COURSE GUIDEBOOK

History of Science: Antiquity to 1700

Part III

1-800-TEACH-12
1-800-832-2412
THE TEACHING COMPANY®
4151 Lafayette Center Drive, Suite 100
Chantilly, VA 20151-1232
www.teach12.com

1203

History of Science: Antiquity to 1700, Part III
Professor Lawrence M. Principe

COURSE GUIDEBOOK

The Great Courses℠
Teaching that engages the mind™

History of Science: Antiquity to 1700

Professor Lawrence M. Principe
Johns Hopkins University

Part III

THE TEACHING COMPANY®

Lawrence M. Principe, Ph.D.

Professor of History of Science, Medicine, and Technology and of Chemistry,
Johns Hopkins University

Lawrence Principe was an undergraduate at the University of Delaware, where he received a B.S. in Chemistry and a B.A. in Liberal Studies in 1983. During this time, he developed his interest in the history of science, particularly the history of alchemy and early chemistry. He then entered the graduate program in Chemistry at Indiana University, Bloomington, where he worked on the synthesis of natural products. Immediately upon completing the Ph.D. in Organic Chemistry (1988), he reentered graduate school, this time in the History of Science at Johns Hopkins University, and earned a Ph.D. in that field in 1996.

Since 1989, Professor Principe has taught Organic Chemistry at Johns Hopkins University. In 1997, he earned an appointment in History of Science and began teaching there as well. Currently, he enjoys a split appointment as professor between the two departments, dividing his teaching equally between the two at both graduate and undergraduate levels. He also enjoys annoying safety inspectors by performing alchemical experiments in his office.

In 1999, Professor Principe was chosen as the Maryland Professor of the Year by the Carnegie Foundation, and in 1998, he was the recipient of the Templeton Foundation's award for courses dealing with science and religion. He has also won several teaching awards bestowed by Johns Hopkins.

Professor Principe's interests cover the history of science of the early modern and late medieval periods and focus particularly on the history of alchemy and chemistry. His first book was entitled *The Aspiring Adept: Robert Boyle and His Alchemical Quest* (1998), and he has since collaborated on a book on seventeenth-century laboratory practices (*Alchemy Tried in the Fire*) and on a study of the image of the alchemist in Netherlandish genre paintings (*Transmutations: Alchemy in Art*). He is currently at work on a long-term study of the chemists at the Parisian Royal Academy of Sciences around 1700.

Table of Contents

History of Science: Antiquity to 1700
Part III

History of Science: Antiquity to 1700

Scope:

This course presents a survey of the history of science in the Western world from the second millennium B.C. to the early eighteenth century. The goal is to understand what science is; how, why, and by whom it has developed; and how our modern conception of science differs from earlier ideas.

The first twelve lectures deal with the ancient world. We begin with the observations of Babylonian astrologers and move to the varied conceptions of the natural world and methods for studying it worked out by the Greeks. Plato and Aristotle are key figures; their methods, worldviews, and challenges have influenced subsequent developments down even to our own day. We next consider the achievements of the later Hellenistic thinkers: Aristotle's successors, Ptolemy's astronomy, Archimedes' engineering and mathematics, among others. We then turn to the Roman versions of Greek learning, as well as to impressive examples of Roman technology. The collapse of the classical age and the attempts to preserve some of its legacy conclude this section.

The next twelve lectures treat the generally less-known science of the Middle Ages, from roughly 500–1400 A.D. After studying the response of the new religion of Christianity to Greek learning, we move to the rise of Islam and survey the Arabic world's embrace of Greek learning and culture and the significant contributions of the Muslim world in a range of scientific fields. Returning to the Latin West, we examine the discovery of Arabic and classical learning by European Christians and Latin developments in astronomy/astrology, physics, alchemy, the origin of the world, and many other areas. Several lectures deal with the rise and culture of cathedral schools, universities, Scholasticism, and intellectually minded religious orders. The fascinating and productive interplay of scientific and theological inquiry is key to this period.

The last twelve lectures cover the Renaissance and Scientific Revolution, from roughly 1450–1700. We begin with the novelties of the post-medieval period, which include a new interest in natural magic, a serious topic bearing some striking resemblances to modern science. Several lectures follow the construction of a new cosmology—Copernicus' heliocentrism, Tycho's observations, Kepler's laws, and Galileo's new physics. The expansion of European horizons with the discovery of the New World led to changes in natural history, as well as to the ways man viewed nature. The new views include those who envisioned a dead mechanical universe functioning like a clockwork, as well as those who saw a world infused with life and vital activity. One lecture looks at the enigmatic Isaac Newton, who created a powerful synthesis of seventeenth-century ideas, but who also spent more time pursuing alchemy, theology, and prophecy. The rise of scientific societies, the growth of technology, the development of chemistry, and calendrical reform provide further topics of study.

Several themes run through the course. Chief among these is the need to understand scientific study and discovery in historical context. Theological, philosophical, social, political, and economic factors deeply impact the development and shape of science. Of particular interest are the variety of ways in which human beings have tried over time to approach and describe the natural world, to evaluate their place in it, and to make use of it. Science is thus revealed as a dynamic, evolving entity, tightly connected to the needs and commitments of those who pursue it. The real context of even familiar scientific developments will frequently come as a surprise and can suggest alternative ways for present-day thinking and science to develop.

Lecture Twenty-Five

Renaissance Natural Magic

Scope: An important aspect of Renaissance natural philosophy was the rise of "natural magic." This concept was often far from what we today would generally consider "magical," because its goal was to understand the correspondences and powers that God had implanted in the world and to make use of them. Renaissance natural magic relied upon mathematics and upon a deep knowledge of astronomy, biology, botany, mineralogy, and other topics in science and technology. This lecture showcases three "*magi*" of the Renaissance: Agrippa von Nettesheim, the humanist author of a major compendium of magic; Paracelsus, the hot-tempered Swiss medical writer and iconoclast; and John Dee, the English mathematician who asked angels to tell him the secrets of God's creation. The interest in natural magic exemplifies the Renaissance desire to find and exploit alternative sources of knowledge.

Outline

I. An important aspect of the history of science in the Renaissance is the greatly increased interest in natural magic.

- **A.** Natural magic was a serious pursuit of scholars and should not be thought of as silly, irrational, or fraudulent.
    1. Natural magic is based on a worldview that there exist connections or correspondences (implanted by God at the creation) between particular groups of objects and that a learned person (a *magus*) could make use of these connections to produce specific effects.
    2. These correspondences mean that one member can influence another and, by action of analogy, learning about one member of a linked group can provide information about the other members.
    3. Natural magic is to be distinguished from demonic magic, which was universally condemned and which tried to make use of evil spirits to produce its effects. (Note that demonic forces use the same network of correspondences as the successful magus; they do not have supernatural powers, only God does.)
    4. The point of importance for us is that the magus had to *discover* these correspondences. This could be done in several ways: in most cases, from textual sources and from observation of and experimentation with the natural objects themselves.
    5. One way to discover the correspondences was by the doctrine of signatures—that God had left "markers" of the hidden relationships between things that the magus should observe.
    6. In a sense, natural magic drew on and exploited natural laws in the same way as more familiar forms of technology.

B. The Renaissance drew on many sources for natural magic.

1. Classical authors, particularly the late classical author Proclus (410–485) wrote about some of the magical correspondences in the world. The Bible also tells of magicians (such as Pharaoh's priests who turn their staffs into snakes).
2. The ancient doctrine of the macrocosm-microcosm, which long undergirded part of astrology, is one basis for natural magic.
3. The *Corpus Hermeticum*, so celebrated in the Renaissance, contains magical notions; its translator Ficino frequently invoked magical ideas.
4. The notion of occult (or hidden) qualities in Scholasticism provides another source. These are qualities of an object that are not readily explicable by its visible form, for example, the medicinal effects of various herbs or the action of the magnet.
5. There is also a close link to humanism, which put a high value on ancient texts and sought new sources of knowledge outside the traditional canons of the universities. Magic was a new source and method of acquiring knowledge.

C. The goal of the magician was to *control and utilize* the hidden links and powers in nature. These could then be turned toward accomplishing medical purposes, gaining knowledge, controlling or redirecting natural events, and so on. Like technology, magic gives man *power* over his physical environment.

D. Several aspects of the natural magic tradition and its deployment can be illustrated with three very different interpreters of it.

II. Heinrich Cornelius Agrippa von Nettesheim (1486–1535) is one example of a Renaissance writer on natural magic who also exemplifies humanist convictions.

A. Agrippa's most important work is the *Three Books of Occult Philosophy* published in 1531–1533.

1. The three books are a comprehensive description of magical correspondences and practices and how they can be used. For Agrippa, magic is the highest natural knowledge.
2. The use of classical sources and allusions is thick, revealing Agrippa's humanist tendencies—a predilection made equally clear by the way he names himself.
3. Agrippa also thought that mathematics was key to the successful use of natural magic.

B. Agrippa wanted to restore what he believed to be a holy ancient magic, purified of accreted superstitions. The correspondences between things can be known only by long experience, but for Agrippa at least, his source of knowledge is primarily textual.

III. Theophrastus Philippus Aureolus Bombastus von Hohenheim, better known as Paracelsus (c. 1493–1541), exemplifies other aspects of the natural magic tradition.

A. While the learned Agrippa admired the classical tradition, Paracelsus largely despised it; the central feature of Paracelsus is his iconoclasm (often seemingly for its own sake).

1. He violently assailed medical authorities (classical and contemporary).
2. He often rejected "foreign" medicaments, institutions, and ideas in favor of native Germanic ones (he was Swiss).
3. He likewise rejected Scholastic argument and method and university learning.
4. His ill temper and violent outbursts made him many enemies and prevented him from finding a settled residence.
5. Unlike Agrippa, Paracelsus did not believe that texts were a satisfactory source of knowledge; experience in the world and in the fire of the chemical furnace were necessary.

B. Paracelsus' worldview was chemically based. Chemical processes stood as explanatory metaphors for the human body, the earth, and cosmic processes.

1. His system incorporated many natural magic notions, such as the use of amulets, the doctrine of signatures, the macrocosm-microcosm, and so on, but also often incorporated Germanic "folk wisdom" in opposition to more learned ideas. Spiritual powers were the cause of changes in the world—not the material interactions known to the Scholastics.
2. Paracelsian notions provided an alternative world system—contrary to that of Aristotle—as well as a medicine contrary to that of Galen.
3. Paracelsus expanded the older Islamic dyad of material principles (Mercury and Sulphur) by the addition of Salt (creating a "trinity"). The utility of chemistry for Paracelsus was as an adjunct to medicine; it could prepare remedies by the process of *Scheidung* (separating toxic parts from wholesome ones).
4. Many Paracelsian notions are bizarre and difficult to comprehend, indeed, they are often *obscurantist*; nonetheless, during his lifetime, he acquired a reputation for healing "incurable" diseases.

C. Paracelsus' ideas and writings are poorly organized, but after being rationalized by his followers, Paracelsianism gained a wide and influential following for more than a century. Many took it up on account of its iconoclastic elements; it was popular among non-university-trained medical practitioners, Protestants, and others outside the traditional university structure.

IV. John Dee (1527–1608), the Elizabethan mathematician and natural philosopher, illustrates some of the realms beyond natural magic and their potentially close connection with things we more readily label as "scientific."

- **A.** Dee was recognized as a mathematician, polymath, and writer, as well as the collector of the largest private library in England.
    - **1.** He wrote the preface to the first English translation of Euclid from the Greek (1570) and argued for the importance of mathematics.
    - **2.** He was asked to choose the date for Queen Elizabeth I's coronation based on astrological considerations. He also urged the queen to explore and exploit the New World.
    - **3.** There was a popular rumor that he was a sorcerer, partly on account of a mechanical flying beetle that he supposedly built and used at Cambridge in the performance of a play by Aristophanes.
    - **4.** He knew and used medieval sources more than most of his humanist contemporaries; Dee used Roger Bacon's multiplication of species idea to account for astrological effects and the action by correspondence.
- **B.** For more than twenty years, Dee carried out conversations with angels.
    - **1.** He used a "Holy Table" and gazing stones (e.g., a mirror of polished obsidian) and "scryers" (Edward Kelly being the most famous) to communicate with spiritual entities.
    - **2.** What was actually going on in these sessions remains a mystery, but the records of these conversations fill many surviving volumes.
    - **3.** What is clear is that Dee thought he could learn the secrets of the universe by appealing for instruction from God's angels.
    - **4.** Many of his surviving notes are full of an "angelic language," which, being the language by which God created the world, would have great power to reveal and command the natural world.

V. The impact of Renaissance natural magic on the development of modern science has been hotly debated. In general, it is clear, however, that several aspects of natural magic can be seen as fostering the development of modern scientific ideas.

- **A.** All the figures we have seen here sought alternative sources of knowledge and methods of learning about the world.
- **B.** The emphasis on *action*—that is, doing or producing something from natural knowledge, rather than knowledge for its own sake—is more similar to modern scientific perspectives than to medieval ones. This emphasis is related to a similar emphasis in humanism itself.
- **C.** The emphasis on discovering things hidden in the natural world can, in some cases, lead to increased observation of the world, a key aspect of science.

- **D.** The emphasis on human power over the world—in part adopted from earlier Neoplatonic ideals (remember Hugh of St. Victor and Roger Bacon?)—was a notable counterpoint to Scholastic notions and is a feature familiar in modern science.

Essential Reading:

Allen G. Debus, *Man and Nature*, chapter 2.

Supplementary Reading:

Brian P. Copenhaver, "Natural Magic, Hermeticism, and Occultism in Early Modern Science," in *Reappraisals of the Scientific Revolution*, David C. Lindberg and Robert S. Westman, eds.

Questions to Consider:

1. For the next several days, be a magician. Cast your eyes over natural objects—flowers, animals, plants, body parts, stones—and try to use the doctrine of signature to construct groups of analogous items that should be linked by correspondences. How does this exercise affect your view of the natural world around you?
2. Natural magic looked toward several sources and ways of gaining knowledge of the natural world that were alternatives to the methods of Scholasticism. Think of modern scientific research. Do its methods more resemble those of natural magic or of Scholasticism? (Or neither or both?)

Lecture Twenty-Six

Copernicus and Calendrical Reform

Scope: The "Scientific Revolution" is often considered to commence with the 1543 publication of the Polish canon Nicholas Copernicus' *On the Revolutions of the Heavenly Orbs*, a book that promoted a sun-centered rather than an earth-centered cosmos. Indeed, astronomy (and physics) would see massive changes in the subsequent 150 years. This lecture looks at the content and reception of Copernicus' ideas and at a related contemporaneous development, the reform of the calendar under Pope Gregory XIII.

Outline

I. The year in which Copernicus' *De Revolutionibus* was published (1543) has sometimes been taken as the starting point of the Scientific Revolution in classical accounts of the history of science.

- **A.** Of course, all periodizations are more or less contrived and should be understood as such.
- **B.** Nonetheless, astronomy and physics are two branches of natural philosophy that did see substantial change and development in the sixteenth and seventeenth centuries.

II. Nicolaus Copernicus (1473–1543) studied widely, and spent most of his life in the post of canon in the cathedral of Frauenburg.

- **A.** Copernicus' education began at the University of Krakow (1491–1494) and continued in Italy at Bologna (canon law), Padua (1501–1503, medicine), and Ferrara (doctor of canon law, 1503).
  - **1.** While in Padua, Copernicus associated with the humanist and Platonist Domenico Maria de Novara.
  - **2.** He was granted the ecclesiastical office of canon at Frauenburg in 1497, but received several leaves to continue his studies and to attend his uncle as physician (1506–1512) and settled there only in 1512.
- **B.** Copernicus' reputation as an astronomer began to circulate by 1509; by 1514, he had written a brief compendium of his ideas on the structure of the heavens (the *Commentariolus*). This short work sufficiently established his reputation as an astronomer in ecclesiastical circles that he was invited to Rome to consult on the problem of reforming the Julian calendar under Pope Leo X in 1515 (Copernicus declined).
- **C.** The composition and publication of *De revolutionibus* is convoluted.
  - **1.** Copernicus had the composition of a fuller work than the *Commentariolus*, presumably the *De revolutionibus*, in mind in 1515, but the work was not published until 1543, clearing the press a few days after Copernicus' death.
  - **2.** Publication was urged on Copernicus by several notable churchmen, but he demurred for a long time.
  - **3.** Although Copernicus wrote the text and most of the front matter of the book, its publication was entrusted to his disciple Georg Joachim Rheticus (1514–1574).

III. The scientific ideas, context, and reception of *De Revolutionibus* must be carefully considered.

- **A.** The fundamental idea of Copernicus' system was that the sun, not the earth, is at (nearly) the center of the universe (heliocentrism rather than geocentrism). The earth rotates on its axis every twenty-four hours and is a planet, revolving around the sun once in a year (geokinetic rather than geostatic).
- **B.** Copernicus could offer very little proof for his system, and there were many reasons not to accept it.
  - **1.** Copernicus pointed to the greater simplicity of his system. In fact, this simplicity is often overstated—Copernicus continued to use Ptolemaic epicycles; otherwise, the predicted positions were highly inaccurate.
  - **2.** Copernicus' system gave no better practical results in calculating planetary positions than did the contemporaneous geocentric systems.
  - **3.** If heliocentrism is correct, there should be visible annual stellar parallax (unless the stars are *enormously* far away), but none could be seen.
  - **4.** The motion of the earth is insensible and unprovable at best.
  - **5.** Heliocentrism disrupts the laws of (Aristotelian) physics: If the earth is not at the center, why do heavy bodies fall to it? Why should the moon circle the earth and everything else circle the sun?
- **C.** Understanding Copernicus' humanism helps us understand his commitment to his system.
  - **1.** Copernicus' humanism is witnessed both by his first publication, a translation of Greek poetry, and the thick classical allusion in *De revolutionibus*.
  - **2.** Copernicus uses the rare instances of *ancient* notions regarding a moving earth or central sun to help validate his own ideas.
  - **3.** Copernicus saw his system as more elegant and aesthetic (in a classical sense) than the "monstrosity" of Ptolemy.
  - **4.** Part of Copernicus' goal was to restore the more ancient, classical goals of astronomy (simple, uniform, circular motion) enunciated by Plato, which had been corrupted in later ages—a clearly humanist sentiment.

5. Copernicus appeals to other humanists in the church (*De revolutionibus* is dedicated to Pope Paul III, known for his humanist interests).
6. Copernicus notes that those who share his (Neoplatonic) interest in mathematics will see the beauty of the system, unlike those steeped in the less mathematical Scholastic system.

D. There was no strong response to Copernicus' book.

1. Most readers sifted Copernicus' ideas, adopting some and rejecting others.
2. A heliocentric system did make some calculations easier (remember, getting planetary positions right for astrological purposes is what most astronomers really cared about).
3. In 1551, the *Prutenic Tables* were published—replacements for the older *Alphonsine Tables*, calculated by Erasmus Reinhold (1511–1553) using Copernicus' mathematical models, even though Reinhold did not believe in heliocentrism.
4. Although Copernicus and Rheticus believed in the literal truth of the system, Andreas Osiander, a Lutheran minister to whom Rheticus entrusted the last stages of seeing *De revolutionibus* through the press, wrote an (unsigned) foreword to the book that undermined the text, saying it was merely hypothetical.
5. This distinction recaps the old division between "saving the appearances" and providing a *literally true* (physicalist) system.
6. In the end, there were probably no more than a dozen thinkers committed to Copernicus' heliocentric system during the fifty years after its publication.

IV. More people were affected by a practical effect of sixteenth-century astronomy, namely, the reform of the calendar.

A. The Julian calendar had steadily accumulated errors over the sixteen centuries of its use.

1. The value for the length of the year used by Sosigenes (365¼ days) was slightly too long (by eleven minutes a year).
2. This meant that the date of the equinoxes slowly drifted backward through the calendar, which causes problems not only with agriculture but with reckoning the date of Easter.

B. Attempts to reform the calendar were sporadic and ineffectual throughout the late Middle Ages; only in the sixteenth century (when the error had grown to ten days), was there a sustained effort.

C. The effort resulted in the Gregorian calendar (named after Pope Gregory XIII and currently in use), which replaced the Julian calendar by papal bull in October 1582.

D. Protestant countries refused to accept the Pope's decree for varying lengths of time. England continued to use the outmoded Julian calendar until 1752; Russia, until 1918 (hence, the celebration of the "Great October Revolution" falls on 7 November); and the Greek Orthodox Church still uses it today.

Essential Reading:

Copernicus, Preface to *On the Revolutions*.

Robert S. Westman, "Proof, Poetics, and Patronage," in *Reappraisals of the Scientific Revolution*, David C. Lindberg and Robert S. Westman, eds.

Supplementary Reading:

John North, *The History of Astronomy and Cosmology*, chapter 11.

Questions to Consider:

1. How many of Copernicus' arguments for the superiority of his system over Ptolemy's would be accepted by modern scientists? Why? What are the differences?
2. Copernicus' theory made one clear prediction differentiating it from Ptolemy's, namely, that there should be an annual stellar parallax. This could not be found, i.e. the test failed. Despite this failure, Copernicus did not discard his theory. Instead, he massively increased the size of the universe—moving the fixed stars far enough away that their parallax would be undetectable. Use this fact as a jumping-off point for considering the relationship between hypothesis and observation. (How can/do/should contrary observations affect our theories?)

Lecture Twenty-Seven

Renaissance Technology

Scope: The Renaissance is well known for its explosion of artistic styles; less well known is the equal (and not unrelated) burgeoning of new technologies at the same time. This lecture looks at developments in mining and refining, military engineering, and other areas and pauses to watch the late fifteenth century's "Great Project," the moving of the 360-ton Vatican obelisk to the center of St. Peter's Square.

Outline

I. The Italian Renaissance is well known for its innovations and new productions in the fine arts, but there was a similar explosion of ideas in technology.

- **A.** The realms of fine art, technology, and science were often interrelated in the Renaissance; the same people were often involved in all three and saw philosophical connections among them.
- **B.** The most famous example of this is Leonardo da Vinci (1452–1519), renown for his work in all three areas.
  - **1.** Leonardo worked in the three areas simultaneously; for example, when dealing with the task of casting a huge bronze equestrian statue, he studied not only the artistic design, but also the anatomy of horses and the technical issues of furnace design and how to manipulate vast quantities of molten metal.
  - **2.** He worked on practical issues relating to the water system of Milan, along with the scientific properties of water flow and hydraulics.
  - **3.** His fertile inventiveness is well known from his notebooks, which include designs for weapons, textile manufacture, clockworks, and his famous flying machine.
  - **4.** He often applied new technologies to artworks and vice versa.
  - **5.** He saw analogies and mathematical proportions everywhere in the world—a unifying thread between art and nature.
- **C.** The mathematical worldview (at least partly inspired by the revival of Plato and Archimedes) that developed in the Renaissance has its counterpart in mathematical treatments of perspective in art, an important development in Renaissance painting.

II. Mining and metallurgy experienced dramatic growth from about 1470 to 1550.

- **A.** An increased need for coin (in the rapidly expanding capitalist system), weapons (in an increasingly unstable Europe), and raw materials for manufacture fueled this boom.
- **B.** One of the most famous writers on mining from this period was Georgius Agricola (1494–1555).
  - **1.** His most well known work, *De re metallica* (*On the Metallic Stuff*), published in 1556, contains descriptions of opening and working mines, smelting ores, and refining metals.
  - **2.** However, it would be wrong to think of this important work as simply a mining treatise; its context and form tell us more.
  - **3.** Georgius Agricola was born Georg Bauer. Early in life, he worked on translations of Galen and Hippocrates; his first mining treatise was written as a dialogue comparing local German and ancient knowledge, and an important part of *De re metallica* involved creating a Latin vocabulary for mining.
  - **4.** These features mark Agricola as a humanist; his purpose was to extend humanist scholarship and philology to a technical craft tradition.
  - **5.** Although Agricola undoubtedly visited mines and their operations, he was actually a physician and teacher of Greek; how familiar he was with the actual processes is open to debate.
- **C.** A slightly earlier work is the *Pirotechnia* (1540) of Vannuccio Biringuccio (1480–c. 1540).
  - **1.** Biringuccio seems to have more first-hand knowledge of workshop practices than does Agricola.
  - **2.** He was director of building at the Duomo in Florence and, later, the head of a foundry and the director of munitions at Rome.
  - **3.** His text describes everything from smelting and refining to mass-production casting, bell-founding, explosives, and fireworks.
- **D.** At the other end of the spectrum from Agricola are the very practical contemporaneous *Bergbüchlein* (mining handbooks). Their utility is reflected in their format, price, and language; they were more geared to actual practitioners.
- **E.** For (probably) the first time, the huge increase in mining made energy sources critical.
  - **1.** Larger, deeper mines required substantial mechanization; the waterwheel was the key power source for running pumps, bucket wheels, crushers, mechanized bellows, and so forth.
  - **2.** Gunpowder for blasting (not to mention warfare) also began to be used.
  - **3.** The need for wood and charcoal as fuel deforested vast regions around mines; around 1500, owing to shortages of wood and charcoal, coal was used in quantity for the first time.

III. Renaissance military engineering was also of importance and, again, related to scientific topics.

   A. The use of cannons (starting in the early fourteenth century) not only made old castle construction obsolete but also required a knowledge of projectile motion.

   B. Niccolo of Brescia, known as Tartaglia (1500–1557), studied projectile motion, as did others in Spain, England, and elsewhere. They generally applied a mixture of practical experience and Aristotelian kinematics.

IV. A spectacular engineering project of the sixteenth century was the moving of the 360-ton Vatican obelisk to the center of St. Peter's Square in Rome.

   A. No obelisk had been moved since Roman antiquity; thus, the move of this obelisk in the Renaissance was a chance to rival the engineering prowess of the revered ancients.

   B. Domenico Fontana (1543–1607) won the contract from Pope Sixtus V to engineer the move.

      1. On April 30, 1586, using the force of more than 900 men and 75 horses operating five 50-foot levers and 40 windlasses pulling on 8 miles of rope, the ancient obelisk was raised vertically.

      2. It was then lowered onto a huge carriage, led down a causeway, and finally, raised to the position where it currently stands.

   C. This monumental task symbolizes the taste, hopes, values, and accomplishments that characterize Renaissance thought and technology.

Essential Reading:

Pamela Long, *Technology, Society, and Culture in Late Medieval and Renaissance Europe, 1300–1600.*

Supplementary Reading:

William Eamon, "Technology as Magic in the Late Middle Ages and the Renaissance."

Bern Dibner, *Moving the Obelisks.*

Questions to Consider:

1. Think of some of the various ways in which art (broadly defined), technology, and science can interact. Are there modern examples of such interactions, and if so, how do they compare or contrast with Renaissance examples?
2. Compare the relationship between Renaissance technology and Renaissance science with that found between modern technology and modern science.

Lecture Twenty-Eight

Tycho, Kepler, and Galileo

Scope: The years around 1600 saw tremendous changes in astronomy. Tycho Brahe's precision in measuring planetary positions partly fueled Johannes Kepler's astronomical discoveries. Kepler's desire to find the hidden harmonies in the planetary system provided a basis for modern celestial dynamics but was embedded in the context of ancient traditions of Neoplatonism, Pythagoreanism, and natural magic, as well as his overarching desire to reveal the majesty and perfection of God's handiwork. At about the same time, Galileo turned a new instrument, the telescope, on the heavens and saw amazing things never before seen by man. This lecture examines these characters, their context, and their work and impact.

Outline

I. Tycho Brahe (1546–1601) was the most precise naked-eye astronomer; his volumes of observations provided keys to several important discoveries about the structure of the heavens.

   A. Tycho was a member of the Danish nobility; his astronomical program was largely made possible by the grant of the island of Hveen from the king. There, Tycho built his observatory-castle Uraniborg, beginning in 1576.

      1. Tycho carried out careful observations for decades and maintained a number of students who assisted in the work.

      2. Positional astronomy was carried out at this time using such instruments as the transit and quadrant to measure stellar and planetary positions.

   B. Several specific observations Tycho made pointed out deficiencies in the Ptolemaic/Aristotelian view.

      1. In 1572, a new star (now recognized as a supernova) suddenly appeared in Cassiopoeia. Tycho showed that this star was further away than the moon; therefore, a change had occurred in the superlunary realm, contrary to Aristotle.

      2. Tycho observed two bright comets in 1577 and 1585; he and others calculated that they, too, were beyond the moon, another example of change in the heavens.

      3. But Tycho also calculated that the comet had apparently crossed planetary orbs; therefore, there could be no solid celestial spheres that carried the planets.

   C. Tycho rejected Copernicus' idea of a moving earth as physically absurd and theologically untenable. In 1588, he presented his own planetary system with the earth at the center, the moon and sun revolving about the earth, and the other planets revolving about the sun.

II. Johannes Kepler (1571–1630) studied planetary motion and distances and worked for a short time with Tycho; he enunciated several astronomical laws.

- **A.** Students today still learn Kepler's "Three Laws of Planetary Motion," but these must be returned to their context to be properly understood historically.
- **B.** Kepler's first teacher of astronomy was Michael Maestlin (1550–1631) at the University of Tübingen, one of the few Copernicans of the sixteenth century.
- **C.** Kepler was initially interested in explaining planetary distances; while lecturing in 1595, Kepler got an idea of how to explain them.
    - **1.** Initially, he looked for simple numerical ratios of the distances, but eventually, he found that nested Platonic solids gave the answer he was seeking.
    - **2.** The Platonic solids—as "dividers" between the planets—gave the right distances and, given that there are only five perfect solids, also showed why there are only six planets.
    - **3.** Here is clear evidence of the return to the ideals of Plato's *Timaeus*; the world is constructed mathematically by God. It must be noted that Kepler asked questions that we would not, such as why is the number of planets six and not more or less?
    - **4.** Kepler's ideas were presented in the *Mysterium cosmographicum* (1596).
    - **5.** Kepler sent out copies of his book; one went to Tycho, who was impressed and invited him to Hveen. Kepler declined but eventually worked with Tycho in 1600 after the latter had moved to the court of Holy Roman Emperor Rudolf II in Prague.
- **D.** Kepler then began working on explaining why the planets move and constructing a planetary system.
    - **1.** He postulated an *anima motrix* ("motive soul") located in the sun that pushes the planets around their orbits.
    - **2.** Using Tycho's observations of the motions of Mars, Kepler found that circles could not predict its motion properly, and finally, he proposed elliptical orbits for the planets ("Kepler's First Law").
    - **3.** This was a highly dramatic move—announced in the *Astronomia nova* (1609)—which abandoned the 2,000-year-old use of combinations of circles.
    - **4.** Kepler's "Equal Area Law" (that a planet sweeps out equal areas of its orbit in equal times) results both from the idea of the *anima motrix* and the desire to maintain the ancient dedication to uniform motion, even in elliptical orbits.

- **E.** Kepler then produced the *Harmonices mundi* (1619), which contained his "Third Law," that the square of the period of a planet's revolution is proportional to the cube of its mean distance from the sun.
    - **1.** But again, context is crucial. The *Harmonices* is all about finding harmonic ratios in the cosmos—an expression of a Christianized Pythagorean-Platonic cosmology.
    - **2.** The Platonic solids, the Pythagorean music of the spheres, and other numerical relationships built into the cosmos are the real subject of the book. They reveal God the Geometer.
    - **3.** Kepler's "Three Laws" were extracted from their context later in the century by Newton. Soon, the deeply religious and metaphysical bases of their discovery and enunciation were lost.
    - **4.** Kepler's work shows how scientific development often occurs in contexts alien to modern ideas of science—even if modern science continues to use the results.
- **F.** Kepler's final work was to produce a new set of tables (remember, getting planetary positions right was still what most practitioners cared about); these were published in 1627 as the *Rudolphine Tables*.

III. Kepler sent his *Mysterium cosmographicum* also to a professor of mathematics at Padua, Galileo Galilei (1564–1642).

- **A.** Galileo's contributions to the history of science fall under both astronomy and physics.
- **B.** In 1609, Galileo constructed his first telescope and, during the winter of 1609–1610, made several important astronomical discoveries. These were published in the *Sidereus Nuncius* (*Starry Messenger*).
    - **1.** The moon has mountains and valleys and seas like the earth; thus, it seems to be made of the four elements, not the quintessence, as Aristotle would have it.
    - **2.** The planet Venus shows phases; therefore, it must sometimes be between the earth and the sun and sometimes on the opposite side of the sun. This is not possible in Ptolemy's system—only in Copernicus' and Tycho's.
    - **3.** Jupiter is surrounded by four moons; thus, there is another center of motion in the universe besides the earth or sun.
    - **4.** Later, Galileo saw sunspots, which he claimed demonstrated solar rotation (like the earth was supposed to have, according to Copernicus), as well as change and corruption in the heavens. This interpretation was highly disputed.
    - **5.** By naming the moons of Jupiter the "Medicean stars," after Cosimo de' Medici, Grand Duke of Tuscany, Galileo attracted his patronage and a well-paid position at his court.

C. Galileo's use of the telescope brings up the issue of scientific instruments in the Scientific Revolution; the validity of instrumental observations was hotly debated.
    1. Some critics claimed that Galileo's observations were artifacts of the instrument; there was reason to believe this.
    2. The matter was put to the Jesuits of the *Collegio Romano*. They verified Galileo's observations but noted that his interpretations of them were not necessarily true.
    3. Instruments continued to play an increasingly important role in the history of science.
    4. Some philosophical objections remain: Even while the development of science in the early modern period emphasized observations of the natural world, instruments in a sense separate us from it.

Essential Reading:

Allen G. Debus, *Man and Nature*, chapter 5.

Supplementary Reading:

Galileo, *Sidereus Nuncius*.

John North, *The History of Astronomy and Cosmology*, chapter 12.

Questions to Consider:

1. Why might science textbook accounts of scientific discoveries (such as Kepler's Laws) often ignore their context and original motivations? How does this omission alter students' impressions of scientific activity? Could one write a textbook that includes the "whole story"? How would it be different?
2. Consider the role of instruments in science (like Galileo's telescope). Choose one or two branches of modern science and consider how much reliance is placed on sophisticated instrumentation to make measurements or detect phenomena. Often, these instruments are enormously expensive (supercolliders, satellites, radio telescopes, and so on) and, therefore, rare or one-of-a-kind and of very restricted access and availability. How does this inaccessibility affect the practice (and practitioners) of modern science?

Lecture Twenty-Nine

The New Physics

Scope: The new views of the cosmic system required a new physics—Galileo firmly believed that the things he saw through the telescope signaled the end of the Ptolemaic and Aristotelian systems. This lecture explores Galileo's attempts to create a new physics, while emphasizing the new methods, goals, and worldview embodied in his system, and how this brought him into conflict with the church. The lecture also looks at parallel developments in physics, particularly William Gilbert's work on magnetism and its impact.

Outline

I. Several aspects of the new astronomical systems and observations from Copernicus to Galileo presented two sorts of difficulties.
    A. First, they undermine the foundations of Aristotelian physics.
        1. With the earth removed from the center, the Aristotelian notion of "natural place" is obliterated.
        2. A moving earth confounds the distinction between natural and violent motion.
        3. The distinction between superlunary and sublunary realms and their respective physics is abolished.
        4. It should be remembered, however, that there was a conflict between Ptolemy and Aristotle as well, which troubled many medieval thinkers, such as Ibn-Rushd.
    B. Second, there was considerable variety of opinion about how truthful astronomical notions were supposed to be.
        1. "Saving the phenomena" was sufficient for most but not all.
        2. Copernicus and Rheticus believed that the heliocentric system was a true depiction of the universe (despite Osiander's inserted comment in *De revolutionibus*).
    C. Galileo had to deal with both of these issues.

II. Galileo's major contributions were in physics rather than in astronomy.
    A. Galileo studied the dynamics of falling bodies; his formulations remain fundamental to classical physics.
        1. Falling bodies were a subject of study throughout Galileo's life, from the unpublished *De motu* (*On Motion*, c. 1590) to his *Mathematics Discourses and Demonstrations concerning Two New Sciences* (1638).

2. In all these places, he used a combination of logic, mathematics, and experiment to show the errors of Aristotle and to develop a new science of motion.
3. He showed that bodies do not fall at rates proportionate to their weight; rather, they accelerate uniformly, their velocity increasing in proportion to the time of fall ("Galileo's Law of Free Fall").
4. By considering the resistance of the medium to the motion of falling bodies, Galileo concluded that, with no resistance, all bodies would fall at the same rate and that, in any medium, there is a maximum speed, or "terminal velocity," reached.
5. He demonstrated that the path of a projectile is parabolic.
6. Galileo's experiments involved balls rolling on inclined planes and pendula; he also used "thought experiments."

B. Two aspects of Galileo's method are at least as important as his results.

1. The first is his conviction that natural phenomena can be (should be) described by mathematical abstraction.
2. This view is clearly distant from Aristotle's predominantly qualitative worldview.
3. The second is how Galileo changes the questions; he is not interested in *why* bodies fall but, rather, in explaining *how* they fall.
4. Both of these features have a classical precedent in Archimedes, who was, in fact, a favorite of Galileo's and of contemporaneous Italian writers.
5. Galileo's view resembles that of an *engineer*. Galileo's Italy was permeated with the ideas of architect-engineers. Indeed, *Two New Sciences*, which presents Galilean kinematics, begins with an inquiry into the strength of beams and the mechanical problems of scale-ups and scale-downs.
6. To a large extent, physics has followed Galileo's lead ever since.

C. Galileo also, once he had decided for himself in favor of Copernicanism, maintained its *literal truth*, which was a position confusing to many of his contemporaries and part of what landed him in trouble.

III. Galileo's conflict with the church authorities is *extremely* complex and cannot be reduced to simplistic readings. It has often been used polemically in ways that violate historical fact and understanding.

A. There were two distinct phases to the so-called "Galileo Affair." In the first (1613–1616), Galileo was warned not to teach Copernicanism publicly as literally true. In the second (1631–1633), he was convicted of "vehement suspicion of heresy" and placed under house arrest.

B. Part of the intellectual problems stem from the seeming contradiction between a geokinetic universe (where the earth is in motion) and certain passages in the Bible.

1. Although Copernicus noted that some theologians might object to his ideas, sustained *Catholic* objections arose only with Galileo.
2. Galileo's *Letter to the Grand Duchess Christina* (1615) stirred up much controversy; there, Galileo not only interpreted Scripture to fit his own ideas but also laid out new professional boundaries for theologians and natural philosophers.
3. Galileo rightly noted that St. Augustine said that biblical interpretation had to be in accord with the current state of scientific knowledge.
4. Although medieval theologians did this freely, Galileo lived during a very troubled time when it was not possible. In the 1560s, the Council of Trent, to check the newly minted Protestant notion of "personal interpretations" of Scripture, which was continually fracturing Christianity into sects, forbade the interpretation of Scripture contrary to the consensus of the Patristic writers.
5. Cardinal Roberto Bellarmino, who was in charge of the first phase of the Galileo inquiry, claimed that *if* the motion of the earth was proven, then the proper authorities would move carefully to amend the official interpretations.
6. Galileo in fact had *no* proof of the motion of the earth (even though he thought the tides were caused by the earth's motion).
7. The first phase ended with the decree by the investigating committee that Copernicanism is absurd in philosophy and erroneous in theology.

C. The second phase began after Galileo published *Dialogue on the Two Chief World Systems*.

1. In the meanwhile, Galileo's friend Maffeo Barberini had become Pope Urban VIII and had given his approval to Galileo's book, provided that Galileo included a fair hearing of the pope's argument that God's omnipotence meant that a given phenomenon might have many possible causes.
2. Galileo (rather foolishly) included the pope's view only on the last page of the book, where it was not only summarily dismissed as unlikely but also spoken by the character made to play the fool in the dialogue.
3. Urban VIII, furious at being betrayed and at Galileo having seemingly "forgotten to mention" that he had been forbidden to teach Copernicanism in 1616, ordered a new investigation.
4. Galileo claimed that he didn't really believe what he wrote, but that did not suffice, and he was sentenced and abjured the earth's motion on 22 June 1633.

D. The Galileo Affair was complex and involved far more than a "science-religion" controversy.

        1. Galileo had the bad habit of alienating his friends and was often perceived as arrogant.
        2. The tumultuous and troubled state of the post-Tridentine church (in the midst of the Thirty Years War) was the necessary background to the events that took place.

IV. The fame of Galileo can overwhelm the other (and often very different) scientific developments going on at the same time.

- **A.** One important example is the magnetic philosophy of William Gilbert (1544–1603), another system (of many at the time) intended to replace Aristotle's worldview.
    1. Gilbert's *De magnete* (1600) investigates the properties of the lodestone and the magnetism of the earth.
    2. It relies heavily on the use of "laboratory models"; in this case, loadstones (which Gilbert calls *terrellae*, "little earths") are heuristic models for the earth.
    3. For Gilbert, magnetism is a cosmic force that "animates" the earth and allows it to rotate.
    4. Gilbert's ideas are probably the inspiration behind Kepler's *anima motrix* (which is reprised by Galileo).
    5. He also coins the word *electricity* (by which, however, he means what we call static electricity) and distinguishes it from magnetism.
- **B.** Gilbert's magnetical philosophy was widely influential in succeeding generations.

Essential Reading:

Maurice A. Finocchiaro, *The Galileo Affair*, introduction.

Supplementary Reading:

Galileo, *Two Chief World Systems* and *Two New Sciences*.

William Gilbert, *On the Magnet*.

Questions to Consider:

1. Galileo's argument that the tides are proof of the earth's rotation was wrong. How might you go about providing clear observational evidence of the earth's rotation to a skeptic? (Do this both with the knowledge and instruments of a seventeenth-century natural philosopher, then with all the modern knowledge and instruments at your disposal. Don't forget to give your skeptic a chance for rebuttal!)
2. Some philosophers and historians of science have argued that Urban VIII was right to claim that a given phenomenon or effect might have many possible causes and that we cannot have sure knowledge of which cause is the true one. On the other hand, Urban's argument potentially leads to a position of total nescience about the world. Use the conflict between Galileo and Urban to consider the assumptions science makes in order to draw conclusions about the world. Are these assumptions warrantable? Can there be science without such assumptions? How do these assumptions differ from religious faith-statements?

Lecture Thirty

Voyages of Discovery and Natural History

Scope: Throughout the early modern period, voyages of discovery westward to the Americas and eastward to Asia brought back stories of new lands and peoples and samples of strange new minerals, flora, and fauna previously unknown to Europe. This lecture looks at how natural history changed as a result and the new way in which the natural world began to be viewed. This lecture also describes the "natural history" method of studying the world—an innovation propounded by Francis Bacon, which stood in contrast to the theoretico-mathematical method used in other fields contemporaneously.

Outline

I. The exploration of the New World and greater contact with Asia brought Europeans into contact with a wide variety of flora, fauna, and minerals unknown to the ancient authorities.

- **A.** Humanist critiques began to erode Pliny—the major source for natural history since antiquity—in the 1490s. The lengthy critiques of Ermolao Barbaro (1454–1493) and Niccolò Leoniceno (1428–1524) were, however, based on Greek texts prior to Pliny, not on the natural world.
- **B.** There were other problems with the accounts of plants and animals dating from classical antiquity.
  1. The classical texts often did not depict plants accurately enough for sure identification and did not include even common plants found north of the Alps. New herbals had to be written and new plants organized.
  2. The same was true of animals.
  3. From 1500 to 1700 (and after), there was an explosion in the number of plants and animals recognized.
  4. Information on the New World and Asia came from travelers, explorers, merchants, and speculators (often to excite interest or investment in exploration) and from settled colonists, frequently Jesuit, Franciscan, or other missionaries.
  5. New food crops were brought to Europe, and there was hope that newly discovered plants could cure previously "incurable" diseases.
  6. New plants from the New World were, in general, fairly slow to be incorporated in the herbals.

II. The proliferation of botanical, zoological, and other information created an "information overload"; new ways of coping with the material had to be created.

- **A.** The ancients left several models of how to deal with such material; there were sixteenth- and seventeenth-century followers of each style.
  1. Pliny was a descriptive writer with an interest in moralizing.
  2. Aristotle and Theophrastus described animals and plants with a view to finding out their "causes"—why they are the way they are.
  3. Dioscorides described plants with a view toward their medicinal utility.
- **B.** In general, medieval authors and encyclopedists followed Pliny (the source best known to them), but it is crucial to note that they tended to view flora and fauna not solely as things but also as *emblems.*
  1. By the end of the Middle Ages, many animals and plants were automatically thought of within a complex network of references built up from ancient sources, biblical citations, fables and parables, mythological references, and metaphorical and analogical associations.
  2. The volume of this information was massively increased by humanist additions from new classical sources and literature.
  3. This perspective has been called an "emblematic worldview"; it is clearly visible in the iconography of medieval and Renaissance art, for example. Plants and animals are not merely *specimens*, as in modern science; they represent a huge raft of associated things and ideas.
  4. Part of this viewpoint rests on the notion that the world is full of messages to be read.
- **C.** During the seventeenth century, this associative view vanished and was replaced by more literally descriptive views simply of the thing as it exists in itself.
  1. The web of analogies in the natural world and its moral and symbolic connection to human life was replaced by a world of individual objects.
  2. This was a crucial and fundamental change in the way human beings thought of the world.
  3. This change moved us toward a more "scientific" way of viewing the natural world.
  4. This change was also certainly related to contemporaneous developments that privileged literalism over metaphor (e.g., biblical interpretation under Protestant/humanist influence).
  5. It also involved the loss of long-term cultural developments and references and the sense of a unified and meaning-filled cosmos, and modified the definition of the "true."

III. "Natural history" became not only a part of natural philosophy but also a new method of investigation that extended well beyond botany and zoology.

- **A.** Francis Bacon (1561–1626), Lord Chancellor of England, espoused the common view of the day that the methods and content of learning had to be reformed.
- **B.** Bacon roundly criticized Scholastic methods but also showed little interest in the kind of mathematical methods used by Kepler, Galileo, and others. He preferred a compilation of descriptive observations, which he called a *natural history*, rather than the construction of grand systems.
  1. Part of Bacon's interest in the value of observation of natural objects *for use* derives from the similar emphasis found in the natural magic tradition.
  2. His view of the expansion of scientific knowledge is linked intellectually to his view of the expansion of Great Britain (the Empire of Knowledge and the Empire of Britain).
  3. Accordingly, Bacon put new emphasis on "mechanical knowledge," the practical works of the trades, as a source of information and of progress.
  4. The natural history could be compiled for any thing or phenomenon: a vegetable, animal, or mineral, but also such things as heat or cold, wind, magnetism, or density.
  5. The disadvantage of the method was that it could be difficult to draw conclusions from a large mass of (potentially contradictory) observations and records.
  6. On the other hand, it emphasized observation and, especially, the making of experiments.
  7. Bacon promoted a new view of nature: Nature was to be "put on the rack" to confess her secrets, and natural things and knowledge were to be used, not just admired.
  8. The issue of experiment in the Scientific Revolution (and earlier) is a vexed one. What is an experiment? How does it differ from observation? What is the status of the knowledge gained by experiment?
- **C.** Bacon's methodology proved to be particularly influential in the second half of the seventeenth century, especially (not surprisingly) in England.
- **D.** What we have seen in this period is a proliferation of methods of learning—late Scholastic methods (the universities), abstractive mathematical methods (Kepler and Galileo), empirical methods (Paracelsians), modeling methods (Gilbert), natural magic (Agrippa and Dee), and the natural history method (Baconians). All of these coexisted in the Scientific Revolution and made their own contributions to various fields.

Essential Reading:

Allen G. Debus, *Man and Nature*, chapters 3 and 6.

Supplementary Reading:

William B. Ashworth, Jr. "Natural History and the Emblematic World View," in *Reappraisals of the Scientific Revolution*, David C. Lindberg and Robert S. Westfall, eds.

Francis Bacon, *The Great Instauration* (selections), in *Selected Philosophical Works*, Rose-Mary Sargent, ed.

Questions to Consider:

1. Although Bacon's idea of collecting large amounts of raw data first and being slow to draw conclusions from them *seems* akin to the general idea of "scientific method," it is not without problems and, in fact, very little science is carried out this way. Can you identify some problems with the Baconian "natural history" method and consider to what extent modern scientists actually would benefit (or suffer) from practicing it?
2. We have noted here that a diversity of approaches to the study of nature was characteristic of the seventeenth century. Is there a comparable diversity of approaches to the acquisition of scientific knowledge and the explanation of scientific phenomena today? Why or why not?

Lecture Thirty-One

Mechanical Philosophy and Revived Atomism

Scope: One of the major new concepts of seventeenth-century natural philosophy was the "mechanical philosophy," an expressly anti-Aristotelian system that envisioned the world as a great machine functioning like a clockwork. The revival of ancient atomism was a related development. Although the mechanical philosophy seemed to provide comprehensible explanations of natural phenomena, it was not without problems—perhaps most crucially, in terms of its theologically unacceptable potential consequences. This lecture explores some of the various versions of the mechanical philosophy in the work of Pierre Gassendi, René Descartes, Robert Boyle, and others.

Outline

I. During the seventeenth century, many world systems were constructed to replace the collapsing Aristotelian world system and Scholastic methodology. Perhaps the most celebrated of these was the "mechanical philosophy," which (in simplest terms) envisioned the world as a great machine functioning like clockwork.

- **A.** It is impossible to speak of a single "mechanical philosophy"; there were nearly as many variations on it as there were "mechanical philosophers." There were, however, some common features.
- **B.** The ultimate explanatory principles were "mechanical" ones only—namely, the size, shape, and motion of particles of matter and their mutual collisions and agglomerations.
  - **1.** Aristotelian qualities and substantial forms were rejected. Sensible qualities are in the sensor not in the sensed.
  - **2.** Action-at-a-distance was inadmissible (as it was with Aristotle); only contact mechanics operate.
  - **3.** Particles of matter, moved in accord with mechanical laws, produce all phenomena.
  - **4.** The mechanical philosophy is, thus, aggressively reductionist; it tried to explain the maximum number of phenomena with the minimum number of explanatory principles.

II. A foundation for many versions of the mechanical philosophy was the revival of ancient atomism.

- **A.** Democritean-type atomism had little support in medieval thought; Aristotle's objections to it were well known, and it retained the taint of atheism carried from Epicurus.
  - **1.** Lucretius' Latin popularization of Epicurus, *De rerum natura*, lost since antiquity, was rediscovered and edited in 1417, and three letters of Epicurus were found soon thereafter.
  - **2.** Galileo tried to build up an atomistic system but did not succeed because of a confusion between physical (indivisible) atoms and mathematical (dimensionless) ones.
- **B.** The successful revival of Epicurean atomism came at the hands of Pierre Gassendi (1592–1655).
  - **1.** Gassendi was a French priest interested in many areas of natural philosophy; for example, he was the first to observe a transit of Mercury (1631), an event predicted by Kepler.
  - **2.** In the 1630s, Gassendi began to construct an atomic system to explain natural phenomena; this was eventually published in the massive *Syntagma philosophica* (1658).
  - **3.** Gassendi's system, like Epicurus', postulates atoms in constant motion in a void. Visible phenomena are the result of the mechanical actions of invisibly small atoms.
  - **4.** Gassendi "baptizes" atomism by removing its atheistic and fatalistic elements; for example, God creates the atoms and sets them in motion, free will exists in the soul, and so on.

III. Not all versions of the mechanical philosophy relied on indivisible (Epicurean) atoms and the void.

- **A.** René Descartes (1596–1650) produced a comprehensive mechanical system in which there was no void and in which matter, though existing as particles, was not indivisible.
  - **1.** For Descartes, as for Aristotle, the world was a *plenum*, that is, absolutely filled and without voids.
  - **2.** This idea follows directly from Descartes' definition of matter as *res extensa*, "extended stuff." This matter exists as particles of different sizes.
  - **3.** If the world is full, then motion is impossible (there is no empty space for things to move into) unless motion is in a circle. Thus, Descartes' universe is full of eddies, or vortices.
  - **4.** The solar system is one great vortex; this explains the motions of the planets and the centrality of the sun.
- **B.** The other "stuff" in Descartes' system is the *res cogitans*—thinking stuff—namely, immaterial stuff, such as the soul, spirits, and God.
  - **1.** A benefit of this division is that it allows Descartes and his followers completely to mathematize natural phenomena, because everything is now explicable mathematically and mechanically.
  - **2.** But, by creating this fundamental division (*Cartesian dualism*), Descartes deanimates nature utterly; matter is completely dead. Everything (even your pet) is reduced to the state of automata.

3. Descartes' division of body and soul has become so ingrained in our thought that we find it difficult to think in other ways and forget that this is not the only option.
4. We have begun to run up against the problems of Descartes' system in the modern mind-body problem and the issues faced (or equally often blithely ignored) by modern brain sciences.
5. Moreover, Cartesian thought (like the mechanical philosophy in general) separates man from the rest of the natural world. Most of his observations are self-created, not existing in the external world. Man is an alien to the world.

C. Descartes' system was open to many objections—atheism, enthusiasm, and especially, arbitrariness.

1. Descartes' explanations (like most of his system) tend to be *a priori*, which conflicted with the seventeenth-century taste for experimental bases for theory and a preference for *a posteriori* explanations.
2. Descartes builds up his system the way Euclid builds up geometry: by progression from proposition to proposition. The impact of actual observation of the world is fairly low.
3. Many of Descartes' explanations are fanciful; good examples occur when he tries to explain seemingly "occult phenomena," such as magnetism, without resorting to the mechanically forbidden action-at-a-distance.

IV. The issue of the void—one feature distinguishing Gassendist and Cartesian world systems—was a celebrated cause in the seventeenth century.

A. Aristotle vigorously denied the possibility of a void.

B. The "Torricellian experiment," devised by Galileo's student Evangelista Torricelli (1608–1647) in 1644, provided evidence of vacua.

1. A long tube filled with mercury and inverted in a basin of mercury would drain so that a column of about 30 inches of mercury would remain. Why? What was above the mercury in the tube?
2. Aristotelians explained the arrested outflow of mercury by reference to *horror vacui*—nature's abhorrence of a vacuum—an explanation based on final cause and natural motion.
3. Mechanists used fluid equilibrium as a cause; the weight of the atmosphere kept the mercury suspended, and the space above the mercury was a vacuum.

C. The famous Puy-de-Dôme experiment of Blaise Pascal (1623–1662) argued in favor of the mechanists.

V. The issue of air pressure and the vacuum was studied by Robert Boyle (1627–1691), who not only coined the term *mechanical philosophy* but developed his own version of it.

A. Using an air pump built by Robert Hooke, Boyle brought evidence to bear in favor of a mechanical explanation of Torricelli's tube, as well as other pneumatic phenomena.

B. Boyle's mechanical philosophy was based on (what he called) corpuscularianism—not atomism.

1. Corpuscles are divisible and alterable, unlike Epicurus' atoms.
2. The atheistical taint of Epicurus was still a problem; hence, Boyle and others endeavored to find a more reputable source for this useful world system.
3. Many of Boyle's ideas devolve from an alternative tradition of particulate matter theories found among the chemists (see Lecture Thirty-Three).

C. Boyle was a great champion of mechanism but was deeply troubled by its possible implications; it removed God from the operation of the world and was deterministic (that is, it offered no free will).

VI. Mechanism had great promise and great peril, and much of the history of science of the latter half of the seventeenth century deals with working through these issues.

Essential Reading:

Richard S. Westfall, *Construction of Modern Science*, chapter 2.

Supplementary Reading:

Margaret J. Osler, "How Mechanical Was the Mechanical Philosophy?" in *Late Medieval and Early Modern Corpuscular Matter Theories*, Christoph Lüthy, John Murdoch, and William Newman, eds.

Questions to Consider:

1. How would a deep commitment to Cartesianism make you treat your pet—or the whole natural world—differently?
2. If you had to devise a system based on a mechanical world and had to preserve free will and God's activity in the world, how might you do it? Think about what the problems of mechanism are and how to get around them.

Lecture Thirty-Two

Mechanism and Vitalism

Scope: Although mechanical ways of thinking about the world were popular in the seventeenth century, there were other options and hybrid systems from which to choose. This lecture examines the coexistence of mechanical and vitalistic conceptions in the life sciences and medicine, the persistence of Aristotelian thought, and the ways in which the mechanical philosophy tried to explain the action-at-a-distance phenomena that were often fundamental to rival systems.

Outline

I. Mechanism and vitalism are two ways of looking at the world—generally opposite but sometimes hybridized in the seventeenth and eighteenth centuries.

- **A.** Mechanism sees a dead world operating like a great machine; vitalism sees a world imbued with life, operating under the direction of active, living immaterial agents.
- **B.** Descartes' world is almost entirely mechanical. Only man has an immaterial, living soul; he is the only vital thing in the world.
- **C.** Mechanical and vitalist systems existed concurrently, and although it might seem easy to distinguish them, when we come to look at most specific characters and their thought, the distinctions appear blurred.

II. Life sciences and medicine are areas in which the issues of vitalism are particularly important.

- **A.** The medical sciences underwent considerable changes during the Renaissance and Scientific Revolution.
- **B.** A key development was the new interest in anatomy, which began in the late Middle Ages and reached a climax with Vesalius' *De fabrica humani corporis* (*On the Structure of the Human Body*), published in 1543, the same year as Copernicus' *De revolutionibus*.
  - **1.** Vesalius showed the errors of Galen and elevated the status of the anatomist.
  - **2.** The interest in dissection in the sixteenth and seventeenth centuries led to the popularity of dissection theaters, where it became fashionable for even the public to gather to watch.
  - **3.** In the seventeenth century, mechanists were often the ones more drawn to anatomy, thinking it would display the "clockworks" of living bodies. Vitalists often questioned what anatomy would actually show, because corpses no longer exhibited the phenomenon of interest—namely, life.
- **C.** A second important development in life sciences is the theory of the circulation of the blood, proposed by William Harvey (1578–1657) in 1628.
  - **1.** Although the notion of the heart acting as a pump is mechanical, Harvey was a vitalist in the sense that he believed that blood was the vehicle and source of life.
  - **2.** Harvey was also an Aristotelian in many ways; we must remember that even while Aristotle was under attack, many Aristotelians continued to exist (and even prosper) throughout the seventeenth century.
- **D.** The invention of the microscope led to a study of the fine structure of animals and plants.
  - **1.** Marcello Malpighi (1628–1694) studied the lung and saw capillaries for the first time, proving Harvey's theory of the circulation.
  - **2.** He then studied the simpler structure of plants in an attempt to reveal the "machinery" behind their mechanism. His interest lay in relating structure and function.
  - **3.** Many natural philosophers hoped that the microscope would reveal even atoms; when it did not, interest in the microscope waned.

III. Other systems concurrent with natural philosophy gave little if any consideration to mechanism; some of these were equally influential.

- **A.** The "chemical worldview" of the Paracelsians was essentially vitalistic.
- **B.** The single most influential new system for medicine and chemistry in the seventeenth century, however, was that developed by Joan Baptista Van Helmont (1579–1644).
  - **1.** Van Helmont was university educated but rejected university learning in almost the same language as Descartes and with the same fervor as Bacon.
  - **2.** He was an equal opponent of Galenic medicine and Scholastic Aristotelianism.
  - **3.** Van Helmont's system was a highly influential combination of mechanism and vitalism.
  - **4.** Van Helmont divided material changes into two categories: the superficial and the fundamental. The superficial occur "mechanically" by the alteration or rearrangement of particles of matter.
  - **5.** In Van Helmont's system, fundamental changes depend on the action of vital *semina* (seeds), and life processes depend on *archei* (regulating spiritual entities).
- **C.** Van Helmont's *archeus* (a term borrowed from Paracelsus) governed the proper functioning of living bodies.

1. The *archeus* oversees digestion, the assimilation of food, and other maintenance roles in the body.
2. Sickness arises from a weakened *archeus*. The imagination can weaken the *archeus* by inducing fear; hence, plague propagates on account of people's fear of it.
3. Curiously enough, in modern popularized versions of molecular biology, DNA becomes, in effect, an *archeus*—it is imagined to regulate and to direct the body and becomes, in effect, a general factotum of the sort envisioned in Van Helmont's *archeus*.

D. Fundamental change arises from the action of *semina*, or seeds, acting on the universal matter, water.

1. For Van Helmont, everything is modified water—a reprise of the ancient monist doctrine of Thales of Miletus and a derivative of Van Helmont's reading of Genesis 1.
2. The "seeds," or seminal principles, are *active principles* implanted in matter by God; their action radically transforms water into all other substances.
3. The Helmontian *semina* can be traced back to St. Augustine's seminal reasons.
4. One of Van Helmont's many proofs of his water theory was the famous "willow-tree experiment," which demonstrated that all the various substances found in a tree are produced from water alone.
5. The careful, patient, quantitative approach displayed in the willow-tree experiment showed that vitalistic systems need not be "vague," "mysterious," or "non-scientific" any more or less than more modern-sounding "mechanical" ones.

E. For Van Helmont, action-at-a-distance was not a problem (as it was in the mechanical philosophy).

1. The *semina* and other objects could extend their power for organizing and changing matter radially without transfer of material substance.
2. The "weapon-salve" was a similar example of this possibility. The weapon-salve was a medicine for wounds which was applied not to the wound itself but to the weapon that made it or the blood of the victim.
3. The cure occurred at a distance by "sympathy" or, as Van Helmont preferred (borrowing a term from Gilbert), by "magnetic" cure.
4. The weapon-salve was also treated by Gassendi (and many others), who explained its action mechanically.
5. Curiously, more people endeavored to explain the action of the salve than actually tried to prove its efficacy.

IV. The explanation of occult phenomena was an important testing ground for the mechanical philosophy.

A. Seeming actions-at-a-distance (such as magnetical and electrical attractions and repulsions) became in the mechanical philosophies the result of "effluvia" of invisible particles—and, thus, were turned into *proofs* of atomic mechanism.

B. However, the failures of mechanism were often patched over by the silent importation of "active principles" from other systems.

V. Thus, it is important always to bear in mind the rich variety of ideas and systems coexisting in the seventeenth century; we should not pick and choose those that seem akin to our own ideas, or "mainstream." The mainstream is often not what we think.

Essential Reading:

Allen G. Debus, *Man and Nature*, chapters 4 and 6.

Supplementary Reading:

Keith Hutchison, "What Happened to Occult Qualities?" *Isis* 73 (1982): 233–253.

Richard S. Westfall, *Construction of Modern Science*, chapter 5.

Questions to Consider:

1. How could one decide between a vitalist and mechanist view of the world? Can you design experiments to do so? Think carefully about the scientific and philosophical consequences of either choice, then decide which one you would prefer. Why?
2. Van Helmont—like many early moderns—is very concerned about the power of the imagination and its effects on the body and its health. Since the nineteenth century, there has been a strong tendency to downplay such interactions, although now they are beginning to be revived, if only sporadically and in very limited senses. How could a study of the action of imagination on the body help to argue on behalf of vitalism or mechanism?

Lecture Thirty-Three

Seventeenth-Century Chemistry

Scope: The seventeenth century was a confusing time for the study of chemistry; there were many systems and goals from which to choose. This lecture looks at the continuing search for the secret of transmutation but also at the development of a "mechanical" chemistry, the use of chemistry in medicine, and the enhanced status of the discipline by the end of the century.

Outline

I. The various subsets of chemistry defined in the Middle Ages continued to develop in the Scientific Revolution, and the status of the discipline as a whole was enhanced by the end of the century.

II. Many chemical matter theories coexisted and developed; the particulate matter theories of the chemists influenced the revival of atomism.

- **A.** The medieval dyad of chemical principles (Mercury and Sulphur), the Paracelsian triad (plus Salt), and newly developed pentad (plus Phlegm and Earth); the water theory of Van Helmont; and the old Aristotelian quaternary (fire, air, water, and earth), all had adherents in the seventeenth century.
  - **1.** These separate systems were devised and sustained for distinct reasons based on utility, practical experiences, and so on.
  - **2.** This array of theoretical systems is characteristic of much of seventeenth-century natural philosophy.
- **B.** The particulate matter theory of medieval alchemists propagated through the centuries and was joined up with revived classical atomism, particularly in chemical contexts. The "chymists" generally provided the best proofs—drawn from chemical observations—for the existence of invisible atoms.
- **C.** Robert Boyle (1627–1691), a key figure in seventeenth-century chemistry, combined several traditions to devise his important "corpuscularian" system.
  - **1.** For Boyle, all corpuscles were made of the same "Universal Catholick Matter."
  - **2.** The shapes alone of the corpuscles determine the macroscopic properties of the bodies they compose.
  - **3.** The shapes and sizes of corpuscles can be altered by interactions with other corpuscles.
  - **4.** Note that Boyle's concept rules out the possibility of distinct elements—this was one argument of his famous *Sceptical Chymist* (1661)—and it further ungirds the possibility of metallic transmutation.
  - **5.** Nonetheless, laboratory results showed that some chemical substances can be recovered unchanged after a series of chemical operations. This implied the existence of more than one level of corpuscular aggregation.
- **D.** Various mechanical corpuscular systems were proposed for chemistry, but such systems often seemed too contrived or too simplistic to explain the complexity of laboratory observations.

III. Endeavors to produce the Philosophers' Stone and transmute the metals increased in intensity and began to wane only after about 1700.

- **A.** The seventeenth century saw the publication of more works on transmutational alchemy than any other.
  - **1.** The methods and theoretical foundations for alchemy multiplied, just as we have seen in other scientific fields during the sixteenth and seventeenth centuries.
  - **2.** Royal and princely courts often had resident alchemists working on the problem of transmutation.
- **B.** The level of studied secrecy in alchemy remained high throughout the seventeenth century.
  - **1.** Such secrecy—and the actual chemical processes it was designed to hide—can be exemplified in the case of George Starkey (1628–1665) who wrote widely popular works under the name of Eirenaeus Philalethes.
  - **2.** Starkey also showed how what we might consider to be quite diverse strands of thought could be drawn together.
- **C.** Robert Boyle himself was a keen searcher after the Philosophers' Stone and the secret of transmutation.
- **D.** Another quest of the seventeenth century was to prepare the *alkahest*, a material described by Van Helmont that could analyze any substance into its ingredients, then return it to its original water.

IV. The expansion of the field of chemistry and its professionalization were important developments of the seventeenth century.

- **A.** Chemistry did not have a regular place in university curricula and suffered from a "low" status because of its strong practical aspects.
- **B.** Pedagogical aspects of chemistry developed during the century.
  - **1.** Andreas Libavius (1540–1616), a Saxon pedagogue, imported humanist tastes and a desire for pedagogical utility into chemistry. He assailed secrecy and stressed preparative utility.
  - **2.** The first university post in a chemical field was in 1609 at the newly founded University of Marburg. The position filled by Johannes Hartmann was predominantly pharmaceutical.

3. Chemical teaching initiated the important series of chemical textbooks that were published throughout the century.
4. An important locus outside the universities was the Jardin des Plantes at Paris, a Crown-funded garden of medicinal plants where a professorship in chemistry was set up.
5. Most of the chemical textbooks, however, dwelt on practical pharmacological preparations, with minimal theory. Most were Paracelsian in character, stressing the utility of chemical preparations to medicine.

C. The status of chemistry was further enhanced when it became institutionalized in learned societies, particularly the Academie Royale des Sciences in Paris. Such institutionalization came at a price; chemistry had to be "purified" of its less desirable connections, such as the quest for transmutation, which was a prime breeding ground for fraud.

D. Nonetheless, chemistry in a form distinct from pharmacy would not appear in the university until the middle of the eighteenth century.

Essential Reading:

Richard S. Westfall, *Construction of Modern Science*, chapter 4.

Supplementary Reading:

Lawrence M. Principe, *The Aspiring Adept.*

Questions to Consider:

1. Consider how a discipline "comes of age." What are the necessary requirements for a new discipline—whether chemistry in the early modern period, or genetics in the early twentieth century, or astrobiology (for example) today—to be accepted and perpetuated among more established disciplines? For example, if you were a wealthy (and wise) potential philanthropist, where would you put your funds, and to what purposes, in order to move a "marginal" discipline into a permanent place of acceptance and respect?
2. Consider the subject of alchemy. Prior to these lectures, what did you associate with alchemy and what evaluation of it did you have? Whence did you derive these associations or definitions? How have these lectures changed your views? What was particularly surprising to discover? How do you now view the relationship of alchemy to other branches of natural philosophy?

Lecture Thirty-Four

The Force of Isaac Newton

Scope: Isaac Newton may be the most recognizable figure of the history of science. This lecture looks at Newton's life, his achievements in physics and astronomy, and his de facto response to the mechanical philosophy in terms of the concept of "force." It also deals with his less well known activities, for the author of "Newtonian physics" spent even more time studying alchemy and biblical prophecies and developing his own (heretical) theology.

Outline

I. Sir Isaac Newton (1642–1727) is a well-known figure. He has often been seen as the "culmination" of the Scientific Revolution and the prototype of the modern scientist.

A. Newton drew together several strands of physics, mathematics, cosmology, astronomy, and other fields; this is sometimes referred to as the "Newtonian synthesis."

B. Newton devised and employed some techniques familiar to modern scientists, but when viewed in his entirety, he remains as "foreign," when compared to the modern scientist, as any seventeenth-century natural philosopher (if not more so).

C. The rapid development of the sciences that characterizes the seventeenth century did not stop with Newton; it has been ongoing (accelerating?) ever since.

II. Many of Newton's most renowned accomplishments derived from work done early in his life.

A. After a not very happy childhood, Newton enrolled at Trinity College, Cambridge University, in 1661.

1. There, he was taught the traditional curriculum, still largely Aristotelian.
2. By 1664, however, he had begun studying the "New Philosophers": Descartes, Gassendi, Boyle, and others.

B. Newton first turned enthusiastically to mathematics and, during the years 1664–1666, worked out the bases of integral and differential calculus.

1. He did not publish or publicize this work.
2. Thus, he was later involved in a bitter priority dispute with Gottfried Wilhelm Leibniz (1646–1716) over the calculus.

C. Newton then moved to kinematics, studying both rectilinear and circular motion and the acceleration of falling bodies.

D. Newton also experimented with optics.

1. He was convinced of the particulate nature of light and proved that white light was composed of discrete rays of differing refrangibility.
2. His experiments with prisms were beautifully elegant; he called them *experimenta crucis* ("experiments of the crossroads") because they were able to decide definitively between possible options.
3. Newton's optics was based on notions of the mechanical philosophy—particulate substances and secondary qualities.
4. Newton's discovery of the differing refrangibility of colors indicated to him how telescope lenses would always produce ill-focused images because of chromatic aberration. In order to avoid the use of large lenses, he devised the reflecting telescope.

III. Newton's first attempt to publicize his findings and ideas did not go well.

A. The Royal Society asked to see his telescope, they elected him Fellow, and he contributed a paper on optics in 1672.

B. Although the paper elicited much support, it also brought some criticism, which Newton could not tolerate.

1. For example, he exploded at Robert Hooke—who had his own ideas of light and the origin of colors—leading to thirty years of animosity.
2. The result was that Newton withdrew from scientific correspondence and fellowship with the Royal Society. He did not publish his *Optics* until more than thirty years later, after he had become president of the Royal Society.

C. In 1684, Newton received a visit from Edmund Halley (c. 1656–1743) bringing a question about dynamics. This question, and Halley's insistence, set Newton to work writing up his system of dynamics, the *Mathematical Principles of Natural Philosophy*, generally known as the *Principia* (published in 1687).

1. In the *Principia*, Newton combined his own insights and methods with Galileo's kinematics with Kepler's planetary laws.
2. He noted that Descartes' vortices will not work nor will they produce the known planetary phenomena.
3. Instead, the planets move in closed orbits under the guidance of a central attractive force that balances their tendency (by inertia) to move in a straight line tangent to their orbits.
4. Thus, Newton enunciated the law of universal gravitation and used it in Book III of the *Principia* to solve a host of observations and problems in celestial dynamics. He rederives mathematically the three laws Kepler derived from observations.

D. The idea of gravitation was not easily accepted; it flew in the face of the entire mechanical philosophy by reintroducing an inexplicable action-at-a-distance that could only be called occult.

IV. Although Newton's work in physics and mathematics is well known, he actually spent more time on two other pursuits: alchemy and theology.

A. Newton wrote more than a million words on alchemy; he carefully studied the writings of a wide variety of alchemical authors.

1. Newton carried out a wide range of experiments and tried to follow alchemical recipes.
2. It has been suggested that Newton's idea of the gravitational force was derived from his reading of alchemy/chemistry, where active principles continued to be used as explanations.

B. The single largest endeavor by Newton involved theology.

1. Newton became convinced that the doctrine of the Trinity and the divinity of Christ were corruptions of the ancient Christian doctrine; he kept this heresy secret.
2. Newton was deeply concerned about the atheistic tendencies of the mechanical philosophy, and it seems likely that he hoped to show that the force of gravity was evidence of the direct action of God in maintaining the universe.
3. Newton was also deeply interested in prophecies and the end of the world. He labored mightily to fix the dates at which prophesies would come to pass; to do so, he wrote a *Chronology of Ancient Kingdoms Amended* to get the dates of ancient events correct.
4. Newton believed that the destruction of the world by fire, as foretold in the Book of Revelations, would occur when a huge comet (possibly the one seen in 1680) falls into the sun, causing it to flare up and incinerate the planets.

C. A common theme in Newton's studies is a belief in the *prisca sapientia* and *prisca theologia*, popular in the Renaissance.

1. Newton thought that the ancients knew the inverse-square law of universal gravitation and the *cause* of gravity, something he deeply desired to know.
2. Newton saw himself as a *restorer* of the ancient knowledge through his scientific labors and of ancient true religion through his theological ones.

D. Newton's pursuits of alchemy and theology were not in conformity with the image of Newton as "rationalist" that the eighteenth century wanted; therefore, knowledge of them was suppressed or downplayed.

1. This is often the fate of historical figures; their biographies are subsequently tailored to fit later ideas of what they *should* have been. This complicates the historian's task.

2. When we restore the totality of Newton's thought and work, we see that he is very little like a modern scientist in either beliefs or motivations.

V. Much of eighteenth-century physical science dealt with extending and consolidating Newton's ideas. Newtonianism is a major portion of the history of eighteenth-century science.

Essential Reading:

Betty Jo Teeter Dobbs, "Newton as Final Cause and First Mover," *Isis* 85 (1994): 633–643.

Richard S. Westfall, *Never at Rest.*

Supplementary Reading:

Dobbs, *Janus Faces of Genius.*

Questions to Consider:

1. We have mentioned how Newton's image was altered by subsequent generations (for example, his theological and alchemical interests were suppressed). Why would this be done to a scientific thinker? What are the benefits? Do they accrue to the thinker himself (posthumously), to the person(s) doing the altering, or to something or someone else? Perhaps you would like to compare this phenomenon to the rewriting of the biography of political figures.
2. How does an integrated portrait of Newton demonstrate the differences between early modern natural philosophy and modern science? (Or between an early modern natural philosopher and a modern scientist?)

Lecture Thirty-Five

The Rise of Scientific Societies

Scope: Scientific societies originated in Italy in the seventeenth century and, ever since, have played a major role in the development of science. Two seventeenth-century societies continue to function today, the Royal Society of London and the Parisian Academy of Sciences. This lecture looks at the nature and functioning of scientific societies and the roles they play.

Outline

I. An important way of looking at the history of science is through the institutions that foster scientific work.

   A. During the Middle Ages, natural philosophy found a home in the university.
      1. The universities continued to be institutional centers for natural philosophy during the seventeenth century but, in general, tended to conservatism.
      2. The universities were widely criticized by important figures of the Scientific Revolution (such as Descartes, Van Helmont, Boyle, and others) as backward and tradition-bound.

   B. The development of an intellectual class outside the university (owing to increased wealth and leisure) led to new associations and groups.
      1. The earliest of these were humanistic and belletristic.
      2. Later, however, groups of scientific "amateurs" (eventually calling themselves "virtuosi") were formed.

II. The earliest scientific societies were organized in Italy in the early seventeenth century.

   A. The most important of these was the Accademia dei Lincei (Academy of Lynxes), organized in Rome in 1603 by Frederico Cesi (1585–1630).
      1. Cesi believed that uncovering the workings of the natural world required a corporate effort of scholars.
      2. The Accademia began small (four members, including Cesi) and, after some difficulties, started to grow after 1609, to include a diverse cast of characters.
      3. In 1610, Giambattista della Porta (1535–1615), an advocate of natural magic, was admitted; he had organized an "Academy of the Secrets of Nature" in Naples in the mid-sixteenth century.
      4. In 1611, Galileo became a member. He showed the members his inventions of the *occhiale* and *occhialino*, which the Lynxes named the *telescopio* and *microscopio*.

5. The Academy failed to become self-supporting and fell apart after Cesi's death and Galileo's condemnation.

B. The Accademia del Cimento was a looser grouping of natural philosophers clustered around the patronage of Duke Ferdinando II de' Medici in Florence.

1. It was active for only a short time: from 1657 to 1667.
2. Many followers of Galileo were active here, and much work was done on the Torricellian tube and the thermometer.

C. Many other Italian cities saw the creation of societies, but their common failing was that none managed to outlive their founders or patrons.

III. The Royal Society of London was founded in 1660 and chartered by Charles II in 1662; it continues as a premier scientific institution today.

A. Many of the most important English scientific thinkers of the day were involved in its founding: Robert Boyle, Christopher Wren, and others.

B. The Royal Society looked largely to Francis Bacon for its inspiration. Bacon had written of a "Solomon's House" in his utopian work *The New Atlantis*, where scientific and technological studies were undertaken.

C. Meetings of the society involved discussion, the presentation of new findings and papers, and demonstrations.

1. Fellows worked independently and brought reports to the society.
2. The society's demonstrator was Robert Hooke, whose air pump, designed for Boyle, was a high-profile feature of the society.

D. An important move was the foundation (in 1665) of the *Philosophical Transactions* as the society's journal.

1. Publication was overseen by the secretary, Henry Oldenburg, who had been a center for correspondence for years.
2. Networks of correspondence were effective and influential ways of sharing scientific (and other) information in the seventeenth century; there were many of them. The *Philosophical Transactions* and, subsequently, other scientific journals grew (in part) out of such informal networks.
3. The journal was a place to publicize the activities of the society and its fellows, assert priority, adjudicate dispute, and disseminate information.

E. The society grew rapidly by the admission of new fellows; only a small portion was actually active, however, and financial problems plagued the early organization.

IV. The Académie Royale des Sciences was founded in Paris in 1666 by the minister Charles Colbert and funded by Louis XIV.

A. Several "stars" of the early Académie were brought to France by Colbert, as he "collected" talent from abroad for the advancement and glory of France and Louis XIV.

1. The Dutchman Christian Huygens (1629–1695) headed the new Académie. He built telescopes and studied Saturn, explaining its rings and discovering its satellite (Titan).
2. Huygens also developed a wave theory of light, proposed that light had a finite speed, developed laws of motion, and greatly improved clocks.
3. The Italian Gian Domenico (later Jean-Dominique) Cassini (1625–1712) distinguished himself in astronomy before being invited to Paris in 1669 as the Académie's highest paid member.
4. Cassini made numerous discoveries in planetary astronomy, organized a survey of France, and worked on the famous "longitude problem" using the eclipse of Jovian satellites as timekeepers.
5. Discrepancies between calculated and observed eclipse times of Jupiter's satellites allowed Ole Römer (in 1676) to claim that light moves with finite velocity and to calculate its speed for the first time.
6. Cassini was head of a dynasty of astronomers; his descendants ran the Paris Observatory for more than a century.

B. The Académie and the Crown had much closer relations than was the case with the Royal Society and the English Crown. This linkage had several effects on the French society.

1. The Académie was the recipient of royal funding, making the recruitment of international and domestic scholars possible.
2. The cost of the stipends kept the number of academicians small, and admissions were (generally nominally) approved only through the king.
3. The regulations (adopted in 1699) also required the recruitment of academicians in a variety of fields, thus maintaining coverage across the scientific disciplines.
4. The Académie had the use of the Royal Library, and the Observatoire de Paris was built for them.
5. The Académie became the official scientific voice of France and was often called on to deal with scientific and technological matters of concern to the Crown (navigation, surveying, flood control, book and invention licensing, and so on) or local authorities (expert opinions in legal matters).
6. The Académie was able to undertake large-scale, expensive, and long-term projects thanks to royal funding.

7. The Parisian academy thus had a stability (financial and otherwise) and attained an official and public status that the Royal Society did not until much later.

C. The academy also published a serial (after 1699), except issued annually, unlike the more frequent *Philosophical Transactions*. Like the Royal Society, the Parisian academy maintained a wide circle of correspondents who contributed to its *Mémoires* and sent in reports.

D. The Académie Royale des Sciences continued to function through the eighteenth century, was closed after the disaster of the French Revolution but reopened a few years later, and continues to function today as part of the Institute de France.

V. Scientific societies played a key role in creating another home for scientific inquiry, in generating a public status for science, and in linking scientific expertise with the state.

Essential Reading:

Richard S. Westfall, *Construction of Modern Science*, chapter 6.

Hunter, *The Royal Society*, chapter 1.

Alice Stroup, *A Company of Scientists*, chapter 1.

Supplementary Reading:

Francis Bacon, *New Atlantis*, in *Selected Philosophical Works*, Rose-Mary Sargent, ed.

Questions to Consider:

1. What are some modern scientific institutions? What role do they play in modern society? In government decision making? In shaping the public image and understanding of science? How do they compare with the seventeenth-century Royal Society and Académie Royale des Sciences?
2. How do institutions affect the social status of science and scientists—whether in early modern or contemporary society? Think about the creation of a "public culture" of science and the ways in which institutions can (or do, or don't) confer authority on their members and their ideas.

Lecture Thirty-Six

How Science Develops

Scope: This lecture glances forward to some of the developments yet to come in the eighteenth century, such as the development and reworking of Newtonianism. It also recapitulates and summarizes some of the themes and overarching trends covered in the preceding thirty-five lectures and contrasts contemporary views of science with the views revealed by our study during this course.

Outline

I. The eighteenth century is sometimes referred to as the Newtonian century.

A. Newton's system of universal gravitation promised to provide a unified worldview, something that could finally replace the now-defunct comprehensive worldview of Aristotle.

1. Eighteenth-century Newtonians worked through the ramifications of Newton's principles to explain phenomena Newton did not (such as apparent idiosyncrasies in the motion of Jupiter and Saturn).
2. Attempts were made to apply Newton's force to chemical problems, but without success. A single purely attractive force cannot explain all the changes in the world.
3. Newtonians vied with Cartesians (who rejected forces in favor of mechanisms) for supremacy. One debate was about the exact shape of the earth; Newton was vindicated in that contest.

B. But Newton's system *did* establish the utility and power of a mathematical view of the natural world.

1. This mathematical (or mathematizing) view was promoted by Kepler and Galileo, but its roots stretch back to Pythagoras and Plato.
2. The mathematical route to the natural world continues to be pursued today in modern physics with entities that can be described *only* in mathematical terms.
3. Yet not all of the sciences use (or require) mathematics to the same extent, for example, the life sciences. There, the descriptive, analytical methods of Aristotle remain important, as does the (somewhat casual) recourse to final causes.

II. The long shadow of classical culture extends over the entire period covered (and beyond) and deeply influenced generation after generation.

A. The (sometimes-rival) thought of Plato and Aristotle recurred in revival after revival, through the Islamic and Christian Middle Ages, and into the Scientific Revolution.

B. The memories (real or mistaken) of the glories of antiquity provided the pattern for renaissance after renaissance.

C. In general, the characters we have studied had a keen sense of the ranks of predecessors lined up behind them and looked to them for inspiration.

  1. Discarded ideas recur frequently, often in unexpected ways (for example, the priest Gassendi as the reviver of atheistic atomism).

  2. In modern times, we have largely lost this sense of the "presence" of history and rarely look back to the "ancients" for inspiration. Did "modernity" begin when we lost our awareness of history?

III. The human motivations for the study of the natural world are a crucial part of the history of science, but these are often soon neglected or forgotten.

A. Utility and application provided an impetus for some studies of the natural world, for example, in natural magic and in scientific societies. This motivation operates powerfully today.

B. The self-transformative power of knowledge was promoted by Plato and his followers, while Platonically influenced medievals (such as Hugh of St. Victor) gave this a redemptive (in the Christian sense) dimension. This motivation is not apparent in modern science.

C. Theology and religious devotion powered the study of the natural world in many contexts throughout the period we have studied.

  1. This fact gives the lie to the facile presumption of an inherent "conflict" between science and religion. That conflict is a relatively recent development.

  2. Religious institutions were the chief patrons of natural philosophical inquiry throughout the pre-modern period.

  3. The notion that study of the natural world was an inherently religious activity was common from the Greeks all the way to Newton.

D. Retrospective views of the development of science (particularly in science textbooks) omit the context and motivations behind specific scientific discoveries.

  1. Scientific development is not a linear progression from discovery to discovery.

  2. Science is not done by "lone geniuses"; the geniuses that develop science are part of human culture, and their motivations and interpretations of the world are deeply influenced by that culture.

  3. The natural world is constant in its reality, but each generation reads the "Book of Nature" over again and provides its own interpretation based on previous interpretations, new ideas, and cultural preoccupations.

  4. The history of science is the best way to approach and to understand the way science *really* develops and works.

Essential Reading:

John Henry, *The Scientific Revolution.*

Supplementary Reading:

David C. Lindberg and Robert S. Westman, *Reappraisals of the Scientific Revolution.*

Margaret J. Osler, *Rethinking the Scientific Revolution.*

Questions to Consider:

1. How has this course altered your conceptions of the development of science in the past and in the present?
2. List some ways in which the methods, practice, and goals of modern science differ from those we have seen for earlier periods during this course. What are the causes behind such differences? What are some of the ways in which the methods, practices, and goals remain the same? What are the causes of the similarities?