its center, gave way to a view of the universe as moving and almost infinite, with the earth merely one of millions of bodies, all subject to the laws of nature. Second, earlier methods for ascertaining the truth, which primarily involved referring to traditional authorities such as Aristotle, Ptolemy, and the Church, were replaced by methods that emphasized scepticism, rationalism, and rigorous reasoning based on observed facts and mathematical laws. Third, although these thinkers remained concerned with their own deeply held religious beliefs, the general scientific orientation shifted from theological questions to secular questions that focused on how things worked.

The primary documents in this chapter emphasize two broad questions that faced these seventeenth-century scientists. First, how can one ascertain the truth? The answers of Descartes, Galileo, and Newton are examined. Second, what is the proper line between science and scriptural authority? Galileo, who came most directly into conflict with Church authorities, provides us with clues.

The secondary documents concentrate on the nature and causes of the Scientific Revolution. In what ways was seventeenth-century science different from the science of earlier centuries? What explains these differences? What were the motives of seventeenth-century scientists?

Most of these intellectual developments were known to only a few throughout Europe. In the eighteenth century these scientific ideas and methods became popularized as part of the intellectual ferment of the Enlightenment.

For Classroom Discussion

What is the core of the Scientific Revolution? Use the sources by Descartes, Galileo, and Newton, as well as the analysis by Shapin.

Primary Sources

The Discourse on Method

René Descartes

Seventeenth-century science needed new philosophical and methodological standards for truth to replace those traditionally used to support scientific assumptions. These were forcefully provided by René Descartes (1596–1650) in his Discourse on Method *(1637). Born and educated in France, but spending his most productive years in Holland, Descartes gained fame as a mathematician, physicist, and metaphysical philosopher. The following excerpt from his* Discourse *contains the best-known statement of his approach to discovering truth.*

CONSIDER: *The ways in which Descartes' approach constitutes a break with traditional ways of ascertaining the truth; the weaknesses of this approach and how a modern scientist might criticize this method; how this approach reflects Descartes' background as a mathematician.*

In place of the multitude of precepts of which logic is composed, I believed I should find the four following rules quite sufficient, provided I should firmly and steadfastly resolve not to fail of observing them in a single instance.

The first rule was never to receive anything as a truth which I did not clearly know to be such; that is, to avoid haste and prejudice, and not to comprehend anything more in my judgments than that which should present itself so clearly and so distinctly to my mind that I should have no occasion to entertain a doubt of it.

The second rule was to divide every difficulty which I should examine into as many parts as possible, or as might be required for resolving it.

The third rule was to conduct my thoughts in an orderly manner, beginning with objects the most simple and the easiest to understand, in order to ascend as it were by steps to the knowledge of the most composite, assuming some order to exist even in things which did not appear to be naturally connected.

The last rule was to make enumerations so complete, and reviews so comprehensive, that I should be certain of omitting nothing.

Those long chains of reasoning, quite simple and easy, which geometers are wont to employ in the accomplishment of their most difficult demonstrations, led me to think that everything which might fall under the cognizance of the human mind might be connected together in a similar manner, and that, provided only one should take care not to receive anything as true which was not so, and if one were always careful to preserve the order necessary for deducing one truth from another, there would be none so remote at which he might not at last arrive, nor so concealed which he might not discover. And I had no great difficulty in finding those with which to make a beginning, for I knew already that these must be the simplest and easiest to apprehend; and considering that, among all those who had up to this time made discoveries in the sciences, it was the mathematicians alone who had been able to arrive at demonstrations—that is to say, at proofs certain and evident—I did not doubt that I should begin with the same truths which they investigated.

SOURCE: René Descartes, *The Discourse on Method*, in *The Philosophy of Descartes*, ed. and trans. Henry A. P. Torrey (New York: Henry Holt, 1982), pp. 46–48.

Letter to Christina of Tuscany: Science and Scripture

Galileo Galilei

The most renowned scientist at the beginning of the seventeenth century was the Italian astronomer, mathematician, and physicist Galileo Galilei (1564–1642). His discoveries

SOURCE: From Galileo Galilei, *Discoveries and Opinions of Galileo*, Stillman Drake, ed. and trans. Reprinted by permission of Doubleday & Company, Inc. (New York, 1957), pp. 182–183.

(2)

about gravity, velocity, and the movement of astronomical bodies were grounded in a scientific method that ran contrary to the accepted standards for truth and authority. In the following excerpt from a letter to the Grand Duchess Christina of Tuscany (1615), Galileo defends his ideas and delineates his view of the correct line between science and scriptural authority.

CONSIDER: *According to Galileo's view, the kinds of topics or questions that are appropriately scientific and those that are appropriately theological; how Galileo's views compare with those of Descartes; why Galileo's views are so crucial to the Scientific Revolution.*

I think that in discussions of physical problems we ought to begin not from the authority of scriptural passages, but from sense-experiences and necessary demonstrations; for the holy Bible and the phenomena of nature proceed alike from the divine Word, the former as the dictate of the Holy Ghost and the latter as the observant executrix of God's commands. It is necessary for the Bible, in order to be accommodated to the understanding of every man, to speak many things which appear to differ from the absolute truth so far as the bare meaning of the words is concerned. But Nature, on the other hand, is inexorable and immutable; she never transgresses the laws imposed upon her, or cares a whit whether her abstruse reasons and methods of operation are understandable to men. For that reason it appears that nothing physical which sense-experience sets before our eyes, or which necessary demonstrations prove to us, ought to be called in question (much less condemned) upon the testimony of biblical passages which may have some different meaning beneath their words. For the Bible is not chained in every expression to conditions as strict as those which govern all physical effects; nor is God any less excellently revealed in Nature's actions than in the sacred statements of the Bible. . . .

From this I do not mean to infer that we need not have an extraordinary esteem for the passages of holy Scripture. On the contrary, having arrived at any certainties in physics, we ought to utilize these as the most appropriate aids in the true exposition of the Bible and in the investigation of those meanings which are necessarily contained therein, for these must be concordant with demonstrated truths. I should judge that the authority of the Bible was designed to persuade men of those articles and propositions which, surpassing all human reasoning, could not be made credible by science, or by any other means than through the very mouth of the Holy Spirit.

Yet even in those propositions which are not matters of faith, this authority ought to be preferred over that of all human writings which are supported only by bare assertions or probable arguments, and not set forth in a demonstrative way. This I hold to be necessary and proper to the same extent that divine wisdom surpasses all human judgment and conjecture.

But I do not feel obliged to believe that that same God who has endowed us with senses, reason, and intellect has intended to forgo their use and by some other means to give us knowledge which we can attain by them.

The Papal Inquisition of 1633: Galileo Condemned

Not surprisingly, Galileo found his views under attack from a variety of corners, including important groups within the Church. Ultimately his defense of Copernicanism, which held that the earth was not the center of the universe, was formally condemned by the Church. When he argumentatively summarized these ideas again in his Dialogue Concerning the Two Chief World Systems *(1632), he was brought before the Papal Inquisition, forced to recant his views, and confined to a villa on the outskirts of Florence. The following are some of the main charges against Galileo during his trial for heresy before the Inquisition in 1633.*

CONSIDER: *Why Galileo's views were so threatening to the Church; some of the long-range consequences of such a stance by the Church toward these views.*

We say, pronounce, sentence, and declare that you, the said Galileo, by reason of the matters adduced in trial, and by you confessed as above, have rendered yourself in the judgment of this Holy Office vehemently suspected of heresy, namely, of having believed and held the doctrine—which is false and contrary to the sacred and divine Scriptures—that the Sun is the center of the world and does not move from east to west and that the Earth moves and is not the center of the world; and that an opinion may be held and defended as probable after it has been declared and defined to be contrary to the Holy Scripture; and that consequently you have incurred all the censures and penalties imposed and promulgated in the sacred canons and other constitutions, general and particular, against such delinquents. From which we are content that you be absolved, provided that, first, with a sincere heart and unfeigned faith, you abjure, curse, and detest before us the aforesaid errors and heresies and every other error and heresy contrary to the Catholic and Apostolic Roman Church in the form to be prescribed by us for you.

SOURCE: Excerpt from George Santillana, *The Crime of Galileo*, p. 310. Reprinted by permission of The University of Chicago Press (Chicago, 1955).

Mathematical Principles of Natural Philosophy

Sir Isaac Newton

The greatest scientific synthesis of the seventeenth century was made by Isaac Newton (1642–1727), who was born in England and attained a post as professor of mathematics at Cambridge University. Newton made his most important discoveries early in life. By the beginning of the eighteenth century he was the most admired scientific figure in Europe. He made fundamental discoveries concerning gravity, light, and differential calculus. Most important, he synthesized various scientific findings and methods into a description of the universe as working according to measurable, predictable mechanical laws. Newton's most famous work, Mathematical Principles of Natural Philosophy *(1687), contains his theory of universal gravitation. In the following selection from that work, Newton describes his four rules for arriving at knowledge.*

CONSIDER: *Why Newton's rules might be particularly useful for the experimental sciences; ways these rules differ from those of Descartes.*

RULE I

We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.

To this purpose the philosophers say that Nature does nothing in vain, and more is in vain when less will serve; for Nature is pleased with simplicity, and affects not the pomp of superfluous causes.

RULE II

Therefore to the same natural effects we must, as far as possible, assign the same causes.

As to respiration in a man and in a beast; the descent of stones in *Europe* and in *America;* the light of our culinary fire and of the sun; the reflection of light in the earth, and in the planets.

RULE III

The qualities of bodies, which admit neither intensification nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.

For since the qualities of bodies are only known to us by experiments, we are to hold for universal all such as universally agree with experiments; and such as are not liable to diminution can never be quite taken away.

RULE IV

In experimental philosophy we are to look upon propositions inferred by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions.

This rule we must follow, that the argument of induction may not be evaded by hypotheses.

SOURCE: Sir Isaac Newton, *Mathematical Principles of Natural Philosophy,* trans. Andrew Motte, rev. Florian Cajori (Berkeley, CA: University of California Press, 1947), pp. 398, 400. Reprinted by permission of the University of California Press.

Visual Sources

The Alchemist

Cornelis Bega

This 1663 painting (figure 6.1) by Dutch artist Cornelis Bega (c. 1631–1664) shows an alchemist at work. Here he is about to place a red, powdery material on scales he is holding—apparently part of a typical alchemist's experiment, perhaps to create new substances or transmute material into gold. The books, papers, jars, bottles, and hidden substances in this room are other tools of his trade. This crowded, shabby interior and the alchemist's unkempt clothing suggest the questionable or futile results of his efforts, but during the seventeenth century some scientists still took alchemy quite seriously.

CONSIDER: *The ways this painting presents a contradictory image of alchemy; how this scene might fit with our understanding of the Scientific Revolution.*

A Vision of the New Science

One of the most important figures of the Scientific Revolution was the astronomer and mathematician Johannes Kepler (1571–1630). Figure 6.2 shows a page from the front of one

4

The picture reveals much about the Scientific Revolution. The instruments emphasize how important measurement and observation were to the new science. The depiction of the old and new pillars suggests that the new scientists were replacing if not necessarily challenging the old, accepted scientific authorities by building on the work of their immediate predecessors—here Brahe on Copernicus, and Kepler on Brahe and Copernicus. The importance of communication among scientists is indicated by tribute to the printing press.

CONSIDER: *How this picture illustrates the ways in which seventeenth-century scientists were breaking with earlier scientific assumptions.*

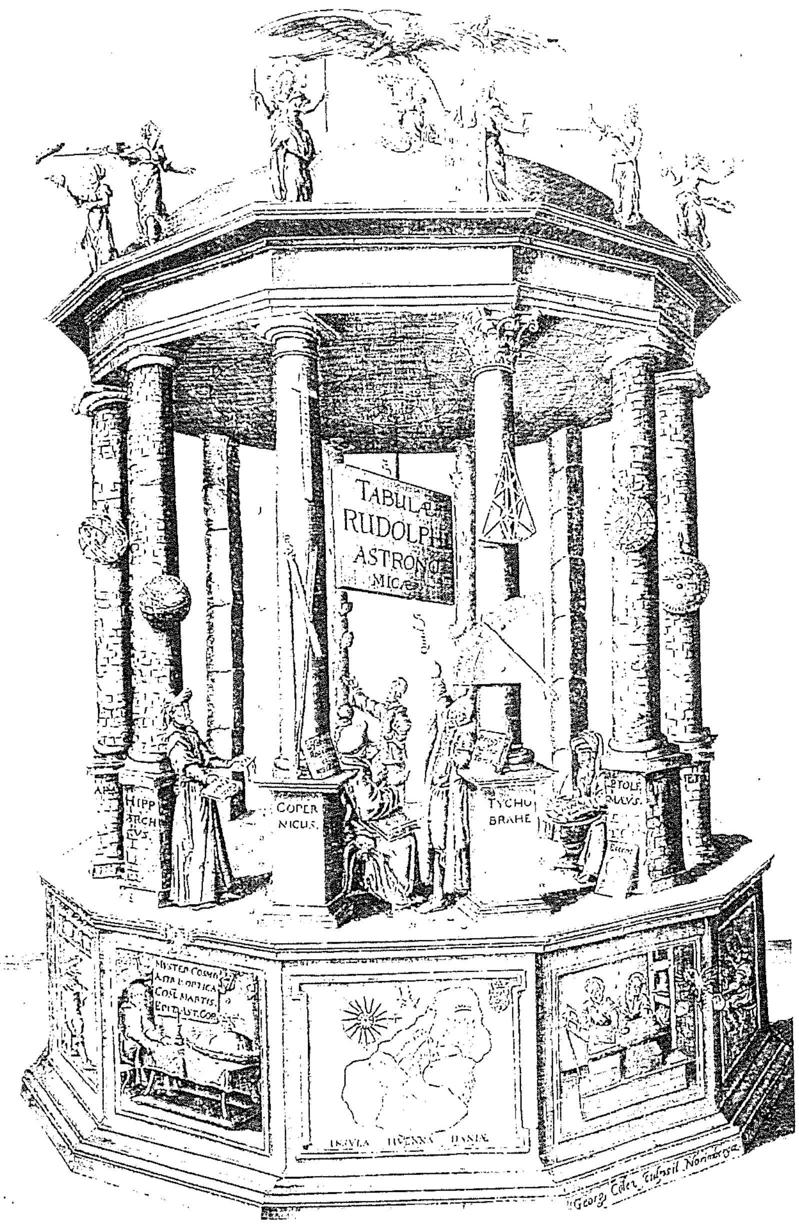


FIGURE 6.2 (Private Collection/© The Bridgeman Art Library International)

The Anatomy Lesson of Dr. Tulp

Rembrandt van Rijn

This 1632 painting by Dutch artist Rembrandt van Rijn (1606–1669; figure 6.3) shows Dr. Nicholass Tulp using the body of a hanged criminal to give an anatomy lesson. Public autopsies such as this took place in The Netherlands as well as other areas in seventeenth-century Europe. Typically they were attended by students, colleagues, and ordinary citizens and were held in anatomy theatres such as this one in Amsterdam. The dress of the seven men—all surgeons—observing Dr. Tulp's work suggests that they are taking part in an important official occasion. Their attentive presence—especially of the two surgeons closest to Dr. Tulp—reveals the growing interest in understanding the human body, the effort to associate surgery with science, and the rising prestige of their profession. However, only Dr. Tulp had attended university. In addition to holding a doctorate in medicine and serving here as a teacher, Dr. Tulp was an important public official in Amsterdam: only he wears his hat in the indoor scene.

On the far right stands an open book, suggesting the learning that has gone into this lecture and the growing connections between academic writings about medicine and the facts of the human body. However, during the seventeenth century surgeons did not enjoy high reputations, and confidence in the medical profession in general was, with some good reason, low. Moreover anatomy lessons such as this were held not only for "scientific" purposes. They had to be justified as research to confirm Christian beliefs about God's omnipotence. There were also less solemn aspects to these events: Observers typically paid a fee, and a banquet often followed the autopsy.

CONSIDER: *The changing views toward science and medicine suggested by this painting.*

The Anatomy Lesson of Dr. Tulp - Rembrandt - Dutch Golden Age/ Dutch Baroque

FIGURE 6.3 (© Erich Lessing/Art Resource, NY)

Secondary Sources

Early Modern Europe: Motives for the Scientific Revolution

Sir George Clark

By the seventeenth century, certain broad historical developments had set the stage for individuals to make the discoveries we associate with the Scientific Revolution. In addition, these individuals were motivated in ways that medieval people were not and used the new and growing body of techniques, materials, and knowledge to make their discoveries. In the following selection, British historian Sir George Clark, a recognized authority on the seventeenth century, examines some of the motives that led people to engage in scientific work.

SOURCE: Sir George Clark, *Early Modern Europe*. Reprinted by permission of The Oxford University Press (Oxford, England, 1957), pp. 164–165.

CONSIDER: *The distinctions Clark makes among different people engaged in scientific work; why, more than thirteenth- or fourteenth-century people, these seventeenth-century people had a "disinterested desire to know."*

There were an infinite number of motives which led men to engage in scientific work and to clear the scientific point of view from encumbrances; but we may group together some of the most important under general headings, always remembering that in actual life each of them was compounded with the others. There were economic motives. The Portuguese explorers wanted their new instrument for navigation; the German mineowners asked questions about metallurgy and about machines for lifting and carrying heavy loads; Italian engineers improved their canals and locks and harbours by applying the principles of hydrostatics; English trading companies employed experts who used new methods of drawing charts. Not far removed from the economic motives were those of the physicians and surgeons, who revolutionized anatomy and physiology, and did much more good than harm with their new medicines and new operations, though some of them now seem absurd. Like the doctors, the soldiers called science to their aid in designing and aiming artillery or in planning fortifications. But there were other motives far removed from the economic sphere. Jewellers learnt much about precious and semi-precious stones, but so did magicians. Musicians learnt the mathematics of harmony; painters and architects studied light and colour, substances and proportions, not only as craftsmen but as artists. For a number of reasons religion impelled men to scientific study. The most definite and old-established was the desire to reach absolute correctness in calculating the dates for the annual fixed and movable festivals of the Church: it was a pope who presided over the astronomical researchers by which the calendar was reformed in the sixteenth century. Deeper and stronger was the desire to study the wonders of science, and the order which it unravelled in the universe, as manifestations of the Creator's will. This was closer than any of the other motives to the central impulse which actuated them all, the disinterested desire to know.

Nature as a Machine: The Clock

Steven Shapin

A new way of thinking about nature became central to the Scientific Revolution. During the seventeenth century, natural philosophers increasingly used the model of a machine to describe the workings of the natural world. In the following selection, Steven Shapin argues that the mechanical clock served as the most appealing metaphor for understanding nature.

CONSIDER: *Why natural philosophers wanted to model nature on the characteristics of a machine; why, of all machines, the clock became the preferred metaphor.*

The framework that modern natural philosophers preferred to Aristotelian teleology was one that explicitly modeled nature on the characteristics of a *machine*. So central was the machine metaphor to important strands of new science that many exponents liked to refer to their practice as the *mechanical philosophy*. Modern practitioners disputed the nature and the limits of mechanical explanation, but *proper* mechanical accounts of nature were widely recognized as the goal and the prize. . . .

Of all the mechanical constructions whose characteristics might serve as a model for the natural world, it was the *clock* more than any other that appealed to many early modern natural philosophers. Indeed, to follow the *clock metaphor* for nature through the culture of early modern Europe is to trace the main contours of the mechanical philosophy, and therefore of much of what has been traditionally construed as central to the Scientific Revolution. . . .

For those sectors of European society for whom the clock and its regulatory functions were important aspects of daily experience, this machine came to offer a metaphor of enormous power, comprehensibility, and consequence. The allure of the machine, and especially the mechanical clock, as a uniquely intelligible and proper metaphor for explaining natural processes not only broadly follows the contours of daily experience with such devices but also recognizes their potency and legitimacy in ordering human affairs. . . .

In 1605 the German astronomer Johannes Kepler (1571–1630) announced his conversion from his former belief that "the motor cause" of planetary motion "was a soul": "I am much occupied with the investigation of the physical causes. My aim in this is to show that the machine of the universe is not similar to a divine animated being, but similar to a clock." In the 1630s Descartes elaborated a set of extended causal analogies between the movements of mechanical clocks and those of all natural bodies, not excepting even the movements of the human body: "We see that clocks . . . and other machines of this kind, although they have been built by men, do not for this reason lack the power to move by themselves in diverse ways." Why shouldn't human respiration, digestion, locomotion, and sensation be accounted for in just the way we explain the motions of a clock, an artificial fountain, or a mill? In the 1660s the English mechanical philosopher Robert Boyle (1627–91) wrote that the natural world was "as it were, a great piece of clock-work." Just as the spectacular late sixteenth-century clock in the cathedral at Strasbourg (fig. 6) used mechanical parts and movements to mimic the complex motions of the (geocentric) cosmos, so Boyle, Descartes, and other mechanical philosophers recommended the clock metaphor as a philosophically legitimate way of understanding how the natural world was put together and how it functioned.

No Scientific Revolution for Women

Bonnie S. Anderson and Judith P. Zinsser

The Scientific Revolution was generally carried out by men. A few women participated directly in the Scientific Revolution, but they were the exception rather than the rule. The Scien-

---

SOURCE: Steven Shapin, *The Scientific Revolution* (Chicago: University of Chicago Press, 1996), pp. 30, 32–34.

SOURCE: Excerpts from *A History of Their Own*, vol. II, by Bonnie Anderson and Judith Zinsser. Copyright © 1988 by Bonnie Anderson and Judith Zinsser. Reprinted by permission of HarperCollins Publishers, Inc.

(US) (7)

tific Revolution was based on principles such as observing, measuring, experimenting, and coming to reasoned conclusions. Were these principles applied by men to change assumptions about women, particularly about female physiology? Bonnie S. Anderson and Judith P. Zinsser address this question in their interpretive survey of women in European history, A History of Their Own.

CONSIDER: *According to Anderson and Zinsser, why there was no Scientific Revolution for women; how perceptions of female physiology relate to broader assumptions about women and men.*

In the sixteenth and seventeenth centuries Europe's learned men questioned, altered, and dismissed some of the most hallowed precepts of Europe's inherited wisdom. The intellectual upheaval of the Scientific Revolution caused them to examine and describe anew the nature of the universe and its forces, the nature of the human body and its functions. Men used telescopes and rejected the traditional insistence on the smooth surface of the moon. Galileo, Leibnitz, and Newton studied and charted the movement of the planets, discovered gravity and the true relationship between the earth and the sun. Fallopio dissected the human body, Harvey discovered the circulation of the blood, and Leeuwenhoek found spermatozoa with his microscope.

For women, however, there was no Scientific Revolution. When men studied female anatomy, when they spoke of female physiology, of women's reproductive organs, of the female role in procreation, they ceased to be scientific. They suspended reason and did not accept the evidence of their senses. Tradition, prejudice, and imagination, not scientific observation, governed their conclusions about women. The writings of the classical authors like Aristotle and Galen continued to carry the same authority as they had when first written, long after they had been discarded in other areas. Men spoke in the name of the new "science" but mouthed words and phrases from the old misogyny. In the name of "science" they gave a supposed physiological basis to the traditional views of women's nature, function, and role. Science affirmed what men had always known, what custom, law, and religion had postulated and justified. With the authority of their "objective," "rational" inquiry they restated ancient premises and arrived at the same traditional conclusions: the innate superiority of the male and the justifiable subordination of the female.

CHAPTER QUESTIONS

1. What were the main ways in which the science of the seventeenth century constituted a break from the past? What were some of the main problems facing seventeenth-century scientists in making this break? How did they handle these problems?
2. How would you explain the occurrence of the Scientific Revolution in the seventeenth century rather than in the sixteenth or eighteenth century?

(9) (8)