History of Science: Antiquity to 1700

Part I

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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.

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Part I

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 One
Beginning the Journey

Scope: This introductory lecture asks fundamental questions about the nature of science and its development, its importance to human civilization, and the reasons for studying its history. This lecture also introduces some themes that will recur throughout the course and provides an overview of the course in terms of the epochs and subjects to be covered.

Outline

I. The introductory lecture has three main components.

- **A.** The first part of the lecture examines why the history of science is worth studying and what science is.
- **B.** The second part looks at what the history of science contains and how it ought to be studied.
- **C.** The third part offers an outline of the content and organization of the course.

II. At present, science and technology are among the most powerful influences on human culture; therefore, understanding what science is and how it developed is crucial.

- **A.** What is science? What are its unique characteristics?
  - **1.** While we all have some definition of science, our definitions are often based on the *current* form of science.
  - **2.** As such, our definitions may be overly restrictive or even misleading if applied to earlier periods.
- **B.** The concepts of "science" and the "scientist" as generally understood today are modern conceptions dating from the nineteenth century.
  - **1.** The word "science" derives from the Latin *scientia*, which simply means "knowledge." "Natural philosophy" was the usual term for the study of the natural world, which we today would generally call "science." Natural philosophy has a broader scope than modern science.
  - **2.** Natural philosophy was done, naturally enough, by natural philosophers. The term "scientist" is a neologism, coined jocularly by William Whewell in 1834.
  - **3.** Science as a profession—that is, as the exclusive domain of professionals who are trained and paid for this activity—is likewise largely a nineteenth-century development.
  - **4.** Consequently, we cannot understand the history of science if we take a narrow (that is, modern) view of its content, goals, and practitioners.
  - **5.** Such a narrow view is sometimes called "Whiggism" (an interest only in historical developments that lead directly to current scientific beliefs) and the implementation of modern definitions and evaluations on the past.
- **C.** We can broadly define *science* (at least for the purposes of this course) as "the study of the natural world," while bearing in mind that that study's intentions, goals, practitioners, and methods have changed drastically over time.

III. Science is dependent on both the external reality of the natural world (the interpreted) and human culture (the interpreter). Thus, it is neither predetermined nor arbitrary.

- **A.** Two perspectives on the history of science define the ends of the spectrum between predetermined and arbitrary development of science.
- **B.** On the predetermined side lies "triumphalism," which views the *progress* of science as the gradual and progressive dawning of scientific truths on humanity.
  - **1.** This view has been favored by those arguing for the importance and uniqueness of science, but it tends towards arrogance and is incomplete.
  - **2.** Such a view fails to recognize the human character of scientific inquiry.
- **C.** On the arbitrary side lies "social constructivism," which, in its strong form, sees even fundamental natural laws (such as the law of universal gravitation) as artifacts of human society. This view is favored by those arguing against the importance and uniqueness of science, but it fails to recognize the existence of a natural

world independent of human perception or the real interest on the part of those who study nature in accurately describing it.

- **D.** The reality lies in the middle, and the most interesting issues in the history of science look at the changing interactions between human beings (in their proper historical context) and the natural world.
  - **1.** The course of scientific development (and technology even more so) is responsive to the intellectual, political, economic, social, and artistic values and needs of a society and must be seen in such contexts.
  - **2.** The style and justification of scientific inquiry are also culturally based, being dependent particularly upon the philosophical and theological commitments of its practitioners.
  - **3.** Thus, it is absolutely crucial to maintain the various human contexts of scientific developments.

IV. We cannot possibly cover all the necessary material in this course; therefore, certain criteria of selection have been implemented.

- **A.** The course will focus on natural philosophy ("science") and, to a lesser extent, technology in the Western world (defined as the immediate heirs of Greek thought, that is, Europe and the Middle East).
- **B.** The history of mathematics and the history of medicine will be included only to the extent that they have an impact on the study of the natural world.
- **C.** The history of education will be important at several points.

V. The course is divided into three sections on roughly chronological grounds.

- **A.** The first section deals with the ancient world, from the ancient cultures of the Babylonians and Egyptians to the fall of the Western Roman Empire, roughly 2000 B.C. to 500 A.D.
  - **1.** Ancient philosophy—the ways of conceptualizing the natural world and man's place in it—is the crucial context for the development of the study of nature.
  - **2.** Engagement with the ancient sources described here forms the basis for the natural philosophy and technology throughout most of the subsequent two sections.
  - **3.** The intellectual foundations of modern science lie ultimately in classical Greek thought.
- **B.** The second section deals with the medieval period (roughly 500 to 1400/1450 A.D.), both in the Christian and the Islamic worlds.
  - **1.** The interactions of the two great monotheistic religions with both the classical tradition and the natural world and with each other is central to this time period.
  - **2.** The relationship between science and religion is complex. The notion that there is an inherent "conflict" between science and religion is, however, a politically motivated construction of the nineteenth century. The following lectures should serve to efface that misconception.
- **C.** The third section deals with the Renaissance and the "Scientific Revolution," roughly 1450 to 1700/1750.
  - **1.** The "Scientific Revolution" is a concept enunciated by twentieth-century historians of science. It holds that the modern scientific worldview was largely formed in the period between the publication of Copernicus' heliocentric theory (1543) and the death of Isaac Newton (1727).
  - **2.** In this section, we will examine the development of new worldviews (and the "dismissal" of Aristotle) and how they responded not only to new observations of the world, but also to new needs and aspirations of early modern society.

Essential Reading:
David C. Lindberg, *The Beginnings of Western Science*, chapter 1, pp. 1-13.

Supplementary Reading:
Sydney Ross, "Scientist: The Story of a Word," in *Nineteenth-Century Attitudes: Men of Science*.

Questions to Consider:

1. Think about how the practice of science resembles the practice of history. What are the similarities and differences? Are there intellectual methods distinctive to research in one or the other?
2. Consider your own thoughts about the relationship between science and religion. What are the bases of your thoughts on the issue? Where did you acquire these thoughts?

Lecture Two

Babylonians, Egyptians, and Greeks

Scope: This lecture explores the origins of man's study of the natural world. The Babylonians, with their complex mathematics and astronomical observation, and the Egyptians are considered first. We then proceed to the earliest Greek thinkers and consider their first "scientific" theories about the natural world and how these were distinct from earlier ways of envisioning and conceptualizing the world.

Outline

I. Where and when do we begin the study of the history of science?

- **A.** Most historians of Western science begin with ancient Egypt and ancient Mesopotamia.
- **B.** The ancient Egyptian and Mesopotamian cultures exerted influence on the ancient Greeks, who in turn laid the foundations for Western thought and the history of science.
- **C.** Both cultures were literate and left historical records.

II. The Mesopotamian civilizations, in particular the Babylonian, developed and flourished in the first and second millennia B.C., largely in the area that is now Iraq. For historians of science, this culture's most noteworthy achievements were in mathematics and astronomy.

- **A.** Our knowledge of Babylonian mathematics and astronomy results from that culture's almost obsessive record-keeping and the durable material, clay, on which they "wrote."
- **B.** Babylonian mathematical notation was complex. It used both aggregation and place-notation and was both decimal and sexagesimal.
  1. Numerals 1–59 were written by *aggregation*, like the later Roman numerals.
  2. Starting with 60, the Babylonians used *place-notation*, as we do today. But while our system is based on powers of 10 (decimal), theirs was based on powers of 60 (sexagesimal).
  3. Place-notation was useful for expressing large numbers and fractions, which is difficult or impossible in aggregation.
  4. Babylonian mathematical texts also used "word problems" where unknown quantities need to be calculated from known data.
  5. The Babylonians may have chosen a base of 60 because its many factors make division easy and, possibly, because fractions and multiples of 60 occur in calendrical phenomena.
  6. The Babylonian sexagesimal system was used for astronomy for centuries and is still preserved today in angle measurements, for example, 60 seconds in a minute, 60 minutes in a degree, and so on.
- **C.** Babylonian astronomy compiled extensive records of heavenly bodies and their motions.
  1. Observations of the moon were especially critical because of their lunar-based calendar; solar observations were required for the regular adjustment of the lunar calendar to the solar year.
  2. By 600 B.C. and probably earlier, the Babylonians had compiled complex tables that allowed the prediction of celestial events, such as lunar phases and solar and lunar eclipses.
  3. Significantly, these predictive tables were compiled seemingly without any physical model of the universe to explain them.
  4. Observations were made by priests, and the needs they served were practical: maintenance of the calendar and astrological predictions of auspicious and inauspicious times.

III. The Egyptians created a flourishing civilization centered on the Lower Nile. Their mathematics and astronomy, however, were not as developed as the Babylonians.

- **A.** Egyptian mathematics used an aggregation notation that was decimal.
- **B.** Temples were oriented on certain terrestrial or celestial axes, which required observational skills and record-keeping over time.
- **C.** Few mathematical texts survive, and those that do are quite rudimentary compared with Babylonian examples.

D. Egyptian astronomy produced a solar calendar of 360 days, with 12 months of 30 days each. The remaining 5 days were festival days and remained uncounted.

E. Egyptian metalworking, glassmaking, and other "chemical" manufacture developed to a high degree but as a craft tradition without apparent speculative or theoretical elements.

F. Although Egyptian civilization was marked by long-term stability (in general) and impressive feats of engineering and organization, study of the natural world was actually quite limited and closely tied to practical applications.

IV. The earliest Greek thinker (we know of) who inquired into the workings of the natural world is Thales (fl. 600–580 B.C.), a native of Miletus, a Greek colony on the coast of Asia Minor (currently Turkey).

A. No original writings by Thales survive, but four of his ideas have been transmitted to posterity by Aristotle.

B. One of Thales' key claims was that "everything is made of water."

1. Aristotle claimed that Thales chose water because water is key to life and growth. On the other hand, it might also have been on account of the various forms water can take (ice, liquid, and vapor). Moreover, Egyptian and Babylonian creation myths often begin with water.
2. The signal importance of Thales' statement is that it is the first known attempt to identify a single material substratum out of which everything is made. (What is the world made of?) This project is ongoing today, albeit in modified form, in nuclear physics.
3. A further importance is that Thales' statement marks a key distinction between the underlying, unseen reality of things and their external appearance. This distinction would prove key to Greek natural philosophy and is crucial to modern science.

C. Thales' fame in antiquity was based partly on his prediction of a solar eclipse that occurred in 585 B.C. during a battle between the Medes and the Lydians. To accomplish this, he probably used Babylonian tables, but he could not have actually predicted the exact day or place where the eclipse would be seen.

D. Other remarkable feats were attributed to Thales, and he developed a reputation in antiquity of mythic proportions. Some features of this character are still found today in popular contemporary conceptions and anecdotes about scientists and, whether or not they are true, in Thales' case, they tell us something about Greek culture and the place of the natural philosopher.

E. Although it is clear that Thales learned from earlier Babylonian and Egyptian works (some accounts say that Thales traveled to Babylon), he (and his Greek culture) are distinct from them in significant ways.

1. Thales was an individual with distinctive ideas; these specific ideas were followed or opposed by subsequent thinkers.
2. We know Thales by name, but we have no similar names to attach to Egyptian and Babylonian ideas.
3. Thales' work was not exclusively practical; his thought dealt also with theoretical notions without practical application.
4. Thales stands at the beginning of a tradition in Greek thought that involved the systematization and explication of observations and the search for causes and principles in nature. These are hallmarks of Western scientific and philosophical traditions of which we (at present) find little evidence in Egypt and Babylonia.

F. Much of the Greek legacy depends on a simple belief which remains at the core of modern scientific inquiry: The world is a regular place. It is not incomprehensible; it is intelligible.

Essential Reading:

David C. Lindberg, *The Beginnings of Western Science*, chapter 1.

G. E. R. Lloyd, *Early Greek Science: Thales to Aristotle*, chapter 1.

Supplementary Reading:

John North, *The History of Astronomy and Cosmology*, chapter 1, "Ancient Egypt" and chapter 2, "The Babylonians."

Otto Neugebauer, *The Exact Sciences in Antiquity*, chapters 2–5.

Philip Wheelwright, *The Presocratics*, chapter 2, "Thales."

G. S. Kirk, J. E. Raven, and M. Schofield, *The Presocratic Philosophers*, chapter 2.

Questions to Consider:

1. The Babylonians' apparent lack of interest in knowing *how* the universe worked—in spite of their ability to make use of observed astronomical cycles for prediction—can strike us as odd. Can you think of examples from modern culture where people make use of things regularly yet do not inquire about why they work? What are the conditions for such a situation? What are the results?
2. Some scholars suggest that Thales' (or more broadly, the ancient Greeks') initiation of scientific study of nature resulted, at least in part, from the nature of the Greek colonies. They point to the unstable, uncertain nature of these fledgling colonies and their contact (through trade) with various outside cultures and people and contrast this situation with the stable, uniform, established, and introspective societies of Babylonia and Egypt. What do you think of this theory? How might these Greek conditions favor the initiation of scientific inquiry?

Lecture Three
The Presocratics

Scope: Several Greek philosophers before the time of Socrates (d. 399 B.C.) grappled with an array of significant issues that laid the foundations of Western natural philosophical thought and method: What is the world made of? How do things change? Where did things come from? Do our senses show us reality? In this lecture, we study their varied explanations for the physical changes around us, their ideas on the origin (and end) of the world, and the new concept of atoms. We will also consider how the influence of Presocratic ideas has resounded in Western thought ever since.

Outline

I. Thales of Miletus (fl. 585 B.C.) was the first of a series of Greek thinkers who dealt, in part, with natural philosophical issues. They are grouped under the title of "Presocratics," that is, those living before Socrates (d. 399 B.C.).

- **A.** Although much of their work can be characterized as "philosophy," many of their questions and activities relate directly to natural philosophy. Several were involved in practical "scientific" affairs.
- **B.** Several Presocratic questions and formulations are fundamental to the Western scientific tradition.
  - **1.** What is the world made of?
  - **2.** How is the universe constructed? (Cosmology)
  - **3.** Where did the world come from? (Cosmogony)
  - **4.** How do changes in the world occur?
  - **5.** How do we gain true knowledge of the natural world? Is the world orderly and knowable? Are the senses accurate guides? (Epistemology)
- **C.** No original texts survive from any Presocratic philosopher; we have only fragments transmitted by other ancient authors.

II. The "Milesian school"—Thales and his followers—is the earliest group of Presocratics.

- **A.** Anaximander (fl. 570 B.C.) was an associate of Thales and a few years younger than he.
  - **1.** Anaximander is reputed to have introduced the *gnōmōn* to the Greeks. The *gnōmōn* was a stick placed in the ground, perfectly perpendicular, and used to measure the angle of the sun or moon above the horizon as well as for surveying and time reckoning.
  - **2.** Anaximander gave a physical and mathematical description of the earth and the universe and attempted to provide physical causes for astronomical phenomena.
- **B.** A still younger colleague, Anaximenes (fl. 550 B.C.), chose air as the basis of all things. Condensation and rarefaction of air gave rise to different substances.

III. Two other Presocratics, Heraclitus of Ephesus (fl. 500 B.C.) and Parmenides of Elea (fl. 475 B.C.), gave largely opposing views of change in the physical world and the value of sense perception for studying it.

- **A.** Central to Heraclitus' thought is the idea that "everything flows," that is, everything is changing constantly; you cannot step into the same river twice.
  - **1.** Fire is central to Heraclitus; it is the source and end of everything and emblematic of constant change.
  - **2.** Beneath the constant change, however, is a unity ("all things are one") found in the *logos*—the reason, principle, or proportion of things.
- **B.** Heraclitus also valued the senses for giving knowledge of the natural world, but the senses must be rightly interpreted.
- **C.** Parmenides of Elea in southern Italy (fl. 450 B.C.) dismissed change as mere illusion; nothing changes. This means that sense perception, as used in the observations central to most ideas of natural philosophy, is useless and vain.
  - **1.** Parmenides divided everything into two categories: that which is and that which is not.
  - **2.** He was looking for a constant principle in the world, just like his predecessors.
  - **3.** Parmenides' willingness to give up the testimony of the senses—his skepticism about sense perception—turns out to be important to much of modern science. For example, the senses do not

indicate the speedy motion of the earth or the preponderance of void (indicated by atomic theory) in seemingly solid objects.

IV. All the foregoing Presocratics can be grouped as *monists*; that is, they held that although physical substances seem to be diverse, they actually all originate from a single source. An opposing school of *pluralists* held that there is more than original substance.

- **A.** Empedocles of Agrigentum in Sicily (fl. 450 B.C.) is credited with the notion of the four elements—fire, air, earth, and water—which he considered as the "four roots" of things.
  - **1.** Empedocles also commented on the origin and ultimate destruction of the world and attributed this (and all intermediate changes) to opposing principles he called Love and Strife.
  - **2.** Empedocles is, in a sense, a compromise between Heraclitean change and Parmenidean constancy. But Empedocles also asserts the value of the senses, contrary to Parmenides.
  - **3.** Some Christians (much later) found Empedocles to be compelling. His portrait is painted in the frame surrounding Signorelli's fresco depicting the end of the world in the cathedral at Orvieto.
- **B.** Empedocles cited the importance of randomness in the formation of the world, but Anaxagoras (c. 500 B.C.–c. 425 B.C.) denied this notion. For him, the world comes about by the action of *nous*, or mind.

V. The union of all these foregoing ideas appeared in the notion of atomism, promoted by Leucippus (fl. 430 B.C.) and Democritus of Abdera (fl. 420 B.C.).

- **A.** Atoms are envisioned as indivisible (lit. "uncuttable") particles dispersed through void space.
- **B.** Things are created and destroyed by the coming together and moving apart of atoms, but the atoms themselves are eternal. (Thus, both Heraclitean change and Parmenidean non-change are preserved.)
- **C.** Atomism, though "familiar" to modern science, had little popularity and influence for several reasons.
  - **1.** It was rejected forcibly by Aristotle for logical and operational reasons.
  - **2.** The moral and expressly atheistic context of atomism, especially as it was developed later by Epicurus (b. 341 B.C.), made atomism distasteful to many in subsequent centuries, particularly to Christians.
  - **3.** Democritean and Epicurean atomism were, however, revived about 2,000 years later, in the seventeenth century.

Essential Reading:

David C. Lindberg, *The Beginnings of Western Science*, chapter 2, pp. 31-35.

G. E. R. Lloyd, *Early Greek Science: Thales to Aristotle*, chapters 2 and 4.

Supplementary Reading:

Philip Wheelwright, *The Presocratics*, chapters 2–6.

G. S. Kirk, J. E. Raven, and M. Schofield, *The Presocratic Philosophers*, chapters 3, 4, 6, 8, 9, 10, and 15.

Questions to Consider:

1. Think about the characteristic questions of the Presocratics noted in this lecture (see above, section I.B). What is the current scientific thinking on these issues? How many of these questions have been answered conclusively? How many are no longer of interest to modern scientists (and why not)?
2. How much do you trust your senses in regard to providing true information about the world around you? How much do modern scientists (compare various fields) trust their senses? How can you verify the senses? How would you function differently in the world if you were to deny the senses to the degree that Parmenides did?

Lecture Four

Plato and the Pythagoreans

Scope: Plato, a student of the executed Athenian philosopher Socrates (d. 399 B.C.), has proven to be one of the most influential thinkers in history. This lecture recounts Plato's response to both the Presocratics and his contemporaries. Key to understanding Plato and his scientific impact is his view of reality and how this affects the value he places on observation (sense perception), the nature of true knowledge about the world, and how that knowledge is to be acquired. The influence of the secretive Pythagoreans is important both directly on Plato and through him, to the relationship between mathematics and the study of the natural world.

Outline

I. Plato, a follower of the executed Socrates (d. 399 B.C.), has had enormous impact on both philosophy and natural philosophy. He also marks a movement of intellectual activities from the more outlying Greek colonies to Athens.

- **A.** Plato's works, written in dialogue format, touch on many issues, including politics, ethics, and the living of a good life.
- **B.** His writings had significant impact on the history of science, owing in particular to:
  - **1.** His theory of being (ontology).
  - **2.** His theory of knowledge (epistemology).
  - **3.** His emphasis on a mathematical basis for nature.
  - **4.** The natural philosophy in his dialogue *Timaeus*.

II. The theory of Forms provides the basis of Plato's epistemology, ontology, and his impact on the history of science.

- **A.** According to Plato, the Forms are the eternal, unchanging exemplars of things. Objects in the world of sense are mere approximations of the Forms.
  - **1.** There is, therefore, an ontological hierarchy in the world. At the lowest level are our imaginings of specific things, then the specific things themselves, then mathematical abstractions of things, then finally the Forms, of which the inferior versions are imperfect manifestations.
  - **2.** This view is summed up in Plato's Parable of the Cave (*Republic*, Book VII), which claims that men who experience the world by sense alone are like prisoners in a cave who see only the flickering shadows of things upon the cave wall and believe that that is "all there is."
- **B.** The Forms come with epistemological consequences, as well as ontological ones.
  - **1.** True knowledge is knowledge of the Forms.
  - **2.** We escape the delusion of sense perception (the cave) through the exercise of reason.
  - **3.** Unlike Parmenides, Plato did not dismiss sense perception as mere illusion. Observation is a wholesome activity—when enlightened by reason—and is the starting point to regain knowledge of the Forms.
- **C.** In terms of the history of science, Plato's insistence on the ontological and epistemological superiority of Forms urges the Platonist to move from particular observable objects to universals, that is, to frame universalized conceptions from individual objects. This is, in effect, a hallmark of "scientific" inquiry—the discovery of regularities and generalized principles from a collection of individual objects or observations.

III. The mathematical content (and other aspects) of parts of Plato's work derives from his association with Pythagoreans.

- **A.** The school was founded by Pythagoras (b. c. 580 B.C.), but it is difficult to separate fact from fiction in regard to Pythagoras' life and teachings.
  - **1.** Pythagoras, a contemporary of the Milesian school, was born in Samos.
  - **2.** He supposedly traveled in Egypt, where he learned astronomy and mathematics.
  - **3.** Pythagoras fled from the tyrant Polycrates to found a school in the Greek colony of Kroton in Sicily.
- **B.** The Pythagorean school was based on communal living, rituals, and secrecy.

C. Pythagoras is famous today for "his" theorem about right triangles, but this must be placed in the proper context of the goals of his school.
   1. The Pythagoreans' great secret was that of incommensurables, that is, irrational numbers.
   2. The Pythagoreans were impressed by the existence of mathematical ratios in music and developed the notion of the "music of the spheres."
   3. The emphasis on mathematics arose from the Pythagorean notion that the world *was* number—the principles of mathematics are the principles of nature.

D. The Pythagorean school was primarily religious—a way of life, not some mathematical "think-tank."
   1. Among their beliefs, the Pythagoreans maintained the immortality of the soul and its transmigration and showed an interest in number mysticism.
   2. Their prime objective was to discover and to live the "good life"—namely, one in harmony with the cosmos—which would bring advancement to the soul.
   3. Mathematics was, thus, key to understanding harmony in the cosmos, in life, and in music.

E. The point for the history of science is nonetheless substantial—to what extent is the natural world expressible in mathematical terms?
   1. In physics today, actions, such as free-fall motion, are expressed in mathematical formulae, and mathematical manipulations allow for prediction of natural events.
   2. The revival of Pythagorean ideas and ideals in the sixteenth century was one of the factors leading to the increasing mathematization of the world, a key factor in the development of modern scientific views.

IV. Plato was deeply impressed by the Pythagoreans, possibly partly owing to the communal society they had created.

A. Platonic dialogues show numerous resonances with Pythagorean ideas—immortality of the soul, reincarnation, an interest in mathematics and harmony.

B. The resonances with Pythagoreanism and their natural philosophical consequences, as well as the theory of Forms, become clear in Plato's *Timaeus*, his most influential work in terms of the history of science.

Essential Reading:

Plato, *Republic*, Book VII.

David C. Lindberg, *The Beginnings of Western Science*, pp. 35–45.

G. E. R. Lloyd, *Early Greek Science: Thales to Aristotle*, chapters 3 and 6.

Supplementary Reading:

Philip Wheelwright, *The Presocratics*, chapter 7.

G. S. Kirk, J. E. Raven, and M. Schofield, *The Presocratic Philosophers*, chapters 7 and 11.

Questions to Consider:

1. Plato and the Pythagoreans were convinced of a close link between mathematics and the natural world. Does mathematics really provide a good description of the world? Is it equally useful in all branches of modern science? Why or why not?
2. Assuming the validity of Plato's doctrine of Forms, do you think everything (every individual object? every species of object?) in the natural world would have to be based on a Form? If so, what would be the consequences?

Lecture Five

Plato's Cosmos

Scope: This lecture begins with a study of Plato's *Timaeus*, in which the Athenian philosopher describes the cosmos and its creation, its fundamental building blocks, human anatomy, and other scientific topics. Plato's interests are not only natural philosophical but also ethical and social. Partly on account of the *Timaeus*, the pagan Plato found great acceptance subsequently among Christians, Muslims, and Jews and was, thus, enormously influential in a wide range of areas.

Outline

I. The *Timaeus* is important because it proved to be one of the most influential of Plato's dialogues, even if, nowadays, it would rarely be listed among the most important save by historians of science.

- **A.** It was the only work of Plato known to the Latin Middle Ages.
- **B.** It contains the majority of Plato's explicitly natural philosophical statements.
- **C.** It contains the story of Atlantis, which has fired the imagination for centuries.

II. The main discourse of the *Timaeus* provides a "likely account" of the origin and structure of the world and its contents.

- **A.** The world is created by the demiurge, a craftsman god. Unlike the Christian creator, the demiurge is neither omnipotent nor the only eternal being—the Forms and matter are coeval with him—nor is he a personal god.
  - **1.** The demiurge creates the world from the existent unformed matter and uses the Forms as patterns, the way a builder uses a blueprint.
  - **2.** But matter is inherently incapable of taking the Forms fully; it thwarts the best efforts of the demiurge. Thus, although the demiurge makes the best possible physical world, it remains imperfect relative to the eternal Forms.
- **B.** The universe is spherical; it rotates and is "alive."
  - **1.** The universe is put together full of harmonies and mathematical intervals; the debt to Pythagoreanism is clear.
  - **2.** Heavenly spheres guide the motions of the sun, moon, planets, and stars. Their motions are regular, mathematically harmonious, and kept within proper bounds.
- **C.** The *Timaeus* presents a matter theory based on a "geometrical atomism."
  - **1.** The demiurge first fashions matter into regular triangles and combines these into the five regular polyhedra—tetrahedron, cube, octahedron, dodecahedron, and icosahedron—now known as the "Platonic solids."
  - **2.** These polyhedra give rise to the four Empedoclean elements; the cube is earth; the tetrahedron, fire; the octahedron, air; and the icosahedron, water. These elements then go to form more complex mixed bodies.
  - **3.** The elements can interconvert by falling apart into the original triangles, which then recombine into different polyhedra. (This interconversion is in contrast to Empedocles.)
  - **4.** This theory, like much of the *Timaeus*, deals with human anatomy and physiology.
  - **5.** Plato then deploys this theory to explain the natures of a wide variety of substances.
- **D.** A substantial portion of the *Timaeus* deals with human anatomy and physiology.
  - **1.** The human body is prepared by lower deities created by the demiurge, but the human soul is created by the demiurge himself.
  - **2.** The parts of the human body are designed to fit their functions.

III. Plato's *Timaeus* must be contextualized; Plato's interest here in cosmological, biological, and other natural philosophical topics needs to be explained.

- **A.** The *Timaeus* is linked with the *Republic*; the opening discourse refers to the topics of the *Republic* and summarizes the characteristics of the perfect state.

B. The cosmology and other natural philosophical claims made in the *Timaeus* can thus be seen as part of Plato's notions regarding the proper ordering of the individual and of society.

  1. The repeated message of the *Timaeus* is that the world is created and governed by mind (*psychē*) not by chance or mere "nature" (*physis*).

  2. One implication is that if the world itself is intelligently ordered, the individual ought to be as well, and so too, the political state (rather than being left to chance).

  3. As each part of the human body is designed to fulfill a specific function, so too, each member of society should be designed to fulfill a specific function.

C. The story of Atlantis fits into this scheme. The ancient Athenians were powerful enough to defeat the great power of Atlantis because they were orderly; that is, their society was like that of Plato's *Republic*.

D. Natural philosophy plays an important role in learning to live rightly as an individual.

  1. Knowledge transforms the knower. A person's choice of objects of contemplation transforms his soul into their likeness. Contemplation of the cosmic harmonies and perfection makes our souls harmonious and perfect.

  2. At the end of the dialogue, Plato makes (possibly tongue-in-cheek) remarks about the origin of animals from unfit (that is, unphilosophical) humans. Their unfitness comes from the neglect or improper use of their minds.

E. Even if the *Timaeus* is not primarily a natural philosophical work, its ideas were very influential. This happens frequently in the history of science—"scientific" ideas often develop and receive influence from sources well removed from what we would today rigidly define as "scientific."

IV. The *Timaeus* found welcome readers among Christians (and Muslims) because of resonances with revealed theology.

A. The world is created, not eternal.

B. The world is created by a single god, not a pantheon; that god is good, eternal, and pleased with his creation.

C. The world is created by intelligent design, not by chance.

D. The study of nature shows its design, teaches about the creator, and directs the wise man toward right living.

V. Several conclusions should be drawn about Plato's impact on scientific thought.

A. Plato's comments on the value of observation are mixed.

  1. Observation of natural objects focuses (by necessity) on imperfect physical objects—dim reflections of the eternal Forms, knowledge of which constitutes *real* knowledge.

  2. The fate of men turned into birds exemplifies the need for the natural philosopher to do more than simply observe nature; he must seek out both *causes* and *meanings* by the use of reason. These goals prove crucial in the history of science.

  3. But observation of the world is a starting point for the rational ascent to the perfect, eternal Forms. *Timaeus* considers vision to be man's greatest physical ability.

  4. Observation of the natural world, and the discovery of abstract laws governing it, reveals evidence of order and design in the world. The study of nature, thus, has a morally (or religiously) didactic purpose.

B. The existence of perfect Forms, inaccessible to our direct observation, implies that the key truths are *separate* from material objects, which feeds into the notion that principles must be abstracted from sense data. This is widely perceived in the modern world as a key scientific principle.

C. The theory of Forms and a belief in the inherently mathematical nature of the world provide a background to new conceptualizations and formulations of nature, that is, ones in which the underlying truths of nature can be idealized in theoretical mathematical "laws." This is clear in the challenge reportedly given by Plato to astronomers.

Essential Reading:

Plato, *Timaeus*.

Supplementary Reading:
Plato, *Critias*.
R.M. Hare, *Plato*.

Questions to Consider:

1. How would a greater appreciation and acceptance of Plato's view of how knowledge transforms the knower change the practice and goals of modern science? How would it change your daily life?
2. How can we determine whether the world is a result of (Empedoclean) randomness or (Platonic) design?

Lecture Six

Aristotle's View of the Natural World

Scope: Like his teacher Plato, Aristotle had tremendous impact on the development of natural philosophy, its methodology, and its aims. This lecture introduces Aristotle, his writings, and his ideas as a response to his predecessors, the Presocratics and Plato. We focus here on Aristotle's views on the value of observation, the nature of change, the composition of matter, and what constitutes real knowledge of a thing. The characterization of Aristotle as first and foremost a "biologist" helps to make better sense of his worldview, and this is contrasted with the modern worldview based instead on physics.

Outline

I. Aristotle (384–322 B.C.), a student of Plato, produced a comprehensive corpus that includes the most expressly natural philosophical ("scientific") works seen hitherto. Aristotle's thought had major influence for 2,000 years, and many of his formulations continue to form the bases of our own thought.

- **A.** Aristotle's works include the study of ethics, politics, logic, and metaphysics, but those of special importance to the history of science deal with (in modern terms) physics, matter theory, cosmology, and biology.
  - **1.** Aristotle wrote more than 150 books, but only about 30 now survive, which still amounts to a substantial corpus.
  - **2.** Aristotle's writings as we have them are terse and are probably lecture notes rather than polished treatises.
- **B.** Aristotle's system was particularly attractive for many generations because it was seen as a comprehensive world-system that subsequent natural philosophers could work with.
- **C.** Aristotle says that the Presocratics studied nature but without a good method; Socrates and Plato had a good method but neglected the study of nature.

II. Aristotle makes frequent reference to Plato and the Presocratics and responds to them.

- **A.** Aristotle often disagreed with his teacher Plato on fundamental issues.
  - **1.** Aristotle rejected the Forms and Plato's ontology.
  - **2.** Aristotle was far more interested in the material world—the study of nature—than was Plato.
- **B.** Aristotle provides his own solutions to two chief questions of the Presocratics: "What are things made of?" and "What is the nature of change?"
  - **1.** Aristotle takes a monist position—the material substratum of everything is the same stuff.
  - **2.** This stuff is not a known substance (such as Thales' water) but a universal quality-less matter (*hylē*) sometimes called "prime matter."
  - **3.** Individual objects arise when matter is "imprinted" with a form (*morphē*). The form is the sum total of its qualities.
  - **4.** Matter takes the form the way a lump of wax takes the impression of a seal.
  - **5.** Matter and form never exist independently of each other.
  - **6.** Aristotle's matter and form theory is known as *hylomorphism*.
- **C.** Change is the replacement of one form by another; the prime matter remains unchanged. By preserving both constancy and change, Aristotle effects a "compromise" between Heraclitus and Parmenides.
  - **1.** Aristotle's world is more like Heraclitus' than Parmenides'. For Aristotle, the world is *dynamic*. "The only thing constant is change."
  - **2.** Change occurs along a continuum between pairs of contrary qualities.
  - **3.** The primary qualities are the pairs hot-cold and wet-dry. Prime matter plus a pair of these primary qualities gives the Empedoclean four elements.
  - **4.** Change always involves a movement from potentiality to actuality.
  - **5.** One thing cannot be turned into just any other thing, only into those things that it already is in potential. Grass can become milk in a cow's stomach, but a rock cannot.

III. True knowledge (*epistēmē*) is "causal knowledge," knowledge of *why* a thing is as it is. This is distinct from artifice (*technē*), which is knowledge of *how to do* something.

- **A.** There are four "causes" of things: the efficient (what makes it), the formal (what its form is), the material (what it is made of), and the final (what its reason for being is).
- **B.** The causes provide an exhaustive list of how an object relates to other objects; the causes situate an object in context, in correspondence with other objects.
- **C.** The final cause is the most difficult for moderns to accept, but it is the key to Aristotle's natural philosophy.
  - **1.** It preserves (and develops) the purposefulness of Plato's system and embodies Aristotle's view of "nature."
  - **2.** "Whatever Nature makes, she makes to serve some purpose."
- **D.** A fundamental divide separates natural and artificial things.
  - **1.** Natural things have an "internal principle of motion (or change)" that propels them toward their final causes. An acorn becomes an oak tree because, as we still say, that is "in its nature."
  - **2.** In some cases, external circumstances prevent a natural object from reaching its natural end. Art (*technē*) can sometimes help complete this end.
  - **3.** Artificial things lack the internal principle of change. Motion or change comes to them only from outside agents. Unlike an acorn, a planted bed rots, but *as wood* not *as bed*. Artificial things do not move toward their final ends without guidance from an external agent.
  - **4.** A division between artificial and natural objects persists today in popular imagination.
- **E.** Final causes (teleology) are formally rejected by modern science, because they do not fit into modern worldviews that see a world without purpose or direction.
  - **1.** But final causes do seem to persist in the sciences, particularly in popularizations and in biology.
  - **2.** This last is a clue to understanding Aristotle rightly, because his worldview is best seen as stemming from his extensive experience in biology.

IV. Seeing Aristotle first and foremost as a biologist may help us better understand his thoughts and the reasons behind them.

- **A.** Aristotle spent many years doing dissections and describing animals and plants; this was probably his main activity during his non-Athens years of 347–335 B.C.
  - **1.** He was a keen observer.
  - **2.** Even though he sometimes recorded mere hearsay, he also recorded several things that were not widely believed until nineteenth-century and twentieth-century biology showed them to be true.
- **B.** For Aristotle, living things show the working of the natural world better than non-living.
  - **1.** Causation and directed purposefulness are clear in nutrition, growth, and anatomy. Purpose is very clear in dissections, of which Aristotle performed many, even though that book is lost.
  - **2.** The centrality of biological studies to Aristotle's thought helps make sense of the importance he accords to the final cause.
  - **3.** Aristotle's system stands in contrast to modern worldviews that base themselves on the behavior of non-living matter and forces (physics). For Aristotle, life helped explain the non-living world; for moderns, life has to be explained in terms of non-life.
  - **4.** Moderns have made a conscious choice to posit non-life physics as fundamental. This is not a self-evident choice. Aristotle made a different choice.
  - **5.** Armed with this realization, Aristotle's dynamics and cosmology will now make more sense.

Essential Reading:

David C. Lindberg, *The Beginnings of Western Science*, chapter 3.

Supplementary Reading:

Jonathan Barnes, *Aristotle: A Very Short Introduction*.

G. E. R. Lloyd, *Early Greek Science: Thales to Aristotle*, chapter 8.

Questions to Consider:

1. Aristotle clearly values *epistēmē* much more highly than *technē*. What are the relative values modern science (and culture) places on *technē* and *epistēmē*? How does this change the goals and practice of science?
2. Why does modern science consider physics-based viewpoints fundamental? Might the current biological revolution (re)assert the primacy of biological worldviews? Can we conceive of a biologically based physics?

Lecture Seven

Aristotelian Cosmology and Physics

Scope: Much of Aristotle's subsequent impact was on the basis of his cosmology, physics, and dynamics. This lecture looks at Aristotle's activity in these areas, bearing in mind his key interest in biology as a means of explaining his intentions. We first explore the structure of Aristotle's cosmos, then show how this relates to his physics of motion. We will conclude by demonstrating the utility of Aristotle's system by using it to explain everyday observations.

Outline

I. Aristotle's cosmology, dynamics, and physics all cohere and are best understood together and with reference to his biological preoccupations.

II. Aristotle took much of his cosmic order from contemporaneous astronomy. The earth is at the center, immobile (as common sense affirms); the celestial bodies move around it.

- **A.** The celestial bodies are carried by the motions of specific spheres arranged concentrically about the earth.
  - **1.** The lowest sphere is that of the moon.
  - **2.** The highest sphere is that of the fixed stars.
- **B.** Aristotle devised a complicated system with more than fifty spheres to account for all the motions of the sun, moon, and planets.

III. Aristotle's universe is divided into two distinct realms with distinctly different physics. The dividing line is the sphere of the moon.

- **A.** Below the sphere of the moon (the sublunary realm) is the realm of change.
  - **1.** Here, things are composed of the four elements; things come to be and pass away.
  - **2.** The four elements have "natural places." Earth, being heavy, has its natural place at the center of the universe; fire, being light, has its natural place just below the sphere of the moon.
  - **3.** The elements have "natural motions" toward those natural places. They naturally move toward them in straight lines; thus, a stone, when dropped, moves toward the center of the earth by virtue of its nature. Similarly, the flame of a candle points upward.
  - **4.** Given this notion, the earth must obviously be spherical (as the Greeks already knew) so that its surface is everywhere equidistant from the center. Moreover, earth's shadow cast on the moon during eclipses shows its shape.
- **B.** Above the sphere of the moon (the superlunary world), there is no change.
  - **1.** Here, things are composed of a "fifth element" (quintessence, or *aether*); nothing comes to be or passes away. This is clear from Babylonian and Egyptian records, which never recorded any change in the celestial bodies or their movements.
  - **2.** While the four elements have natural rectilinear motion toward their natural places, the fifth element has natural circular motion; hence, the heavens never "run down."

IV. Aristotle's dynamics flow from this cosmology, and his notions of motion are connected to biological exemplars.

- **A.** Aristotle has a broader definition of motion than we do. He posits three kinds: local motion (change of place, our idea of motion), motion of quality (change of form), and motion of quantity (change of magnitude). For example, an apple maturing from red to green is a natural motion of quality.
  - **1.** This seems strange to us because our (physics-based) science is predominantly quantitative. Aristotle's (biologically-based) natural philosophy is primarily qualitative.
  - **2.** This, again, is a *choice* of how to base a scientific world-system; neither is self-evident or right-wrong.
- **B.** Motions are of two kinds: "natural" (according to nature) and "violent" (contrary to nature).
- **C.** Natural local motion (a falling rock) is about finding a natural place by the influence of the "internal principle of motion or change."

1. The mover is internal to the naturally moving object. It actualizes the potential; it moves the object toward the final cause of its motion, that is, being in its natural place.
2. The growth of an acorn into a tree is, thus, analogous to the falling of a heavy body.
3. The falling object does not stop until it either reaches its end (natural place) or is stopped (artificially) by the interference of an external agent.

D. Violent motion (a rock thrown upward) is artificial and opposes natural motion.

1. The mover is external to the artificially moving object (compare artificial objects, which have no internal principle of motion/change).
2. Because the object moves contrary to nature, the violent (or artificial) motion soon perishes, the natural motion takes over, and the rock falls to earth (its natural place).
3. But the rock keeps rising even after it leaves the hand (external agent) pushing it. Thus, there must be another external motive agent; Aristotle postulates (not too successfully) that the motion is given by the medium through which it is moving.

V. The best way of really understanding Aristotle is to spend time thinking like an Aristotelian: identifying the four causes of specific objects, explaining observations in accord with Aristotelian views. When this is done, Aristotle's incredible utility for studying and explaining the world becomes clear, and his longevity as an authority is made easier to understand.

Essential Reading:

Aristotle, *Parts of Animals*, Book I, chapters i and v; Book II, chapter i.

Aristotle, *Physics*, Book II, chapters i-iii, viii-ix.

Supplementary Reading:

Terence Irwin and Gail Fine, *Aristotle: Selections*.

Questions to Consider:

1. For the next couple of days, choose various objects that you see and try to identify their four causes. Does the identification of the Aristotelian causes give you further insight into the objects and their places in the natural (or artificial) order of things?
2. Aristotle's world is suffused with the idea of "nature" as an explanatory principle. Think about the word "nature." What are the different meanings we assign to it? How do we continue to use "nature" as an explanatory principle? Reflect on the utility of this usage in both science and daily life.

Lecture Eight

Aristotle's Legacy and Hellenistic Natural Philosophy

Scope: Like Plato, Aristotle founded a school (the Lyceum) in Athens that perpetuated his work and ideas. This lecture also surveys the wider world of Hellenistic science that developed in the expanded Greek world created by Aristotle's student Alexander the Great. Special emphasis is paid to Alexandria, with its great Library and the Museum, and to the work and legends of Archimedes.

Outline

I. In 335 B.C., Aristotle returned to Athens after a twelve-year absence and founded a school called the Lyceum, similar to Plato's Academy. The Lyceum carried on some of Aristotle's natural philosophical projects.

- **A.** Aristotle's immediate successor was Theophrastus (b. c. 371 B.C.); he headed the Lyceum from 322 to 286 B.C.
  - **1.** Theophrastus wrote authoritative texts on plants and minerals.
  - **2.** He disagreed with Aristotle on several issues, including the elemental status of fire and the universality of final causes.
  - **3.** He bought land and buildings for the Lyceum that ensured its stability and continuance.
- **B.** The third leader of the Lyceum (286–268 B.C.) was Strato of Lampsacus.
  - **1.** None of Strato's works survives, but he was called "the physicist" in regard to his primary interest in natural philosophy, and he disagreed with Aristotle on many issues.
  - **2.** Strato conducted experiments to demonstrate his ideas.
  - **3.** He argued that falling bodies accelerate and used a stream of falling water and the dropping of weights into soft earth to show this.
  - **4.** He argued for the existence of the vacuum (contrary to Aristotle), using the compression and dilation of air as proof; he may well have been an atomist.
- **C.** It is significant that the two immediate successors to Aristotle freely disagreed with him. This freedom to criticize is crucial to the development of Greek thought (and Western thought in general).
- **D.** The Lyceum continued to function for more than two and a half centuries, until it closed around the middle of the first century B.C.

II. Around the time of Aristotle's death, the Greek world changed drastically. His one-time student Alexander the Great (356–323 B.C.) created a vast empire, initiating the Hellenistic age.

- **A.** The Hellenistic period is sometimes seen as a period of "decline" for Greek natural philosophy, but this is a matter of perspective.
- **B.** Hellenistic natural philosophers were busy elaborating and following out the programs initiated by Plato, Aristotle, Pythagoras, and others.

III. The city of Alexandria in Egypt, founded by Alexander in 332 B.C., became a major center of Hellenistic thought and culture.

- **A.** The Library and Museum of Alexandria (founded c. 300 B.C.) were chief centers of scholarship and were supported by (sporadic) royal and other patronage.
- **B.** Many scholars worked in Alexandria throughout (and after) the Hellenistic period.
  - **1.** Euclid, known for his axiomatic and deductive system of geometry, was connected with the city in the third century B.C.
  - **2.** Eratosthenes of Cyrene (c. 276–195 B.C.) was head of the Library. Among his accomplishments was an experiment to measure the size of the earth.

IV. Elsewhere in the Hellenistic world, further developments occurred in several areas of natural philosophy.

- **A.** In astronomy, Hipparchus (second century B.C.) compiled an extensive star catalogue, measured the distance of the moon from earth, and determined the length of the lunar cycle to within one second of the currently accepted value.

B. Archimedes (c. 287–212 B.C.) studied in Alexandria but lived most of his life in his native Syracuse and produced advanced works on mathematics and mechanics.

   1. Archimedes' work shows a further step in the mathematization of natural phenomena.

   2. Tales of Archimedes' cleverness reached heroic proportions in antiquity, particularly in regard to his technological "wonders."

   3. One of these was a spherical contrivance that represented the motions of the sun, moon, and planets. It was seen and described by the Roman orator Cicero.

   4. Archimedes is most famous for the principle named after him ("Eureka!") and for supposedly setting the besieging Roman fleet on fire with mirrors.

Essential Reading:

David C. Lindberg, *The Beginnings of Western Science*, chapter 4.

Supplementary Reading:

G. E. R. Lloyd, *Early Greek Science: Thales to Aristotle*, chapter 9, and *Greek Science after Aristotle*, chapters 1–3.

Questions to Consider:

1. This lecture introduced the important idea of centers for learning—Aristotle's Lyceum and the Library and Museum of Alexandria. Why are such centers or institutions important? How do they benefit scholarly or scientific work? What is the nature and role of such institutions today?

2. The historical Archimedes (like many classical figures) is surrounded by myths. Myths may not be literally true, but they do tell us some important things, for example, about the myth-makers. What do the Archimedean myths say about Hellenistic and Roman expectations of natural philosophers and technologists?

Lecture Nine

Greek Astronomy from Eudoxus to Ptolemy

Scope: This lecture examines the development of systems of astronomy from Eudoxus and other followers of Plato to the one proposed by Claudius Ptolemy in Alexandria during the second century A.D. We examine how and why these systems were devised and how they were used. The differences in goals and claims between classical and modern astronomy are highlighted.

Outline

I. Observational astronomy was practiced by the Babylonians, Egyptians, and other ancient peoples, but without (as far as we know) an explanatory framework (physical astronomy). The thrust of Greek astronomy was to explain observations.

- **A.** The Presocratics gave physical descriptions of the universe, but despite some important conceptual steps, these descriptions were quite rudimentary and not well correlated with observations.
- **B.** In a crucial development, Plato is supposed to have challenged his students to devise a system for explaining the apparently irregular motions of the planets using a combination of uniform circular motions.

II. Observed celestial motions are quite complex; there are three distinct motions to be explained.

- **A.** The diurnal motion: Each day, the celestial bodies rise and set once, moving across the sky from east to west.
- **B.** The annual motion: Constellations visible in the summer are not seen in the winter. This is because each night, a given star rises slightly earlier than the night before. Thus, the stars, besides their diurnal motion, seem to revolve around the earth from east to west once in a year.
- **C.** The proper motion of the planets: The seven planets (the moon, Mercury, Venus, the sun, Mars, Jupiter, and Saturn) have their own motions of three kinds.
  - **1.** Planetary proper motion is restricted to the zodiac, and the planets appear to move, at a variable speed, from west to east from night to night (that is, rising later each day) against the backdrop of fixed stars.
  - **2.** With the exception of the sun and the moon, the planets occasionally stop (a station), move backward through the zodiac (retrogradation), stop again, then resume their usual motion.
  - **3.** The planets—especially the moon—move in a wavy path, oscillating slightly north and south within the band of the zodiac during their east-west motions.

III. Plato's challenge was first taken up by his student Eudoxus of Cnidus (fl. 375 B.C.).

- **A.** Eudoxus' works are themselves lost, but they are transmitted to us by Aristotle, who adopted Eudoxus' general ideas.
- **B.** Eudoxus' universe is composed of 27 nested concentric spheres rotating at various, but uniform, speeds, with axes inclined to one another.
  - **1.** The earth is immobile at the center.
  - **2.** The highest sphere carries the fixed stars daily from east to west.
  - **3.** The sun and moon are moved by a combination of the motions of three connected spheres; the highest rotates east to west and contributes the diurnal motion, the next rotates west to east and contributes the proper motion through the zodiac, and the lowest contributes the north-south motions in the zodiac. The *sum* of these three motions approximates the apparent motions of the planets.
  - **4.** The other planets are moved by four spheres; the lower two account for retrograde and the slight north-south motions. Again, the *cumulative sum* of these *four motions* approximates the apparent motions of the planets.
- **C.** Eudoxus had success in expressing the complex observed motion as a sum of uniform circular motions, but his system failed to account for two well-known observations: The planets change in brightness (implying that their distances change), and the seasons are of different lengths (meaning that the sun's velocity was not constant).

D. Subsequent natural philosophers, particularly Callippus of Cyzicus (fl. 330 B.C.) and Aristotle (both also Academy students), altered Eudoxus' system by adding further spheres.
    1. Aristotle was concerned about the communication of motion from one set of spheres to the next.
    2. He added numerous spheres to counteract this motion.

E. Eudoxus' achievement was in attempting to "save the phenomena" by reducing apparent complex and irregular motions to a combination of underlying mathematical simplicity and regularity, a goal in harmony with Platonic commitments to an orderly world designed on mathematical principles.

IV. Two major innovations were suggested by other Greeks, although these were not widely accepted.

A. Heraclides of Pontus (another student of Plato's Academy) suggested replacing the diurnal motion of the heavens with the diurnal rotation of the earth on its axis.

B. Aristarchus of Samos (third century B.C.) hypothesized a heliocentric system, in which the annual motion of the heavens was replaced by the annual motion of the earth around the central sun.

C. Both of these systems were in conflict with prevailing physics and common sense, and there was no evidence in their favor.

V. The culmination of Greek astronomy comes finally with Claudius Ptolemy (second century A.D.). Ptolemy's system formed the basis of astronomical thought and calculation for the next 1,500 years.

A. Ptolemy used the notions of the epicycle and eccentric to create a system different from the Eudoxian concentric spheres model.
   1. Both innovations are probably the work of the mathematician Apollonius of Perga (fl. 220–190 B.C.) and were developed further by Hipparchus of Samos.
   2. An eccentric is a planetary orbit whose center does not coincide with the center of the earth.
   3. An epicycle is a "secondary orbit" on which the planets move, which is centered on a primary orbit (the deferent) around the earth.

B. The combination of epicycles and eccentrics explains all the observed phenomena: variable speed, retrograde motion, changes in planetary brightness (distance), and the inequality of the seasons.

C. The result was a system that was both explanatory and predictive.

VI. The reasons behind Greek astronomical speculation were diverse.

A. For Plato and his followers, physical astronomy was part of their program of revealing the design inherent in the universe and its mathematical basis.

B. For Aristotle, physical astronomy was part of his comprehensive system and interleaved with his physics.

C. For many Greeks, Ptolemy in particular, physical astronomy gave a better ability to calculate past and future celestial positions, necessary for astrology. Ancient astrology was a serious matter involving complex calculations.

VII. The level to which the physical models of the Greeks were taken to be "true descriptions" of the cosmos rather than models designed to "save the phenomena" probably varied among various theorists, but the question itself marks an essential difference between pre-modern and modern astronomy.

Essential Reading:

David C. Lindberg, *The Beginnings of Western Science*, chapter 5.

Supplementary Reading:

G. E. R. Lloyd, *Greek Science after Aristotle*, chapters 5 and 8.

John North, *The History of Astronomy and Cosmology*, chapter 4, "The Greek and Roman World."

Questions to Consider:

1. The Platonic interest in simple circular motions is based in part on Greek ideas of the harmonious and the aesthetic. Can you think of notions or guiding principles in modern science that are based on aesthetics?
2. Astrological prognostications have been made since the time of the Babylonians. What is the allure and promise of astrology that explains its longevity?

Lecture Ten

The Roman Contributions

Scope: The Romans produced a staggering civilization that was very different from that of the Greeks. In this lecture, we explore the differences between them in terms of scientific work. Specifically, the Romans' most notable achievements lay in technological advancements rather than the more speculative sciences of the Greek world. Here, we will explore not only the intellectual status of technology, but also how the pursuit of science responds to the needs and temper of a society, rather than developing according to some simple notion of "progress." We will examine several case studies of Roman engineering and technology.

Outline

I. The Romans, who had conquered most of the Greek world by the end of the first century B.C., showed little interest in the topics that Greek natural philosophers had pursued.

- **A.** Science does not develop "automatically"; it is shaped in many ways by the prevailing culture.
  - **1.** The Romans' practically minded culture gravitated toward practical applications (technology), rather than speculative natural philosophy (science).
  - **2.** We have to disengage interest in scientific topics from other measures of a society's "success."
- **B.** Technology is far more evident in Roman culture than original natural philosophy is.

II. The status of technology has long been problematic.

- **A.** The practicality of "applied science" argues for its importance but also mediates against its study.
  - **1.** The deployment of scientific principles for practical affairs runs counter to much of both Platonic and Aristotelian ideals; *technē* is lower than *epistēmē*.
  - **2.** Some of this bifurcated evaluation of technology developed in the ancient world remains strong today.
- **B.** Technology in the ancient world had two major aspects: the production of things useful to human life and of "wonders." This is similar to its position in the modern world.
  - **1.** In the Hellenistic world, Hero of Alexandria's works are filled with automata and "miraculous" devices, using air pressure or falling weights as driving forces.
  - **2.** Some topics that we would consider technological were primarily craft-knowledge in antiquity. They were practiced by workers guided solely by experience, with little or no theoretical content.
  - **3.** Knowledge of historical technology often comes more from artifacts than from texts.

III. The Roman Empire saw larger cities, required a high degree of administration, and undertook massive building programs. The success of these developments often depended on skillful technology.

- **A.** One example is the Roman desire to provide an abundant supply of fresh, clean water to the cities.
  - **1.** Using tunnels, sluices, and aqueducts, Roman engineers were able to supply abundant water to cities across the empire.
  - **2.** The water line supplying the city of Nemausus (modern Nîmes) runs for 35 miles; about 20 miles runs underground (3 miles through solid rock) and about 4 miles, on elevated aqueducts (including the 1,100-foot-long, 180-feet-high Pont du Gard).
  - **3.** In cities, lead plumbing brought water directly into the houses of the rich.
  - **4.** The city of Rome used about 150 to 200 million gallons of water a day.
- **B.** Roman city dwellings often developed new technology (such as central heating), but the attempt to build higher and higher buildings challenged the limits of the available materials.
  - **1.** One particular Roman invention in this regard was concrete.
  - **2.** The advance of technology is often checked by the physical limits of available materials.
- **C.** The expanse of the Roman Empire—in which trade, communication, and the movement of the military were vital—required an extensive network of paved roads. By the third century A.D., there were over 4,000 miles of Roman roads.
- **D.** The Romans also developed technologies of mass production, for example, in the manufacture of glass and other household items.

E. Curiously, comparatively little interest was shown in labor-saving devices or power sources; this is probably a result of the great abundance of slaves (as war booty).

Essential Reading:

Frances and Joseph Gies, *Cathedral, Forge, and Waterwheel*, chapter 2.

Supplementary Reading:

J. G. Landels, *Engineering in the Ancient World*, chapters 2 and 9.

G. E. R. Lloyd, *Greek Science after Aristotle*, chapter 7.

Questions to Consider:

1. Roman science and technology were quite different than their Greek counterparts, owing, in part, to the differences between Roman and Greek culture. How do the priorities set by our own culture mold and direct our science and technology? Think of examples of how our modern society's values would lead us to attribute little value to ideas and pursuits prized by the Greeks (and vice versa).
2. Does the modern scene for science and technology more resemble that of Greece or Rome? How and why?

Lecture Eleven

Roman Versions of Greek Science and Education

Scope: A more formalized system of education was one development of the Roman world, and the school system set up by the empire set the standards for the next 1,500 years. A related development was the "popularization" of Greek science for Roman readers, such as Lucretius' verse recapitulation of Epicurean atomism, *On the Nature of Things*. The initiation of the "encyclopedia" tradition is also part of the Roman contribution, such as Pliny the Elder's massive *Natural History*.

Outline

I. An example of a Roman contribution to the history of science is the Julian calendar—necessary for civil, religious, and financial purposes and used throughout Europe for nearly 1,600 years.

- **A.** The development of this calendar again showcases the Roman interest in practical applications of natural knowledge.
- **B.** The calendar was commissioned by Julius Caesar in the middle of the first century B.C., and the task of devising it was given to Sosigenes the Alexandrian.
  - **1.** Sosigenes began with the Egyptian 12-month solar calendar.
  - **2.** He determined the length of the solar year as 365.25 days and, thus, suggested a four-year cycle: three years of 365 days, followed by a fourth with an extra day in February.
  - **3.** To implement the Julian calendar, the immense error of the earlier Roman calendar of 10 months with uncounted winter days had to be corrected; the year (we call) 44 B.C., then, had to be 445 days long to bring the vernal equinox back to 25 March.
  - **4.** The regulation of the new calendar was the duty of Roman priests; indeed, time-keeping and calendrical maintenance was generally the province of priests—in Babylon, Egypt, Rome, and later in Latin Europe.
  - **5.** Sosigenes' year was eleven minutes too long, which meant that, over time, errors accumulated. The Julian calendar was corrected and reformed to its present state (the Gregorian calendar) by Pope Gregory XIII in the sixteenth century.

II. Although the Romans did not produce notable developments of Greek natural philosophy, they did produce popularized versions of it for Roman readers.

- **A.** The Roman leisured classes had an interest in Greek learning and culture; this fashionability expanded the audience for Greek natural philosophy, but this audience operated at a rather low level.
  - **1.** As Horace wrote (*Epistles* II, I:156) "*Graecia capta ferum victorem capit et artis intulit agresti Latio*"—"Captive Greece captured the rude victor and introduced the arts to rustic Latium."
  - **2.** The Roman baths were an important locus for reading and learning.
- **B.** Lucretius' *De rerum natura* (*On the Nature of Things*) was a popularization in verse of Epicurean atomism and philosophy.
- **C.** While Eudoxus, Hipparchus, and others were generally little known in Rome, the *Phaenomena*, a work in verse by the Greek popularizer Aratus de Soli (third century B.C.), was the most popular work on astronomy and weather prognostication among the Romans, being generally read in Latin translations.
- **D.** A comparable example from outside of natural philosophy would be Vergil's *Georgics*, and popular verse work on agriculture and country life.

III. The popularizing trend also produced a new genre of writing, the encyclopedia.

- **A.** Encyclopedic works were intended to give an overview of the state of knowledge in a field and were well adapted to amateur readers.
- **B.** For the history of science, the most important such work is the *Historia naturalis* (*Natural History*) by Pliny the Elder.
  - **1.** Pliny (23–79 A.D.) was an upper-class Roman official with an interest in natural philosophy and history. Of his eight known works, only the *Historia naturalis* survives. Pliny was killed in the eruption of Vesuvius that buried Pompeii on 24 August 79.

2. The *Historia naturalis* was completed in 77 A.D., is composed of thirty-seven books, and deals with astronomy, geography, zoology, botany, medicine, mineralogy, and various technical subjects in a plain and often entertaining style.
3. Pliny's text includes borrowings from acknowledged sources (Aristotle, Theophrastus, Eudoxus, and others), many of which are now lost in the original, as well as hearsay, folklore, and his own observations.
4. Pliny often moralizes while recounting natural philosophical information.
5. The *Historia naturalis* became a major source of natural knowledge throughout the Middle Ages.

IV. At the time of the Roman Empire, many Greek schools were available, as were Greek tutors, but the Romans developed a new kind of schooling with a "standardized" curriculum.

A. Such schools were frequented predominantly by the children of the urban middle class.

B. The basis of the Roman was borrowed, again, from late Hellenistic educational systems. Educated Romans, from the first century B.C., were expected to be bilingual.

C. The seven liberal arts—topics suitable for Roman aristocrats—were at the core of this curriculum.

1. Verbal arts—rhetoric, grammar, and dialectic—constituted the first course of study, later called the *trivium*.
2. Mathematical arts (as defined by Pythagoras)—arithmetic, geometry, astronomy, and music—constituted the second, later called the *quadrivium*.

D. The real innovation of the Romans came in the form of "professional" schools—first law, then in the fourth century, medicine.

E. The late imperial Roman educational system formed a major basis for schools for the next 1,000 years, and some traces of the Roman organization of education survive today.

Essential Reading:

David C. Lindberg, *The Beginnings of Western Science*, pp. 133–149.

Supplementary Reading:

William Stahl, *Roman Science*.

Questions to Consider:

1. What does the desire for popularized versions of Greek science among the Romans say about their society? Can your answer also explain the relative lack of interest among the Romans for the more technical aspects of Hellenistic natural philosophy?
2. What sorts of studies common in modern education are missing from the trivium and quadrivium? Can you identify how the emphases were different in classical education versus the more modern?

Lecture Twelve

The End of the Classical World

Scope: After a long period of decline, the city of Rome fell to barbarians in 476 A.D. This lecture visits that time and immediately thereafter to see what of classical scientific and philosophical thought was saved from the wreck of classical civilization—how, why, and by whom. The rise of Christianity is key here, and this lecture also deals with why the Middle Ages inherited only what it did from the classical world. This topic brings up a consideration of the cultural factors on which the continuance of science and technology depends.

Outline

I. The decline of the Roman Empire disconnected the Latin West from Greek natural philosophy—that is, from the established sources and centers of scholarship.

- **A.** From the second to the fifth centuries A.D., the knowledge of Greek language and culture dwindled in Roman lands.
  1. Native Latin culture itself developed and displaced the older borrowed Greek culture. The aristocracy changed as well, and the taste and fashionability for Greek learning waned.
  2. The division of the empire into Eastern and Western halves further separated the West from the remains of Hellenistic culture.
  3. Combined with the lack of Roman interest in theoretical and advanced natural philosophy, the loss of the knowledge of Greek meant that only the popularized Latin versions of Greek natural philosophy survived the fall of the empire in Western Europe.
  4. The consequence was that the Latin Middle Ages received very little intellectual inheritance from the Romans.
- **B.** Boethius (c. 480–524) is considered the last bilingual philosopher of the empire.
  1. He translated some of Aristotle's logical works and other Greek texts into Latin (thus preserving them for the Middle Ages).
  2. He showed little interest in specifically natural philosophical issues.
- **C.** Disintegration of administrative and organizational systems and disruptions due to increased barbarian incursions undercut the maintenance of Roman technology.
  1. An illustrative example is the inability of Constantine's engineers (fourth century) to redredge the silted Roman harbor at Ostia, even though this had been done during the early empire. As a result, the city of Rome itself was left without an adequate port.
  2. Similarly, aqueducts and other sanitary waterways fell into disrepair, and their original purpose was eventually forgotten (they tended to be used merely as bridges in the Middle Ages).
  3. The construction of large stone buildings could rarely be accomplished by the sixth century. Knowledge of glassmaking and other material techniques (often originally for the luxury trade) disappeared.

II. Even in the Eastern (Greek) half of the Roman Empire, the ancient schools and institutions that had been host to natural philosophy dwindled away or were closed.

III. The rise of Christianity introduced major new ways of thinking to the empire, including new values and requirements. The relationship between young Christianity and the pagan world in which it developed is complex (and will be treated by itself in Lecture Thirteen).

IV. In the West, some Christians attempted to preserve or extend the traditions of Roman learning.

- **A.** Cassiodorus (485–580), a civil servant and officer under Ostrogothic rulers, retired from governmental life to found a monastery at his villa (the Vivarium) in southern Italy. His expressed goal was to preserve ancient learning, which he saw as imperiled.
  1. Cassiodorus' *Institutiones* continues the Roman encyclopedia style by enumerating the seven liberal arts and showing their importance to Christians.

2. Cassiodorus' monks copied selected works of antiquity—again, not a great deal from natural philosophy. The works of Greek theorists were already out of their reach.

B. St. Benedict of Norcia (480–547) retired as an ascetic to a hermitage but eventually founded the monasteries bound by the *Regula* (*Rule*). The *Rule* stipulated daily work and reading (*lectio divina*), which required the presence of books.

1. Although the early Benedictines did not pursue scholarly aims, the copying and preservation of texts was soon adopted (probably from Cassiodorus' model).
2. Benedictine *scriptoria* spread as centers of literacy and scholarship throughout Western Europe.

C. The Roman encyclopedia tradition was carried on in a Christianized context in the *Etymologies* of St. Isidore of Seville (c. 600 A.D.), a bishop in Visogothic Spain.

V. In the end, the Latin West was able to hold on to very little of ancient culture, including natural philosophy and technology.

A. More was preserved in the east, where Greek was still spoken, but the decline of ancient science was dramatic there as well.

B. In the broad view, the Roman Empire bequeathed three invaluable gifts to posterity—the idea of a unified Europe, the universality of the Latin language, and the memory of former greatness.

C. Specifically, in natural philosophy, however, the Latin Middle Ages began with scarcely more than a dozen works from all of antiquity, and these were predominantly Roman popularizations, recensions, and encyclopedic works.

Essential Reading:

David C. Lindberg, *The Beginnings of Western Science*, pp. 149–159.

Supplementary Reading:

G. E. R. Lloyd, *Greek Science after Aristotle*, chapter 10.

Questions to Consider:

1. The world of learning is crumbling (how do you recognize this fact?). You are seriously concerned (like a late imperial scholar) with trying to preserve some remnants of your culture. You can choose any twelve books to preserve. What twelve would they be and why?
2. Reconsider the above question. How are your choices of what you are going to save conditioned by your own interests, those of your current culture, and those of the future culture you imagine? How does this exercise help to explain the situation and actions of fifth- and sixth-century scholars?

Timeline

2000–500 B.C. .... Babylonian civilization
600–580 B.C. .... Thales of Miletus flourishes
6th c. B.C. .... Pythagorean school founded
399 B.C. .... Socrates executed
388 B.C. .... Plato founds the Academy
384 B.C. .... Aristotle born at Stagira
348/7 B.C. .... Death of Plato
335 B.C. .... Aristotle founds the Lyceum at Athens
332 B.C. .... Alexandria founded
323 B.C. .... Alexander the Great dies after creating a vast empire; Aristotle flees Athens and dies a year later
c. 300 B.C. .... Museum and Library founded at Alexandria; Euclid flourishes
212 B.C. .... Romans conquer Syracuse; Archimedes killed
86 B.C. .... Romans sack Athens
44 B.C. .... Start of Julian calendar; Julius Caesar murdered
30 B.C. .... Rome annexes Hellenistic Egypt
79 A.D. .... Pliny the Elder killed in the eruption of Vesuvius
150 .... Ptolemy flourishes
c. 162–8 .... St. Justin martyred at Rome
c. 270 .... Library of Alexandria destroyed during civil warfare
313 .... Edict of Milan legalizes Christianity in the Roman Empire
325 .... Ecumenical Council of Nicaea
354–430 .... Life of St. Augustine
410 .... Rome sacked by Alaric
476 .... Last of the (Western) Roman emperors slain by the barbarian Odoacer
524 .... Boethius executed
c. 530 .... St. Benedict writes the *Rule*, origin of the Benedictine Order
622 .... Muhammed flees to Medina from Mecca—beginning of Islamic calendar
711–718 .... Spain annexed to Islamic Empire; Muslim fleet destroyed at Constantinople by Greek fire
750–1000 .... Translation movement into Arabic
756 .... Umayyad caliphate established in Spain
762 .... Al-Mansūr founds Baghdad as seat of `Abbasid caliphate
782 .... Patriarch Timothy I debates the nature of Christ with Caliph al-Mahdī using the methods of Aristotle's *Topics*
800 .... Charlemagne crowned Holy Roman Emperor

c. 1020	School of Chartres founded
1020s–1030s	Al-Hazen (Ibn al-Haytham) active in Cairo
1085	Christian forces capture Toledo
1099	First Crusade takes Jerusalem; Latin Kingdom established
1125–1200	Latin translation movement; texts from Arabic enter Europe
1187	Saladin captures Jerusalem
c. 1200	University of Paris established; Oxford, about twenty years later
1205	St. Dominic founds the Order of Preachers (Dominicans)
1209	St. Francis founds the Order of Friars Minor (Franciscans)
1258	Baghdad sacked by the Mongols
1275	Alphonsine Tables compiled
1277	Condemnation of 1277; 219 propositions condemned at the University of Paris
1270s–1280s	Willem of Moerbeke translates Aristotle from Greek
1330s	"Oxford Calculators" active
1348	Black Death (bubonic plague) arrives in Europe; within a few years, it kills one-third of the European population
1400–1500	Humanism develops as a major intellectual force, first in Italy, then elsewhere
c. 1450	Johannes Gutenberg invents moveable-type printing
1452	Constantinople falls to the Turks
1492	Columbus lands in the New World; last of the Muslims expelled from Spain
1517	Luther nails up his theses
1522	Magellan's expedition circumnavigates the globe
1543	Copernicus' *De revolutionibus* and Vesalius' *De fabrica* are published
1545–1563	Council of Trent
1560s–1570s	Paracelsus' unpublished works begin to appear in print
1572	"Tycho's new star" appears in Cassiopeia; he begins construction of Uranibourg in 1576
1577	A bright comet appears and is calculated to be superlunary
1582	Start of Gregorian calendar
1586	Fontana successfully moves the Vatican obelisk
1588	Tycho proposes the Tychonic system
1600	Gilbert's work on the magnet is published
1603	Accademia dei Lincei founded at Rome
1607	Jamestown founded in Virginia
1609	Kepler proposes ellipses as planetary orbits
1610	Galileo's telescopic discoveries appear in the *Sidereus Nuncius*
1620	Plymouth colony established in Massachusetts

1632 .... Galileo's *Dialogues on the Two Chief World Systems* published; the next year, he is condemned

1642 .... Birth of Newton, death of Galileo

1648 .... Van Helmont's works published

1658 .... Gassendi's natural philosophical system published

1660 .... Royal Society of London founded; given Royal Charter in 1662

1666 .... Académie Royale des Sciences founded in Paris; Paris Observatoire founded the following year

1687 .... Newton's *Principia* published

1699 .... Paris Academy reorganized

Glossary

Aggregation notation (see place notation): A method of writing numbers that depends upon numerals with fixed values that are to be added up to provide the desired total value, for example, Roman numerals.

Ancilla: Latin for "handmaiden"; compare the English derivative *ancillary*. Used in the history of science to describe the status of the natural sciences relative to theology in the Middle Ages, as enunciated most influentially in the writings of St. Augustine and other Patristics.

Anima motrix: Literally, "motive soul"; according to Johannes Kepler, a motive power located in the sun that pushes the planets around in their orbits.

Archeus: A term coined by Paracelsus but further developed by Van Helmont. In the latter author, the *archeus* was a guiding spiritual principle that maintained the processes and functions of living bodies.

Astrolabe: An observational and calculating instrument, originally of Hellenistic origin but developed in the Arabic world, which allows for the measurement of elevations, the calculation of local time and the rising and setting of bright stars and the sun on any day, and astrological information.

Carolingian: Of or relating to the period or culture under Charlemagne.

Circumscription: In geometry, the practice of drawing one figure as tightly as possible around another; for example, a circle circumscribed around an isosceles triangle touches it at three points.

Collegio Romano: The Roman College of Jesuits, opened in 1565 in Rome; it was both an educational institution and seminary, as well as a place where notable Jesuits carried out natural philosophical studies.

Condemnation of 1277: An order issued in 1277 by Etienne Tempier, the bishop of Paris, banning the masters of the University of Paris from holding or defending 219 propositions considered false, many of them deriving from Aristotle or contrary to Christian teaching on free will, God's omnipotence, and so on.

Corpus: Latin for *body*, in literary terms, the *body of writings* produced by an author.

Council of Trent: A highly significant meeting of Catholic theologians and hierarchy that took place in the northern Italian city of Trento from 1545 to 1563. The purpose was to address the problem of Protestantism by internal reforms, regularization of doctrine, and measures to prevent further schism.

Creatio ex nihilo: "Creation out of nothing," an article of Christian faith stressing that God alone is eternal and is the creator of everything.

Deferent: The primary orbit of a planet around its center of motion; the deferent carries the epicycle.

Demiurge: Plato's craftsman god, an eternal but not omnipotent being who organized (equally eternal) matter into the world using the Forms as the blueprint.

Determinism: The idea that future events are pre-determined; there is no free will.

Dualism (Cartesian dualism): The idea that the human being is composed of two distinct entities, a material body and an immaterial soul.

Eccentric: A planetary orbit that is not centered on the geometrical center of the cosmos.

Epicycle: The secondary orbit of a planet, centered on the primary orbit (deferent) around the center of motion. The deferent carries the epicycle; the epicycle carries the planet.

Epistēmē: Greek for "knowledge," specifically the knowledge of what and why a thing is (for example, in medicine, *epistēmē* would be knowledge of the disposition of the internal organs and their functions; compare *technē*).

Epistemology: The study of knowledge; epistemology studies what we know (or can know) and how we know it (or think we know it).

Error of the double truth: An error condemned in 1277 that holds that the same proposition may be true in theology but false in philosophy.

Experimentum crucis: A term used by Newton, literally "experiment of the crossroads," to describe an experiment that allows one to decide definitively between two competing theories.

Forms, Plato's theory of: The notion that material objects are but dim reflections or shadows of idealized immaterial Forms that exist outside of the physical world; these Forms are eternal and unchanging and are vaguely remembered by us from the time before our birth.

Geocentric: Literally, "earth-centered"; used to refer to the Aristotelian, Ptolemaic, and Tychonic systems in which the earth is at the center of the cosmos.

Geokinetic: Literally, "earth moving"; used to refer to cosmic systems in which the earth is in motion, such as the Copernican system.

Geostatic: Literally, "earth stationary"; used to refer to cosmic systems in which the earth is at rest.

Gnōmōn: A stick or pole fixed vertically in the ground for the purposes of measurement, surveying, or astronomical study. For example, the length of the *gnōmōn* and the shadow it casts can be used to calculate the elevation of the sun above the horizon. The spine in the center of a sundial is also called a *gnōmōn*.

Hadith: An accepted and attested saying of the Prophet Muhammed.

Heliocentric: Literally, "sun-centered"; used to refer to the Copernican system. (Actually, Copernicus' system has the sun slightly off center and is more rigorously labeled heliostatic, that is, with a stationary sun.)

Hellenistic: An adjective describing the Greek-dominated world and culture created by Alexander's conquests.

Hexameral literature: Theological writings that comment on the first chapter of Genesis (the "Six Days" of Creation), an important locus for natural philosophical inquiry during the Middle Ages.

House of Wisdom (*Bayt al-Hikmah*): An institution founded in Baghdad in the eighth or ninth century; it presumably included a depository of records and texts and appears to have been a locus of scholarly activity.

Humanism: A broad-based intellectual movement of the Renaissance characterized by a love of classical antiquity; an interest in texts, textual purity, and elegant literary style; contempt for Scholasticism; and an interest in active civic life.

Hylomorphism: The Aristotelian doctrine that everything is composed of matter (prime matter, or *hylē*) together with form (*morphē*); the matter is the amorphous stuff out of which the thing is made, while form is the constellation of all the qualities of the thing.

Impetus: In medieval physics, the "impressed motion" of an object that keeps it in motion after it has lost contact with the mover. Akin (but not identical) to the modern idea of momentum.

Ius ubique docendi: "The right of teaching anywhere," a right bestowed on recipients of a master's degree in the Middle Ages, guaranteeing them the right to take up residence and offer classes at any university.

Jesuits: The Society of Jesus, a religious order of priests founded by St. Ignatius Loyola and officially recognized in 1540. Their origin and work was initially tied closely with the Counter Reformation; Jesuits paid particular attention to education and scholarly pursuits.

Kinematics: A branch of physics dealing with the study of moving bodies.

Libri naturales: A term given to certain books of Aristotle's that dealt specifically with natural phenomena, such as *On the Heavens*, the *Physics*, the writings on animals, and other (sometimes spurious) works.

Loadstone: A naturally magnetic iron mineral, known today as magnetite.

Madrasa: An Islamic school, generally connected to a mosque.

Magus: A practitioner or student of natural magic.

Mechanical philosophy: A collection of worldviews popular in the seventeenth century, characterized by the vision of the world as a machine in which the sole basis for natural phenomena was matter and motion.

Mercury-Sulphur theory: A theory on the composition of metals, proposed in the writings attributed to Jabir ibn-Hayyan, which states that metals are produced in the earth from the combination of two ingredients called Mercury and Sulphur.

Mesopotamia (lit. "between the rivers"): The area between the Tigris and Euphrates rivers, now largely within Iraq, home to several important civilizations during the first and second millennia B.C.

Minima naturalia: The smallest possible piece of a substance that retains the qualities of the substance.

Monism: The philosophical position that all the varied substances seen in the world are actually, at their fundament, composed of the same stuff.

Mozarabs: Christians of the Iberian peninsula who lived under Muslim rule.

Natural magic: A body of knowledge dealing with the deployment of connections or sympathies/antipathies between objects in the natural world toward useful ends.

Natural place (natural motion): The Aristotelian idea that the four elements have specific places (based on their relative weights) in the sublunary world and move naturally toward those places.

Naturalism: The idea that phenomena in the natural world should be explained using natural causes, not the recourse to miraculous or direct interventions by God.

Occult quality: The hidden qualities of a thing (as opposed to the manifest qualities, namely, those that are recognizable by the senses).

Ontology: The study of being; ontology studies what exists and how it exists.

Parallax: An optical phenomena wherein objects that are closer to the viewer change their positions relative to objects that are further away when the vantage point of the viewer changes.

Philosophers' Stone: A substance prepared in the alchemical laboratory by a secret process which, when cast upon a quantity of molten metal, transmutes it in a few minutes into pure gold (or silver). The Philosophers' Stone is first mentioned in the writings of Hellenistic Egypt (c. 300 A.D.) and was a chief pursuit of alchemists down to the 18th century.

Place notation (see aggregation notation): A method of writing numbers that depends upon numerals whose individual values are given by a combination of their inherent values and their places in the overall numeral (that is, whether in the "tens place" or the "hundreds place"), for example, Arabic numerals.

Platonic solids, or the "perfect polyhedra": The five solid bodies that are composed entirely of identical faces which are regular polygons, namely, the tetrahedron (triangular faces), the cube (square faces), the octahedron (triangular faces), the dodecahedron (pentagonal faces), and the icosahedron (triangular faces).

Plenum: Latin for "full"; a description of the world in which there is no void space—the universe is absolutely full of matter. A view held by Aristotle and Descartes, among others.

Pluralism: The philosophical position that there is more than one material substratum for the varied substances seen in the world.

Presocratic: Dating from before the time of Socrates (d. 399 B.C.), particularly to refer to a miscellaneous assemblage of Greek thinkers of the sixth to fourth centuries B.C.

Prime matter: In Aristotle's natural philosophy, the entirely quality-less "stuff" (*hylē*) of which everything is made; prime matter becomes a particular substance or object when wedded to a form (see hylomorphism).

Prisca sapientia: "Original wisdom," the mass of knowledge which some believed that God had imparted to figures of great antiquity—often biblical patriarchs, such as Adam, Seth, Solomon, and others—and which had become gradually lost or corrupted over time.

Qibla: The direction Muslims face during formal prayer: originally toward Jerusalem but soon changed toward Mecca.

Quadrivium: The four mathematical arts of the classical Roman educational system (the seven liberal arts): arithmetic, geometry, astronomy, and music.

Reductionism: The idea that a maximum number of phenomena or a maximum amount of data should be explained by the minimum number of principles.

Retrograde motion: The backward (east to west) motion through the zodiac that the superior planets (Mars, Jupiter, and Saturn) appear to have during part of the year. It is caused (in modern terms) when the earth "laps" these planets in its annual journey around the sun.

Saving the phenomena: The idea, particularly important in pre-modern astronomy, that the prime function of theoretical systems is to explain the observed phenomena, rather than being necessarily literally true representations of the natural world.

Scholasticism: The philosophy and method of "the Schools," namely the medieval university, based heavily on Aristotelian writings and logical principles and incorporating a formalized methodology of questions and responses.

Scriptoria: The workshop, usually at a monastic center, used for the copying of manuscripts.

Seminal reasons (*rationes seminales*): Active principles implanted in the world that organize matter into specific forms.

The Sentences: Four books of theological questions and answers written in the mid-twelfth century by Peter Lombard; nearly all subsequent medieval theologians wrote an orderly commentary on the *Sentences*. "Sentences" is a translation of the Latin *sententiae*, which is actually better rendered as "opinions."

Sexagesimal: A mathematical system using a base of sixty, rather than ten as in our modern decimal notation.

Signatures (doctrine of signatures): The notion that God had "marked" natural objects with signs ("signatures") that gave clues to their otherwise hidden powers, correspondences, and natures.

Substantial forms: In scholastic philosophy, the sum total of the qualities of a thing that make it what it is.

Syriac: A Semitic language of the Levant, the official language of several Christian liturgies and of the Nestorians.

Technē: Greek for craft or art; specifically, knowledge of how to do or produce something (for example, in medicine, *technē* would be the knowledge of how to perform a particular operation or cure a particular illness; compare *epistēmē*).

Transmutation: In alchemy, the conversion of one metal into another, usually a base metal (lead, tin, mercury, copper, or iron) into a noble one (gold or silver). See Philosophers' Stone.

Tridentine: Of or relating to the Council of Trent.

Trivium: The three verbal arts of the classical Roman educational system (the seven liberal arts): grammar, rhetoric, and dialectic (or logic).

Tychonic system: A cosmological system proposed by Tycho Brahe in 1588 as an alternative to the Ptolemaic and Copernican systems. According to the Tychonic system, the earth is located at the center, the moon and sun move in orbits around the earth, but the planets revolve on orbits around the sun.

Zodiac: A narrow band in the sky to which the motions of the planets, sun, and moon are restricted. This band is traditionally divided into twelve constellations—the "natal" constellations, Aries to Pisces—and into twelve astrological "houses"—regions that govern particular aspects of terrestrial existence.

History of Science: Antiquity to 1700

Part II

Professor Lawrence M. Principe

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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.

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Part II

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 Thirteen

Early Christianity and Science

Scope: The Christian church developed within pagan classical culture and had to come to terms with the intellectual legacy of that culture. This lecture examines the debates over what Christians should accept from pagan learning, particularly in the scientific sphere. What natural philosophy did Christians and Christianity require? Special attention is paid to the arguments and solutions offered by St. Augustine of Hippo.

Outline

I. Study of the complex relationship between science and religion becomes particularly important after the rise of the "world religions" Christianity and Islam.

II. One theme recurs in medieval culture and throughout our look at the Middle Ages in these lectures: the pervasiveness of monotheistic religion.

- **A.** Monotheistic religion is the foundation for the two cultures of the Middle Ages that we will examine: Christian Europe and the Islamic world.
- **B.** Monotheistic beliefs undergird some principles of science.
  - **1.** If one conceives of the world as governed by one single, omnipotent god, that implies that there is a stability and constancy to nature.
  - **2.** Such a conception allows for the existence of natural laws.
- **C.** No serious historians of science today accept the simplistic view of an essential or protracted "warfare" between science and religion.

III. Christianity developed within pagan classical civilization and had to define its relationship to its intellectual content and legacy.

- **A.** In the earliest times, Christianity interacted little with pagan intellectual culture; during the second century, however, interactions became significant as more educated classes embraced Christianity and more advanced apologetics were required.
- **B.** The phrase "Athens and Jerusalem" is a classical formulation of these early interactions.
  - **1.** The phrase is derived from a rhetorical question posed by the early Christian writer Tertullian (c. 155–c. 230): "What has Jerusalem [i.e., Christianity] to do with Athens [i.e., pagan philosophy]?"
  - **2.** The context of the question implies that Tertullian thought Christians had no need of pagan learning (including natural philosophy).
  - **3.** Tertullian explicitly ridiculed the study of the natural world as unnecessary.
  - **4.** Tertullian's real view was probably not as extreme as this one quotation implies; furthermore, many other Christians disagreed with this position.
- **C.** St. Justin Martyr (d. 162–8) and St. Clement of Alexandria (d. 211–15) had previously argued that some Greek learning was consonant with and supportive of Christian thought.
  - **1.** Both chose (Neo)platonism in particular as most akin to Christianity.
  - **2.** Both argued that truth can never oppose truth; the pagans achieved part of the truth through the action of reason, a divine gift. This reason or *logos* is alignable with the *Logos* of St. John's Gospel, that is, Christ.

IV. Influential formulations of the relation of pagan learning (and natural philosophy in particular) and Christianity were worked out by St. Augustine of Hippo (354–430).

- **A.** St. Augustine's writings held great authority in Christian theology for 1,000 years (throughout the Middle Ages) and down to the present day. Much of Christian theology depends on St. Augustine's work.
- **B.** St. Augustine's autobiographical statements in his *Confessions* make clear the enormous positive impact Greek thought had on his conversion to Christianity. Augustine, like Clement and Justin, preferred Platonic thought above all others.

C. St. Augustine dealt with natural philosophical topics most explicitly in his *De Genesi ad literam*, a literal interpretation of the opening chapters of Genesis dealing with the creation of the world.

1. The first two chapters of Genesis relate closely to natural philosophical issues (astronomy, cosmology, physics, botany, zoology, and so on); thus, interpretation of these chapters became a major locus for serious scientific inquiry in the Middle Ages (see Lecture Twenty).
2. The term *literal* had quite a different meaning for St. Augustine than it does now. For Augustine, a literal interpretation had only to explain what the words actually meant and was not restricted to the common signification ("literal meaning") of the words.
3. The *De Genesi* was a work of long gestation. Augustine made two aborted attempts to interpret Genesis prior to it. The key point is that he maintained that Biblical interpretations had to explain the words of the text, as well as be *rational*, *consistent*, and *in conformity* with the current state of demonstrable scientific knowledge.
4. Augustine maintains that a Christian must have familiarity with scientific knowledge; otherwise, he will draw foolish interpretations of Scripture that conflict with known scientific facts.
5. Knowledge of the natural world is necessary as an aid to the proper understanding of Scripture.
6. Augustine's attitudes toward Genesis and the means of interpreting Scripture are in sharp contrast with those of modern fundamentalist "biblical literalists."

D. Like Plato, Augustine argues that knowledge of the natural world reveals the goodness and power of its creator; thus, scientific inquiry can be seen as a religious or devotional activity.

E. We must be careful not to overstate St. Augustine's interest in scientific and other non-theological knowledge. He was aware of the issue of distinct intellectual classes among Christians.

1. Some Christians, such as leading theologians and intellectuals, required rational and intellectual analyses, which in turn, required a broad base of knowledge; St. Augustine himself fell into this category.
2. For many, however, excessive interest in non-theological learning could draw them away from the divine knowledge that was truly important.
3. An even larger number were incapable of rigorous intellectual exercise, yet their faith—simple though it might be—sufficed for them, while highly intellectual treatments would be confusing and even perilous; St. Augustine's mother, St. Monica, was an example of this last group.
4. Thus, it should be noted that although non-theological learning, such as scientific knowledge, was important for theologians, it remained an adjunct or supplement.

V. In a practical sense, the Christian church needed classical learning for several reasons.

A. Christianity depends on Scriptures, which must be interpreted. Literacy and verbal arts (the *trivium*) at least were needed, and knowledge of the world was necessary for scholars to make proper interpretations.

B. Mathematical arts (the *quadrivium*) were also needed.

1. Three of the quadrivial arts are necessary, for example, for accounting, building, and church music.
2. Perhaps most important was astronomy, which was necessary for time keeping (for prayers) and to fix the date of Easter, the chief Christian holy day.

VI. The attitude toward scientific knowledge, as finally defined by the early church (particularly St. Augustine) and that became current in the Middle Ages, was that natural philosophy was an *ancilla*, or "handmaiden," to theology. This status is, in fact, akin to the status of natural knowledge in much of classical thought.

Essential Reading:

Edward Grant, *The Foundations of Modern Science in the Middle Ages*, chapter 1.

Supplementary Reading:

David C. Lindberg and Ronald L. Numbers, *God and Nature*, chapter 1.

Questions to Consider:

1. Today, is science an *ancilla* to anything? Technology, capitalism, or material production; career or fame?
2. Scientific knowledge is sometimes seen as inimical to religious belief; for St. Augustine and his followers, the view was quite the opposite. Why do you suppose some believers today see a danger in scientific knowledge?

Lecture Fourteen

The Rise of Islam and Islamic Science

Scope: The origin of Islam in the early seventh century and its rapid spread across Asia, Africa, and into Latin Europe gave rise to a vibrant civilization that eagerly adopted and extended Greek natural philosophical and other thought. This lecture outlines the rise of Islam, why Greek science was valued by early Muslims, and the institutional and social features that encouraged the translation of Greek texts into Arabic.

Outline

I. The state of natural philosophical study in the Christian West was quite low for many reasons from about 400 to 800 A.D. A far greater level of such study, however, developed in the Islamic world.

II. The Islamic Empire (or "House of Islam") expanded outward from the Arabian peninsula with great speed during the seventh and early eighth centuries. It spanned a realm from Spain across North Africa, the Middle East, and Persia, all the way to India.

- **A.** The expansion annexed lands previously ruled by the Byzantine, Roman, and Persian Empires, creating a new and broadly multicultural empire. Thus, conditions made stable cross-cultural exchange possible.
- **B.** During the first few centuries of the Islamic Empire, the majority of the inhabitants (outside the Arabian peninsula and Levant) were neither Muslims nor Arabs. This allowed for significant cultural exchange over a long period of time.
- **C.** Al-Mu`āwiyah, of the Umayyad dynasty of caliphs (successors of the Prophet), set up a capital at Damascus (661), in the middle of previously Byzantine lands. Although the caliphs were Muslim Arabs, the governmental administrators (at least until about 700) and much of the populace were Greek-speaking and often Christian, Arabs, and Greeks.
- **D.** The Umayyads were overthrown in 750 by the `Abbasids, and the last Umayyad prince fled to Spain, where the Umayyad dynasty continued. Meanwhile, the second `Abbasid caliph, al-Mansūr, founded the city of Baghdad in 762 as the new capital, now much further east (in Mesopotamia) and on the Persian frontier.

III. The first stage for the history of science in the Islamic Empire was the widespread "translation movement," lasting from about 750 until 1000, which turned hundreds of Greek (as well as Persian and other) texts into Arabic.

- **A.** Much of this work was done in Baghdad; the `Abbasid caliphs al-Mansūr (r. 754–775), Hārūn ar-Rashīd (r. 786—809), and al-Ma'mūn (r. 813–833) were among the chief promoters and patrons of this work.
  1. Physicians also often sponsored the translation of medical works, such as those of Galen and Hippocrates, for their own use.
  2. The three sons of Mūsā ibn-Shākir, called the Banū Mūsā ("Sons of Musa"), were celebrated engineers and lavish patrons of the translators in early ninth-century Baghdad.
  3. The output of books in Baghdad argues for a highly literate culture.
  4. The translation movement was assisted by a very important technological advance—the production of paper—which the Muslims learned from Chinese prisoners in 751.
- **B.** An institution called the Bayt al-Hikmah ("House of Wisdom") was one center of activity in Baghdad. Little is known about it, but it seems to have been a library where books and records were kept and a limited number of scholars worked.
- **C.** The translators were a mixture of Muslims, Christians, Sabians, and Jews, as well as Arabs, Persians, and Greeks. The fact that many were well paid for such work demonstrates the keen desire for Arabic speakers to have access to Greek scientific, mathematical, and medical texts.
  1. One notable translator was Hunayn ibn Is-haq, a Nestorian Christian; we have his own account of more than 100 books he translated.
  2. Another key translator was Thābit ibn-Qurra (836–901), a Sabian, who also wrote influential texts on astronomy. His nephew, son, and a grandson were also translators.

IV. Many factors of the early Islamic Empire fostered the translation movement.

  A. The practice and intellectual tenor of early Islam promoted the study of Greek (as well as Persian and Hindu) scientific and mathematical texts.

    1. Like Christians, Muslims have a holy book, the Qur'ān; reading and interpreting the Qur'ān for Muslims—as Christians had discovered in terms of the Bible—requires literacy, interpretational skills, and a wide knowledge of things and phenomena in the natural world.

    2. As Islam became more settled, an increased ability to engage in defense and promotion of Islam was necessary. This ability was already developed in Christianity—partly by use of Greek thought—and the Muslims did the same.

    3. Some aspects of early Islamic culture saw the study of nature as a religious obligation. The Prophet himself gave an intellectualist turn to Muslim devotion with his *hadith* ("a saying"): "Seek out knowledge even if it is in China."

    4. Muslims pray five times a day facing Mecca (the *Qibla*). In a far-flung empire, fairly advanced geographical and astronomical techniques are required to determine the shortest line toward Mecca.

    5. The Muslim calendar is lunar, and the time of the first appearance of the new moon is important to mark time, including the beginning and end of the holy month of Ramadan.

  B. Non-theological reasons played a role, as well.

    1. There was also political utility, in terms of assimilating the cultures now dominated by Islamic rulers.

    2. The inherent utility of medicine made Greek medical texts (Galen, Hippocrates) highly sought after.

    3. Greek mathematics (Euclid, Archimedes, Appollonius, and others) was useful in surveying, accounting, and engineering.

    4. Greek astronomy (Ptolemy and others) was valuable for calendrical purposes, as well as horoscopy and prognostications.

Essential Reading:

David C. Lindberg, *The Beginnings of Western Science*, chapter 8.

Supplementary Reading:

Dimitri Gutas, *Greek Thought, Arabic Culture*.

A. I. Sabra, "Greek Science in Islam," *History of Science* 25 (1987): 223–243.

Questions to Consider:

1. Ibn-Khaldūn makes a close link between the development of a sedentary Muslim culture and the development of Muslim intellectual culture. Does this seem reasonable? What are the links between a settled life and an intellectual culture? How do the two interrelate?

2. What sort of benefits accrue to a sponsor of scholarly/scientific inquiry? Why would a ruler (caliph, prince, king, or president) channel money and privileges to such activity? Try to be exhaustive in listing the benefits, and think about how the value of such benefits has changed over time and cultures.

Lecture Fifteen

Islamic Astronomy, Mathematics, and Optics

Scope: Scholars in the Islamic world built extensively on the scientific foundations they adopted from the Greeks. This lecture examines some of the developments in the "mathematical sciences" and notes how these sciences were integrated into Muslim society. The various theories of vision are also examined here, and some of the contributions of medieval Muslim scholars still visible in modern science are also noted.

Outline

I. Just as astronomy was one of the most important scientific disciplines of the Greeks, so was it also one of the high points in the Arabic world.

A. One of the first Greek books translated into Arabic was Ptolemy's *Almagest*; the title we now use is actually the Arabic title.

1. Its importance to Muslims, as to Ptolemy, was only partly cosmological; the astrological significance was at least as important.

2. The use of astrology by the `Abbasids is clear in the founding of Baghdad on 30 July 762, a propitious date chosen for al-Mansūr by his Persian astrologer Nawbakht.

B. Arabic astronomers produced new star charts and improved methods of calculation for astronomical events and calendrical reckoning.

1. About half of the bright stars visible on any night bear Arabic names to this day: Betelgeuse, Deneb, Mizar, Vega, Aldebaran, and others. Many modern astronomical terms are also of Arabic origin, such as zenith, azimuth, nadir, and so on.

2. Arabic astronomers perfected the design and use of the astrolabe, the most important astronomical observational and calculatory instrument.

3. The astrolabe can determine the user's local time and latitude, calculate the rising and setting times of the sun and stars on any day of the year, and provide astrological data. The astrolabe was used until the seventeenth century in Europe.

4. Arabic astronomers also produced portable Qibla-finders to determine the correct direction to Mecca.

C. Mention of a few Arabic astronomer-mathematicians gives an idea of the scope of astronomy in the Muslim world.

1. The Sabian Thābit ibn-Qurra (836–901) translated and commented upon Ptolemy, Euclid, Archimedes, Aristotle, Appollonius, and others, but also made observations of solar and lunar motion. His translations preserve otherwise lost works of Archimedes, and he calculated (very accurately) that there was an error in length of the Julian year which would amount to one day in 130 years.

2. Al-Battānī (c. 858–929), a Muslim but of a Sabian family, made more accurate determinations of the length of the year and seasons, introduced trigonometry to astronomical calculations, and discovered the movement of the line of apsides. He observed a solar eclipse at Antioch on 23 January 901 and, for the first time, showed the possibility of an annular eclipse. Later, he would become the best-known Arab astronomer in Europe (under the name Albategnius).

3. Ibn al-Haytham, known to Latins as Alhazen (c. 965–1039), criticized the disjunction between Ptolemaic cosmology and physical principles. His greatest contributions were in optics and theories of vision. He lived much of his life at al-Azhar in Cairo.

II. Considerable developments in mathematics also occurred in the Islamic world.

A. One of the most notable achievements was the introduction and improvement of place notation—the system we use today and still call "Arabic numerals."

1. This system was originally Indian and was eventually transmitted to Europe through a handbook written by al-Khwarizmī (fl. 825).

2. A key feature is the use of the zero (*zifr*) as a place holder, which avoids the ambiguity of the much older Babylonian place notation.

B. Al-Khwārizmī also wrote the *Kitāb al-Jabr wa al-Muqābalah*, the earliest known treatise on algebra (as well as works on the astrolabe and geography).

C. Trigonometry was also perfected by Arabic mathematicians, who added the remaining five functions to the partial system (one function only) of the Greeks.

III. Optics is another area in which the Arabic world made particular contributions.

  A. The chief problem of early optics was: "How is the image of an external object transmitted to the eye?" There were three theories of vision in the ancient classical world.

    1. Euclid studied vision and, like most Greeks (for example, Plato), considered that vision was *extromissive*, that is, we see by emitting a "visual ray" from the eye. Euclid's key contribution was a (typically Greek) geometrical analysis of vision—the visual ray issues as a *cone* and is, thus, treatable by geometrical rules.
    2. Ptolemy adopted and extended this extromissive theory of vision.
    3. A second theory was promoted by the atomists (Epicurus). They conceived of *simulacra*, thin films that continuously peeled off of all visible objects and flew into the eye. This view is *intromissive*.
    4. A third view (also intromissive) comes from Aristotle, who held that objects alter the air intervening between them and the eye, thus transferring their qualities to the eye via the medium of air.

  B. The extromissive "visual ray" theory of Euclid and Ptolemy was upheld by al-Kindī (c. 801–c. 866).

  C. Ibn al-Haytham, however, produced a new view of vision that was intromissive but that preserved the geometrical treatment of Euclid and Ptolemy and avoided objections to other theories. Several of his ideas, particularly the conceptualization of the "ray theory of light," still form the basis of optics.

Essential Reading:

John North, *The History of Astronomy and Cosmology*, chapter 8.

Supplementary Reading:

David C. Lindberg, *Science in the Middle Ages*, chapter 10, "The Science of Optics."

Questions to Consider:

1. If so many stars and astronomical terms still bear medieval Arabic names, what does that say about how Arabic learning was received by the Latin West? What does it say about the relative development of contemporaneous Latin astronomy before the discovery of Arabic sources?
2. If you were required to defend the extromissive theory of vision, how might you do so?

Lecture Sixteen

Alchemy, Medicine, and Late Islamic Culture

Scope: Islamic contributions to the Hellenistic study of *chēmia* not only created the word *alchemy* but also laid the foundations for the development of chemistry. In addition, Islamic medical discoveries and writings were highly important and proved influential in later periods. This lecture also looks at the competing natural philosophical and intellectual components of two rival groups of Arabic thinkers, the *falāsifa* and the *mutakallimūn*. Finally, it examines the variety of reasons that have been given by scholars for the decline of Islamic intellectual preeminence evident in the thirteenth century.

Outline

I. Important developments in alchemy were made in the Arabic world, and indeed, chemistry can be said to be of Arabic origin.

- **A.** The background of Arabic alchemy lies in Hellenistic Egypt.
  - **1.** Greek *chēmia* appeared early in the Christian era and was initially involved with the refining of metals and the making and coloring of alloys, especially to mimic gold and silver.
  - **2.** Little survives of the early Greek texts, but we know that soon, practitioners were attempting to make real gold by transmutation.
- **B.** The Islamic world took up Greek texts on alchemy during the translation movement of the ninth century, but soon (by the end of the century), they surpassed them with original contributions.
  - **1.** The term *alchemy* is itself Arabic (the Arabic article *al* plus the Greek *chēmia*) and deals with the study, treatment, refining, and production of specific material substances.
  - **2.** Some Arabic contributions are still visible today in the vocabulary of chemistry: *alcohol*, *alkali*, *aluminum*, and so on.
  - **3.** The practical chemical processes of distillation, crystallization, sublimation—as well as the vessels for carrying them out—were greatly improved by Arabic alchemists over the more rudimentary methods devised first in Hellenistic Egypt.
- **C.** Naturally occurring substances, such as salts, stones, metals, bitumens, and so forth—now able to be collected over the broad extent of the House of Islam—were classified and tested by Arabic alchemists.
  - **1.** Methods for the isolation and synthesis of many chemical products were devised.
  - **2.** For example, the Persian physician ar-Rāzī (c. 865–925), known to Latins as Rhazes, wrote comprehensive treatises on the classification of chemical substances and the preparation of compounds; possibly his most important work is *Kitāb al-asrar* (*The Book of the Secrets*).
- **D.** (Al)chemical theory was also developed by Arabic thinkers.
  - **1.** The most important theory was the Mercury-Sulphur theory of the metals formulated by "Jābir ibn-Hayyan."
  - **2.** Jābir may never have existed as a real person; more than 2,000 works are attributed to him, but these were written over a lengthy period (850–1000) and are productions of a Shi'ite school or sect.
  - **3.** The Mercury-Sulphur theory states that the metals are produced from the various combinations of two underground exhalations. The basis for this is found in Aristotle's *Meteorologica*. The composition of all metals from the same ingredients gives theoretical backing to the goal of transmutation.
  - **4.** Transmutation was to be carried out by a prepared substance the Hellenistic alchemists called the Philosophers' Stone, or *xērē*. (The Arabic transliteration of this word, *al-iksir*, is still with us as *elixir*.)
  - **5.** Alchemists in the Islamic world, and later in the Latin world, endeavored to produce this secret substance.
  - **6.** The Islamic Mercury-Sulphur theory was the foundation of chemical theory for more than 800 years; developments from it were still of major importance in 1700.
- **E.** Another important writer on alchemy was Ibn-Sina, known to Latins as Avicenna (980–1037), a Persian philosopher and physician.
  - **1.** Avicenna's *Kitāb ash-Shifa'* (*Book of the Remedy*) adopted the Jabirian Mercury-Sulphur theory but denied the possibility of metallic transmutation, largely on Aristotelian grounds.

2. Many of Ibn-Sīnā's (Avicenna's) writings are medical. His *Qanūn* (*The Canon*) is an immense compilation of medical knowledge and techniques; after it reached Europe, it was considered authoritative there until the seventeenth century.

II. A very interesting division in Islamic scientific thought existed between two rival groups, the *falāsifa* and the *mutakallimūn*. The latter promoted a special theory of matter.

A. The *falāsifa* (derived from the borrowed Greek word *philosophia*) considered themselves as the heirs and advancers of Greek thought. Their commitments were generally to (Neo)platonism and Aristotelianism.

B. The *mutakallimūn* were practitioners of *kalām* (literally, "discourse"), a kind of Islamic speculative and disputational theology.

1. Although *kalām* was predominantly theological in character, it also included epistemology, ontology, logic, and physical theories.
2. Most curiously, two important topics of contention in *kalām* were cosmology and matter theory.
3. The matter theory of the *mutakallimūn* of the ninth and tenth centuries (and probably earlier) was radically atomistic—matter, space, motion, and even time were all composed of discrete "smallest units."
4. These views seem to be derived from a branch of Greek thought completely different from that adopted by the *falāsifa*, namely, Epicureanism. But the works of Epicurus are atheistic and, as far as we know, seemingly unknown in the Islamic world.
5. Why the *mutakallimūn* adopted these ideas is unclear (as well as when and from whom), but it is likely to have been for theological purposes—possibly to confound the dualist Manicheans, who believed in good and evil gods and the idea that matter was evil.
6. Thus, a *theological need* may actually have promoted a particular *scientific conception* of the world; this is not an uncommon event in the history of science.

C. The *mutakallimūn* and the *falāsifa* exemplify two different ways scientific knowledge can be transmitted between cultures.

1. The *falāsifa* actually had, and read, the books of Greek natural philosophers.
2. We can only guess at how the *mutakallimūn* picked up some of the basics of Epicurean atomism—there is no evidence that they had Epicurean texts—perhaps they drew on speculations by those in the Christian community who were familiar with Greek texts.

III. By the thirteenth century, a decline in Islamic civilization was evident, and by 1500, Islamic scientific culture was trailing that of the Latin West. The relative importance of the various causes for (or degrees of) this decline are still under debate.

A. On the one hand, there was widespread destabilization of the Islamic Empire. The *pax islamica* had come to an end.

1. The fragile unity of the Islamic world was increasingly disrupted by factionalization.
2. The reawakening of the Latin West brought armies against Islamic lands. In the eleventh century, Muslims lost much of Spain and all of Sicily, and the First Crusade conquered the Levant, establishing a Latin kingdom at Jerusalem in 1099.
3. In the east, Mongol hordes were on the move against Islam, ending with the tragic destruction of Baghdad in 1258, an astounding loss to Western civilization.
4. But such military losses may be *signs* rather than *causes* of decay.

B. There were certainly intellectual reasons, as well.

1. One theory points to dissension between the *mutakallimūn* and *falāsifa*; the claim is that conservative Islamic theologians increasingly viewed intellectual systems based on Greek models as "foreign" (that is, "un-Islamic").
2. According to this model, victory over the *falāsifa* by the *mutakallimūn* undercut the development of Islamic natural philosophical thought.
3. Yet the opposition to Greek thought was scattered and isolated, and many *mutakallimūn* showed no clear enmity toward borrowed (and adapted) intellectual systems. Moreover, by the twelfth century, Greek thought had been advanced and developed in an Islamic context for 300 years and was hardly "foreign" any more.

4. One problem may have been the rise of occasionalist philosophies, in which every action is a direct effect of God's will, thus eliminating the idea of regular natural laws, which are the crucial support for rational inquiry into the natural world.

C. In fact, we still know relatively little about the texts written in the later period of the Islamic Empire (after 1300), and so the drawing of broad conclusions may be premature. The scholarly study of the history of science in the Islamic world has frequently come to an end at the period when the Latin West reawakens; for this reason, the end of the story is not yet written.

Essential Reading:

A. I. Sabra, "Situating Arabic Science: Locality versus Essence," *Isis* 87 (1996): 654–670.

Supplementary Reading:

Alnoor Dhanani, *The Physical Theory of Kalam: Atoms, Space and Void in Basrian Mu`tazili Cosmology.*

Questions to Consider:

1. Think for a while about the consequences of a radically atomistic view of the world like that of some of the *mutakallimūn*, where both time and space exist in "smallest units" (that is, are "quantized," in modern parlance). How would this change our view of the natural world and changes or motion in it?
2. Without our modern notions of elements and distinct atoms, how would it be possible to determine whether or not base metals can be converted into gold? Can you think of arguments in favor of transmutation?

Lecture Seventeen

The Latin West Reawakens

Scope: Despite sporadic attempts to reignite Latin culture during the early Middle Ages, only in the twelfth century did sustained development (scientific and otherwise) appear. This lecture looks at the "Renaissance of the Twelfth Century" and the great Latin "translation movement," when Latin European scholars eagerly availed themselves of the intellectual wealth of the Islamic world.

Outline

I. In the twelfth century, and throughout the rest of the Middle Ages, Latin culture waxed while Islamic culture waned.

- **A.** The intellectual and cultural history of the "West" is incomplete and probably incomprehensible without the full inclusion of Arabic culture as part of the West.
- **B.** We should speak of three interdependent facets of Western culture: Greek, Latin, and Arabic, all heirs to the same classical traditions.
  1. The remainder of this course will focus on the "Latin West"—basically the Latin-speaking lands of what was the Western half of the old Roman Empire.
  2. This is distinguished from the Greek West—the Eastern half of the old Roman Empire (Asia Minor, Greece and its archipelago, and the Balkans).
  3. A third part of the West is the Arabic West. Arabic culture and civilization are integral and essential parts of Western culture and civilization.
- **C.** In religious terms, Christianity and Islam spring from a common Levantine root, and both religions developed theologies that paired their individual revelations to the intellectual and philosophical traditions of ancient Greece.

II. A few attempts were made in the period 600–1000 to reorganize Latin culture in Europe after the collapse of classical civilization, but these were largely local and short-lived.

- **A.** At the local level, there always remained centers of learning and works of scholarship, generally at the monasteries. Specifically natural philosophical endeavors were not, however, widely pursued.
- **B.** The crowning of Charlemagne, first as King of the Franks, then in 800, as Holy Roman Emperor had some effects.
  1. By Charlemagne's edict, cathedrals and monasteries were required to maintain schools, initially for training the clergy.
  2. Charlemagne's court and palace school attracted scholars, notably Alcuin of York, who helped develop a new style of writing, called Carolingian. It was intended to be easier to read and to write and was thought to imitate Roman writing (it didn't).

III. Lasting changes began in the eleventh century, sparking what has been termed the "Renaissance of the Twelfth Century."

- **A.** Many causes for this reawakening have been suggested; the relative importance of each is still under debate.
  1. Barbarian raids dwindled dramatically, allowing for the resumption of stable coastal life and trade.
  2. European population surged in the 1100s; more people allows for more urbanism, more division of labor, and more leisure time, all of which mean more space for intellectual development.
  3. It has been suggested that a significant climatic change occurred in the period 1000–1200, making Europe warmer and wetter; a longer, richer growing season allows for greater population.
  4. Farming technology improved with the invention of satisfactory harnesses for horses, more efficient waterwheels, and crop rotation, providing improved crop yields with less work.
- **B.** Whatever the relative importance of each member of this constellation of causes, the effects of the Twelfth-Century Renaissance were dramatic.
  1. In art, the so-called Gothic style and the age of great cathedral building began.
  2. In religion, numerous reforms were started, such as the Cistercian and Cluniac.

3. Changes occurred also in language and literature, law, music, and education. The twelfth century was a time of significant and nearly universal cultural change across Western Europe.

IV. The most important event for natural philosophy in the twelfth century was the European translation movement, which brought the wealth of Arabic libraries into the Latin world.

A. The earliest translations seem to have been made in monasteries in the tenth century in northern Spain. These translations introduced knowledge of such things as the abacus and astrolabe, but were limited and seem to have had little impact.

B. The stability of the twelfth century allowed for the exploration and assimilation of Arabic knowledge. The period of translations from Arabic occurred in the period 1125–1200 and, predominantly, in Spain.

1. The eleventh-century military gains of Christian forces against the Islamic Empire (Toledo conquered in 1085, Cordoba in 1236, Seville in 1248) increased awareness of the wealth of Arabic learning.
2. Spain provided the prime location for translating activities because of the settled Arabic culture, the presence of numerous Christians (Mozarabs), and the relative ease of travel there.
3. Translators came from all over Europe, seeking Arabic texts and making translations.
4. Several translators note specifically that their activity was aimed at bringing to the Latin world new knowledge of which it had previously had no cognizance.
5. Medieval Latins readily acknowledged the superiority of Arabic intellectual culture. Arabic authorship of a text became a mark of quality; indeed, during the twelfth through the fourteenth centuries, some Latin authors wrote under Arabic pseudonyms to give authority to their writings.
6. The most productive of the translators from Arabic was Gerard of Cremona (c. 1114–1187). He came to Spain to find Ptolemy's *Almagest*, found it in Toledo, mastered Arabic, and stayed there the rest of his life.
7. Gerard translated about eighty books on astronomy, mathematics, physics, and medicine, including both classical works (by Euclid, Aristotle, Galen) and Arabic ones (by Banū Mūsā, ar-Rāzī, Ibn-Sina, al-Khwarizmī).

C. Translation activity also occurred in Sicily, where the Normans had created a stable trilingual and multiethnic (Latin, Greek, and Arabic) culture.

1. The multicultural/multiethnic atmosphere of twelfth-century Spain and Sicily bore similarities to that of the ninth-century Islamic Empire, the locus of the previous "translation movement."
2. A few translators went to the Levant (for example, to the Latin Kingdom of Jerusalem); one who did was Adelard of Bath (fl. 1116–1142), who translated several works on astronomy and wrote his own works on scientific topics.

D. In the thirteenth century, a second phase of translation began. Attention now turned eastward, toward Byzantine lands, in the hopes of obtaining Greek originals of classical texts.

1. The techniques of translation sometimes left something to be desired. Some texts of classical Greece had passed through Syriac, Arabic, and Spanish before being rendered into Latin.
2. The greatest Greek translator was Willem of Moerbeke (c. 1215–1286), a Flemish Dominican who lived a considerable part of his life in Greece (from 1278, he was bishop of Corinth).
3. Willem was encouraged by his friend St. Thomas Aquinas, who complained of the quality of the then-available translations of Aristotle made from Arabic.
4. Willem translated about fifty books, including nearly all the works of Aristotle and Archimedes.

E. Curiously, both phases of the translation movement (like the earlier Arabic translation movement) focused on scientific, mathematical, and logical works.

1. Some theological works were translated, for example, the Qu'ran in 1143, but essentially nothing literary or historical.
2. This focus seems to argue for a demand by twelfth- and thirteenth-century scholars for logical and natural philosophical works in particular.

Essential Reading:

David C. Lindberg, *The Beginnings of Western Science*, pp. 183–190, 203–206.

Edward Grant, *The Foundations of Modern Science in the Middle Ages*, chapter 2.

Supplementary Reading:

Charles H. Haskins, *The Renaissance of the Twelfth Century*.

Robert L. Benson and Giles Constable, *Renaissance and Renewal in the Twelfth Century*.

Frances Gies and Joseph Gies, *Cathedral, Forge and Waterwheel*, chapters 1–3.

David C. Lindberg, *Science in the Middle Ages*, chapter 2.

Questions to Consider:

1. We have seen two great "translation movements," one in Islam and the other in Christianity. How do the two resemble each other and how are they different?
2. Cross-cultural borrowings have often been of great importance to the development of human civilization. With the two great translation movements of the Middle Ages as a background, think about current-day cross-cultural borrowings and consider the similarities and differences. Why, how, and what do we borrow from other cultures? Why, how, and what do they borrow from us? Are there differences in terms of how voluntary this borrowing is now versus the medieval movements?

Lecture Eighteen

Natural Philosophy at School and University

Scope: In the history of science, the setting in which scientific studies took place and the institutions that fostered and sponsored them are of great importance and interest. This lecture looks at the changing nature of such "institutions." Of particular note are the monastic and cathedral schools, which were the origins of that great medieval institution, the university. We will examine universities (particularly the one at Paris), what it was like to be a student or professor there, and what the place and content of scientific studies were. Who was involved in the study of the natural sciences and why?

Outline

I. In the study of the history of science, it is important to know not only *what* was known and *by whom*, but also *where* natural philosophy was done, that is, what locales and institutions supported learning of various sorts, including natural philosophy.

- **A.** Nowadays, very little scientific work is done outside the context of an institution of some sort: research institutes, scientific societies, schools and universities, or corporations.
- **B.** Many, but not all, of the historical characters we have encountered belonged to some larger association or institution.
    1. Plato's Academy and Aristotle's Lyceum are models of ancient schools.
    2. The Museum and Library at Alexandria were established centers and the recipients of princely patronage.
    3. In Islam, specific locales, such as the House of Wisdom in Baghdad, were patronized by caliphs, but many mosques and *madrasas* (schools) were also centers for learning; Ibn al-Haytham was connected to al-Azhar mosque in Cairo.
    4. In the Latin West, schools developed along the Roman model and eventually grew into that curious and very medieval institution, the university—the major institutional home for learning in the Middle Ages.
    5. Note that, in almost all cases, across various cultures, the centers of learning and scholarship were coincident with religious institutions—whether pagan, Muslim, or Christian.

II. The schools required by Charlemagne's edict were slow to develop. Only in the improved conditions of the eleventh and twelfth centuries did schools begin to flourish.

- **A.** Most schools in this period were located in monasteries or attached to cathedrals.
- **B.** The teaching was based on the traditional seven liberal arts, the *trivium* and *quadrivium*.
- **C.** The school of Chartres was founded around 1020 by Fulbert and grew into an important center of scholarship.
    1. The Chartres school placed special emphasis on the *quadrivium* (the mathematical arts) and on *physica* (natural philosophy).
    2. The Royal Portal (built 1145–1155) of the cathedral preserves one memory of school; it is surrounded by statues of classical figures representing the seven liberal arts. This is not an uncommon motif in medieval cathedrals.
    3. The school of Chartres' greatest period was the first half of the twelfth century. Bernard of Chartres (master of the school c. 1115–1126), his brother Thierry of Chartres, and especially his student William of Conches (b. c. 1090) wrote important texts.
    4. Thierry is supposed to have introduced the *rota* (literally, *wheel*), or zero, to Latin mathematics.
    5. William of Conches' *Dragmaticon philosophiae*, written between 1143 and 1149, presents a dialogue between William and Geoffrey Plantagenet, Duke of Normandy and father of King Henry II of England. Almost all of its contents deal with natural philosophy—which implies that William's teaching bore a similar emphasis.
    6. William's text is comprehensive. It uses "thought experiments" to explore natural principles; it shows knowledge of atomic theory and of planetary epicycles as amended by Abu Ma`shar.

7. William ends his treatise with the significant line: "It is through knowledge of the creatures that we arrive at knowledge of the Creator."

D. Another important school was that of the Abbey of St. Victor, outside of Paris.

1. The school was public, and students arrived at many different ages and levels of experience.
2. One of the masters of the school, Hugh (d. 1140 or 1141), wrote a text, the *Didascalicon*, on what should be learned and why. The emphasis differs significantly from that of William of Conches. It is dependent on the classical *trivium* and *quadrivium* and pedagogical traditions dating back to St. Augustine and Imperial Rome.
3. Hugh of St. Victor's text presents knowledge as *redemptive* of fallen man. His outlook is Platonic but fully Christianized.
4. Man's fall (in the Garden) affected his relationship to God, his ability to know things rightly, and his body. The infirmities of these three are healed by spiritual (theology), intellectual (liberal arts and natural philosophy), and technological (the "mechanical arts") knowledge.
5. Hugh's interest in technology ("mechanical arts") is remarkable. The mechanical arts are able to relieve man's physical weakness and help reunite man with divine wisdom.

E. Schools such as these represent—in varied forms—a great flowering of Platonic views of knowledge in a Christian context.

1. There was, however, considerable local variation in the emphasis of the curriculum.
2. These two schools exist on a crucial "border." They flourished at the very start of the translation movement and before the rise of the universities.

III. The first universities grew out of large urban schools toward the end of the twelfth century. The rise of universities led to the decline of the older schools.

A. The emergence and growth of the university indicates both the growth in the body of available knowledge and the social demand for education on a larger scale.

B. The university was structured on the model of the guild—a corporate body able to administer, regulate, and protect the rights and privileges of its members—and was endowed by ecclesiastical or (less often) secular authorities. There was little formal structure, no real estate holdings, and considerable flexibility as a result.

C. Three universities important in the thirteenth century were Bologna, Paris, and Oxford.

D. The University of Paris consisted of four faculties: the faculty of arts (the substantial majority) and the three higher faculties, law, medicine, and theology.

1. During the 1200s, Paris had about 1,200–1,500 students. Students entered at the age of fourteen or fifteen, attached themselves to a master, and spent three or four years to obtain a bachelor's degree; most left before obtaining a degree.
2. With two or three more years of study, a master of arts degree could be obtained, and the right to teach the arts anywhere (*ius ubique docendi*).
3. Some students then proceeded to the higher faculties to become master (or doctor) of law, medicine, or theology. Theology was the most rigorous, requiring ten to sixteen years of further study beyond the arts level.
4. All students and faculty had clerical status.

E. The combination of Aristotelian corpus and medieval university gave rise to the system of Scholasticism.

Essential Reading:

Edward Grant, *The Foundations of Modern Science in the Middle Ages*, chapter 3.

Supplementary Reading:

William of Conches, *A Dialogue on Natural Philosophy* (*Dragmaticon Philosophiae*), ed. Italo Ronca and Matthew Curr.

Hugh of St. Victor, *Didascalicon*, preface, books 1–2.

Pearl Kibre and Nancy Siraisi, "The Institutional Setting: The Universities," in *Science in the Middle Ages*, David C. Lindberg, ed.

Questions to Consider:

1. William of Conches and Hugh of St. Victor are quite clear about the reasons one should study and learn—these are predominantly theological. What are the reasons for study and learning today? Do you think all medieval students went to schools for the reasons their teachers outlined in their texts?
2. Think about modern institutions that are intended to foster learning. How many different sorts are there? How would the intellectual world be different if these did not exist?

Lecture Nineteen

Aristotle and Medieval Scholasticism

Scope: The works of Aristotle were some of the most influential works the Latin West reacquired from the Islamic world. Aristotelian investigative methods gave rise to the system of Scholasticism, and university curricula were highly dependent on Aristotle. Yet Aristotle was a pagan who held some views contrary to Christian doctrine. This lecture will look at the fate of Aristotle in the medieval Christian world, and the way his natural philosophy—despite occasional condemnations—developed within Christian theology.

Outline

I. Scholasticism was a method for studying any subject—theology, natural philosophy, medicine, and so on—based on the oral format of medieval university instruction.

- **A.** The key development came with the introduction of Aristotle and his logical methods.
  - **1.** By the second half of the thirteenth century, university curriculum became centered on the Aristotelian corpus (largely displacing Platonic thought—at least for a time).
  - **2.** The *Libri naturales* ("natural books," that is, works on scientific topics, such as the *Physics*, *On the Heavens*, the texts on animals, and so on) of Aristotle were important parts of the curriculum.
  - **3.** The value of Aristotle was the comprehensiveness of his system and the apparently universal applicability of his logic and methodology.
- **B.** The combination of Aristotle's corpus with the didactic traditions of the schools gave rise to Scholasticism.
- **C.** The basic unit of the medieval Scholastic method was the question, and the format was the commentary.
  - **1.** Students heard lectures, but these were supplemented with disputations.
  - **2.** The disputation was fundamental to the Scholastic method. A yes-no question was posed by the master; it was then answered by one student (the *respondens*), and this student's response was critiqued by another (the *opponens*). A resolution was then given by the presiding master (the *praeses*).
  - **3.** All students had to participate in such disputations in order to earn their degrees.
  - **4.** Twice a year, special disputations (the *Quodlibeta*) were held publicly and seem to have attracted many spectators.
  - **5.** The same disputative method was employed in writings, first in the written forms of the master's lecture notes, then in more general texts.
  - **6.** For example, all of St. Thomas Aquinas' *Summa theologica* is in a strict disputational format. But the form was used in natural philosophy, as well as in theology.
- **D.** The questions could be drawn as interpretations of an authoritative text (the Bible, Aristotle, Augustine, and so on) or to construct theoretical systems.
  - **1.** Thus, one way to carry out an orderly study of astronomy, for example, was to take a classical text—Aristotle's *On the Heavens*—and write a commentary on it. (St. Thomas, for one, did this.)
  - **2.** Every theology student had to write a commentary on Peter Lombard's *Four Books of Sentences*. Originally, these questions were completely theological, but over time, more natural philosophy was incorporated.
  - **3.** Because Peter's original *distinctiones* (chapters in a sense) were preserved, there was a high degree of order; one could look through what fifty or a hundred authors had to say on a specific topic easily by just going to "commentaries on Lombard, distinction such-and-such."

II. The fervent embrace of Aristotle by the universities and the adoption of Scholastic methods eventually provoked criticism.

- **A.** Aristotle was a pagan who maintained positions contrary to Christian doctrine (for example, that the world is eternal).
  - **1.** This had already been a problem in the Islamic world: al-Kindī used logical argument to reject Aristotelian views contrary to Qur'anic revelation.

        2. One of the most important Muslim Aristotelians, Ibn-Rushd (known to Latins as Averroës, or simply "the Commentator"), however, actually rejected several Islamic articles of faith in favor of Aristotle's views.
    - **B.** Official denunciations of Aristotle appeared at Paris in the early thirteenth century, without much effect.
    - **C.** The major strike against Aristotle began when an investigation of teaching was initiated in 1277.
        1. The investigation had been supported by the scholar Peter of Spain (c. 1220–1277), who had studied at Paris, was interested in natural philosophy, and became professor of medicine at Siena and, eventually, Pope John XXI in 1276.
        2. The result was the Condemnation of 1277, issued on 12 March 1277, by Etienne Tempier, the bishop of Paris, at the urging of the doctors of theology against the masters of arts.
        3. The Condemnation cited 219 propositions—generally Aristotelian and many dealing directly with scientific issues—which could not be maintained as true.
        4. Most of these propositions had to do with putting limitations on divine power (for example, God could not create more than one world).
        5. Others dealt with the "error of double truth"—that a thing true in theology can be false in philosophy—or with limitations placed on human free will.
        6. The Condemnation was local in effect and was partly retracted later.
    - **D.** It has been argued that the Condemnation of 1277 was salutary for natural philosophy overall, because it forced scholars to think beyond Aristotelian claims, since these Aristotelian formulations were officially declared false.
        1. For example, since the Condemnation of 1277 had rejected the proposition that God could not create more than one world, some medievals began to think about the possibility of other worlds.
        2. These "other worlds" would be located outside the sphere of the fixed stars.
        3. If these worlds were like ours, they might have "extraterrestrial" life in them, some of which might be intelligent (and perhaps in need of a Redeemer).
    - **E.** In later periods, the claim was made that the Middle Ages followed Aristotle blindly. This is far from the truth. Aristotle was frequently no more than a "point of departure," and many Scholastics freely criticized Aristotle and struck out in new directions. The Condemnation of 1277 helped this trend.
- **III.** The universities and schools provided an institutional home for natural philosophy.
    - **A.** It may be argued that this is one reason for the success of science in the Latin West.
    - **B.** In contrast, the Arabic West had no corresponding autonomous, collective institutions of learning.
    - **C.** The disputative nature of the medieval university required the development of rules and orderly methods of formulating questions, supporting arguments, and refuting the opinions of others—all crucial elements in scientific research today.

Essential Reading:

David C. Lindberg, *The Beginnings of Western Science*, chapter 10.

Supplementary Reading:

Edward Grant, *The Foundations of Modern Science in the Middle Ages*, chapters 4–5, 7.

Questions to Consider:

1. The Scholastic method was eventually rejected from theological inquiry (particularly by Protestants). Think about how this elimination of a rigorous investigative methodology changed the nature and content of religion.
2. Compare the Scholastic method with what we now call the scientific method. How are they similar and different?

Lecture Twenty

The Science of Creation

Scope: The origin of the world has always been a topic for scientific inquiry. This lecture examines some approaches to this question from the Middle Ages. Although the creation by God of the world out of nothing was an undoubted article of faith, medieval natural philosophers strove to understand the natural causes at work in creation and how God organized his creation. This lecture will examine the fascinating Hexameral literature—commentaries on the first chapters of Genesis—which was widely used by medieval thinkers as the format for investigations into natural philosophy.

Outline

I. In the Middle Ages, natural philosophers and theologians were frequently the same people.

- **A.** One important locus for natural philosophical inquiry was in commentaries on the opening chapters of Genesis.
  - **1.** Genesis 1–2 describes God's creation of the world.
  - **2.** It was, therefore, a logical place to ground study of physics, astronomy, earth sciences, matter theory, botany, zoology, and all the other branches of natural philosophy.
- **B.** Many treatises on the six days of creation were written; the genre was known as *Hexaemera* from the Greek words for "six days."
- **C.** In some cases, especially the later ones, it seems clear that the authors were actually more interested in natural philosophy and seem to use the biblical commentary format largely as a vehicle or organizational principle.

II. The Patristic writers began the Hexameral tradition, particularly St. Basil and St. Augustine.

- **A.** St. Basil's commentary was in the form of homilies given to audiences of tradesmen—thus, God's creative handiwork was paralleled to their own productive labors.
  - **1.** For Basil, God is the direct cause of things.
  - **2.** Basil's interests are homiletic and devotional, not natural philosophical, even though he shows a certain level of knowledge of Greek natural philosophy.
- **B.** St. Augustine was generally more influential in the Latin West than St. Basil.
  - **1.** St. Augustine set the tone for much of the later Hexameral literature in his literal commentary on Genesis; that is, the interpretations of Scripture must accord with received scientific knowledge and logic and should explain the expressions used in the text.
  - **2.** For example, St. Augustine rejected the notion of six natural days for creation in favor of an instantaneous creation that developed over time.
  - **3.** He developed the idea of "seminal reasons" (*rationes seminales*). These are hidden potentialities created by God within matter; at the appropriate time and places, they "unfold" like seeds to produce new things.

III. Key to examples of later medieval Hexameral literature is *naturalism*; that is, arbitrary, miraculous actions of God are not acceptable explanations for natural philosophy.

- **A.** This view is often explained by the notion of primary and secondary causes.
  - **1.** God is the ultimate primary cause of everything, but that fact has little explanatory power. Medieval theologians viewed unnecessary recourse to the primary cause as a "cop-out."
  - **2.** Secondary causations—that is, the actions of natural forces (created initially by God)—were adequate explanations; these were the focus of inquiry.
  - **3.** Medieval theologians held that God nearly always works through secondary causes; God's direct intervention produces miracles, and they are exceedingly rare.
  - **4.** Already in the Middle Ages, some theologians endeavored to find naturalistic explanations for biblical miracles, such as the parting of the Red Sea.
  - **5.** Thus, while man could never comprehend the miraculous instant of *creatio ex nihilo* (creation out of nothing), everything after that initial moment should be explicable on the basis of secondary causation.

B. This method reveals a confidence in human reason and inquiry to understand a rational, orderly world which became so dominant in the eleventh and twelfth centuries and stems from a Christianized Platonism that emphasizes the power of the human intellect and the salvific nature of knowledge.

IV. Several specific medieval Hexameral writers will illustrate these points, the variety of interpretations possible, and the way natural philosophy was used and extended in a theological context.

A. Two twelfth-century writers at the school of Chartres, Thierry of Chartres (d. after 1156) and William of Conches (d. after 1154), showed keen interest in the natural philosophy of creation.

B. Thierry of Chartres wrote a *Tractatus de sex dierum operibus* (*Treatise on the Works of the Six Days*).

1. The text works its way through Genesis 1, verse by verse. Each verse provides a chapter. Thierry is clear that he will expound the text *secundum phisicam*, that is, according to the way nature works.
2. Thierry posits the primary cause initially in Aristotelian terms: God as efficient (Father), formal (Son), and final (Holy Spirit) causes and the created four elements as the material cause.
3. Using the second person as the formal cause reveals a Christianized Platonism (the forms of the *Timaeus* = *Logos* = Christ).
4. But references to divine causation nearly disappear after the first few pages, and the creation thereafter unfolds *naturaliter* (naturally).
5. The "separation of the waters" above and below the heavens (Genesis 1: 6–7) is a clear example of the natural development of the world; the motive force (the proximate efficient cause, to use an Aristotelian term) is the heat of the celestial fire. God creates the elements *ex nihilo*, then the elements interact according to their inherent nature.

C. William of Conches, Thierry's contemporary, goes further. His *Dragmaticon philosophiae* is at first not recognizable as Hexameral literature—almost no biblical quotations, no explicit exegesis, but the dialogue extends over six days, and each day's topics correspond to the topics associated with each day of creation in Genesis.

1. William was also deeply influenced by Plato's *Timaeus*.
2. God created a "chaos," a mixture of the elements at the beginning; then, they begin to move according to their natural properties.
3. He also deals with the issue of "waters" above the heavens, leading the Duke to exclaim that William ignores God's power. William retorts that God's omnipotence is not an adequate explanation of natural things.
4. William uses logical analysis based on the observable properties of natural bodies and notes that it is often necessary to disagree with the opinions of the Church Fathers in matters of natural philosophy.
5. For William, life on earth arose from the natural action of heat on mud. Even man originated thus, even though God gave him a rational and immortal soul.
6. In fact, "several species" of humans could be generated naturally this way, and indeed, they still could be today. The fact that this did not happen is presumably God's unwillingness for it to occur.

D. Robert Grosseteste (c. 1168–1253), the bishop of Lincoln, also promoted a Platonic reading of Genesis but was particularly interested in the topic of light.

1. Light was the key aspect of Neoplatonic thought that was popular at this time and built into the contemporaneous Gothic cathedrals with their huge windows.
2. Grosseteste favored an instant of creation (like Augustine); for him, the six days are merely six parallel ways of expounding the creation.
3. For Grosseteste, God created a dimensionless point of light imposed on a dimensionless point of prime matter. The natural spherical expansion of this point—according to the usual laws for the diffusion of light from a point source—subsequently generated the universe.
4. Grosseteste's interest in light was primarily theological—it was the means of divine creation and the vehicle of knowledge—but Grosseteste's interest manifested itself in studies of optical phenomena (reflection, refraction, the rainbow, and so on) and astronomy.

E. Henry of Langenstein (d. 1397) wrote a lengthy commentary on Genesis that is a veritable compendium of fourteenth-century natural philosophy. Given his later dates, Henry's view is predominantly Aristotelian, not Platonic, but also includes a wide array of sources.

F. In all cases, we see the "open border" between scientific and theological speculation. Theology and Scripture do not restrict natural philosophy but, often, actually provide an impetus and a locus for it.

V. Given that the Condemnation of 1277 had rejected the proposition that God could not create more than one world, some medievals began to think about the possibility other worlds.

   A. These "other worlds" would be located outside the sphere of the fixed stars.

   B. If these worlds were like ours, they might have "extraterrestrial" life in them, some of which might be intelligent.

Essential Reading:

Genesis 1; Gospel of John 1.

David C. Lindberg, *The Beginnings of Western Science*, pp. 197–203.

Supplementary Reading:

William of Conches, *Dragmaticon philosophiae*.

Steven Dick, *Plurality of Worlds*.

Questions to Consider:

1. Why do you suppose that some modern Christians (and others) are so concerned about scientific "incursions" into religion, even though many devout medievals (including theologians) had no problem even with the idea that life arose on earth naturally without direct divine intervention? What has changed?

Lecture Twenty-One
Science in the Orders

Scope: The monastic orders had been preservers and promoters of natural philosophical (and other) learning since late antiquity. But the major new orders of the Middle Ages—the Franciscans and Dominicans—developed new natural philosophical outlooks and programs as part of their theology. This lecture looks at these two orders, their origins, their distinctness, and the scientific work of some of their shining lights, such as Roger Bacon among the Franciscans and St. Albert the Great among the Dominicans.

Outline

I. Centers maintained by religious orders had been centers of learning since late antiquity (such as Benedictine abbeys), but the High Middle Ages saw the emergence of two new orders—Franciscans and Dominicans—the mendicant (begging) orders.

- **A.** Both orders began in the early thirteenth century.
  - **1.** St. Dominic (c. 1170–1221) created an "Order of Preachers"; their mission was to preach effectively both to strengthen the church and confront heretical movements. The Dominicans became the intellectual elite of the late medieval church.
  - **2.** St. Francis of Assisi's (1186–1226) followers, the "Friars Minor," sought a renewal of Christian piety through the embrace of a simple existence of personal charity, poverty, and communal life.
- **B.** Both orders were organized under a central leadership, unlike the earlier monastic communities, which were largely independent. The Mendicants were thus essentially pan-European.
- **C.** By the end of the fourteenth century, both had become powerful intellectual forces and maintained high profiles in the universities.
  - **1.** Throughout the later thirteenth century, a struggle took place at the universities between the secular teachers and the Mendicants.
  - **2.** The universities were based on a guild structure, and the Mendicants were outside of the guild.

II. St. Albert the Great, the "Universal Doctor," (c. 1200–1280) was a prolific writer and important teacher in the early Dominican Order.

- **A.** After study at Padua, Albert became a Dominican and, eventually, went to the University of Paris (c. 1241), where he became the first German master of theology and lectured on theology from 1245 to 1248.
  - **1.** Albert founded a new school in 1248 at Cologne.
  - **2.** St. Thomas Aquinas was his student.
- **B.** At the request of the Dominicans, Albert wrote a massive paraphrase and commentary on all of Aristotle, including the important Arabic commentaries.
  - **1.** Albert's work thoroughly established Aristotelian thought at Paris and elsewhere. He probably did more than any other single person to establish and propagate Aristotle's thought and method.
  - **2.** Albert's writings are deeply Aristotelian throughout; Albert argued that logic (meaning Aristotle's) should be the basis of study.
  - **3.** Albert also compiled a list of Aristotle's errors and argued that authority alone was not sufficient—the true causes of things had to be known.
  - **4.** His methodology for natural philosophy includes substantial empiricism and observation.
- **C.** Albert wrote profusely on natural philosophy.
  - **1.** His *De vegetabilibus* is a wide-ranging comparative study of plants, and his *De animalibus* is noteworthy especially for its content on reproduction and embryology.
  - **2.** The *De mineralibus* describes and classifies minerals; Albert also studied fossils.
  - **3.** Albert wrote on the rainbow, comets, and tides and composed a commentary on Euclid's *Elements*.
- **D.** Albert, like his contemporaries, argued that the study of the natural world leads to a glorification of God, but he claimed also to have tried to "satisfy curiosity."

III. Roger Bacon, the "Marvellous Doctor," was an English Franciscan and was keenly interested in natural philosophy, but in ways very different from Albert the Great and for quite different reasons.

A. Bacon received his master of arts circa 1240 and lectured at Paris on Aristotle from 1241 to 1246 (overlapping with Albert the Great); he returned to Oxford and became a Franciscan around 1257.

B. Bacon's greatest intellectual change in mid-life was his move from predominantly Aristotelian to predominantly Neoplatonic thinking.

1. As a result, Bacon believed that mathematics, not logic, should be the basis of all studies. Mathematics describes and analyzes the world better than does logic; mathematics is the "alphabet of philosophy" and the "door and key to the sciences."
2. Bacon's thought depended on the "multiplication of species," that is, that the means of change/causation propagate radially from one object to another, like the propagation of light.
3. For example, a vessel of water placed near the fire becomes hot (like the fire); the quality (or "species") of hotness is multiplied in the water.
4. Given that light can be treated mathematically in optics, so too can causation (that is, all change).
5. This leads to a comprehensive analysis of the mathematical laws of radiation, reflection, and refraction in various media.
6. The immediate background to Bacon's conception lies in his commitment to light metaphysics adopted from Grosseteste, but dates back ultimately to al-Kindī, who envisioned a vast network of rays of influence connecting all bodies in the universe (this was a fundamental basis of al-Kindī's astrology).

C. Bacon's wrote his *Opus maius* (*Greater Work*) and *Opus minor* (*Lesser Work*) in 1266–1267 at the request of Pope Clement IV. Bacon also wrote a supplementary *Opus tertium* (*Third Work*) and other texts.

1. These works touch on almost every aspect of natural philosophy and education.
2. Mathematics and optics are central; Bacon writes about magnifying lenses and burning mirrors among other topics.
3. Bacon emphasizes the need for foreign language instruction; he himself wrote Greek and Hebrew grammars.
4. He also suggested a correction to the Julian calendar, namely, adding an extra day every 125 years. (The basis of this system was eventually adopted—though not from Bacon—in the current Gregorian calendar.)
5. Bacon strongly promoted the idea that knowledge of scientific and technical matters could give man great power to harness and deploy the hidden forces of nature.

D. Bacon was probably imprisoned for a time; the mythology says this was because of his natural philosophical work, but a far more likely reason is more interesting.

1. Bacon's natural philosophical and educational work was motivated by his deep concerns over a major threat to the church, which is why his works went to the pope.
2. Part of his fears were about the Mongols (who were then threatening to overrun Christendom) and Muslims. He recognized that Christians were a minority in the world (a testimony to the broadening of European horizons in the High Middle Ages) and, thus, persuasive arguments were needed to convert the infidels; science strengthens Christendom.
3. But a greater fear for Bacon was the anti-Christ, whom he thought was about to appear. Scientific knowledge, according to Bacon, would provide the best weapons for Christianity against the anti-Christ.
4. The thirteenth-century Franciscan Order was struggling to suppress its radical "Spiritualist" branch, which was caught up in a prophetic and apocalyptic frenzy; Bacon's concerns with the anti-Christ linked him to the Spiritualists and rendered him suspect.

IV. Bacon and Albert exemplify divisions between the medieval Franciscans and Dominicans.

A. Bacon strongly criticized the Dominicans (Albert and Thomas Aquinas in particular), their education methods, and their Aristotelian innovations.

1. Many Franciscans (such as St. Bonaventure) were neo-Augustinians; although they used Aristotle, it was only with heavy influence from St. Augustine's Christianized Neoplatonism.
2. Most Dominicans favored more strictly Aristotelian methods.

- **B.** Curiously enough, the two Mendicant orders, in a sense, continued the ancient division between the more mathematical approaches of Plato and Pythagoras and the more qualitative, logical approaches of Aristotle.
- **C.** Many members of both orders made important contributions to natural philosophy (and theology) and had a major impact on university culture.

Essential Reading:

C.H. Lawrence, *The Friars*.

Supplementary Reading:

Gordon Leff, *Paris and Oxford Universities in the Thirteenth and Fourteenth Centuries*.

Christopher Dawson, *Mission to Asia*.

Questions to Consider:

1. St. Francis wanted his followers to avoid getting involved in scholarly pursuits, yet the Franciscans soon developed a significant presence at the universities. What are some possible reasons that they may have turned to intellectual pursuits?
2. Roger Bacon's request that the Pope patronize science and technology in order to provide weapons against the anti-Christ may well be one of the earliest calls for government sponsorship of research for defensive purposes. Consider how science and technology today are linked to the defense industry. Can you think of examples from recent history (or other periods) which illustrate aspects of this relationship and how science and technology are affected by the preparations for war and defense?

Lecture Twenty-Two

Medieval Latin Alchemy and Astrology

Scope: Alchemy and astrology are sometimes dismissed as "pseudo-sciences," but they were seriously pursued by learned scholars in the Middle Ages. Alchemical texts first came to the Latin West from the Islamic world, but by the thirteenth century, original Latin treatises were being written. Some of these show important innovations in matter theory and practical processes, even though the field was soon shrouded in secrecy. Astrology offered the hope of an anchor in an uncertain world. It promised to provide warnings about sickness or danger for individuals, as well as for states. Importantly, licit astrology spoke only of tendencies because it was careful to preserve the autonomy of human free will. This lecture surveys the developments in this often-obscure field.

Outline

I. Alchemy arrived in the Latin world in the twelfth century, along with other translations from Arabic; it soon began to develop further in Europe.

- **A.** Robert of Ketton translated the first alchemical treatise in 1144, because the Latins "knew nothing" of this subject.
- **B.** Arabic alchemy did, however, meet up with a craft tradition and "recipe literature" already established in Europe, which dealt with glassmaking, refining, metalworking, and the manufacture of salts, pigments, and dyes. One example is the eleventh-century *On Diverse Arts* by Theophilus, a craft manual for monastic workshops and centers of production.
- **C.** The most significant work of early Latin alchemy is Geber's *Summa perfectionis* (*Sum of Perfection*), written about 1280, which fuses these two traditions, European craft and technological knowledge with Arabic alchemy.
  1. The author took the name of the Arabic Jābir, although he was probably Paul of Taranto, an Italian Franciscan lecturer.
  2. The text deals with both theory and practice and contains a detailed summary of the state of knowledge of metals and minerals and how to work with them.
  3. This includes the theory on the transmutation of base metals into gold.
  4. It adopts the Mercury-Sulphur theory of Jābir, but adds a deeper level of explanation based on a particulate matter theory. There are "smallest parts" of various substances, known as "*minima naturalia*"; they are not indivisible like classical Democritean atoms.
  5. Geber uses this particulate theory to explain the properties of the metals; for example, dense metals, such as gold, are made up of smaller particles that can pack more tightly than large particles (like those in tin). Gold's small particle size also means that the pores between particles are smaller; therefore, gold (unlike tin) resists the action of fire and acids trying to break it apart.
- **D.** Many other alchemical texts appeared in the thirteenth century.
  1. Roger Bacon and St. Albert the Great both wrote on alchemy to some extent. Bacon was more insistent on the power of alchemy, however.
  2. Bacon actually argued that alchemically produced gold is *better* than natural gold.
  3. This is a powerful statement about the power of human artifice (that is, technology), which flies in the face of the limitations of Aristotelian thought placed on the power of artifice.

II. In the fourteenth century, alchemical texts became more secretive and used imagery and parables rather than clear language.

- **A.** Geber's *Summa* is written almost entirely in clear and straightforward Scholastic style; it picks up on some of the "initiatic style" of Arabic texts. This would contribute to the development of secrecy in almost all subsequent European alchemy.
  1. The reasons for this move toward secrecy are complex and include the legal strictures placed on alchemical practices, as well as the status of knowledge as privileged.
  2. Some texts linked chemical operations to theological truths.
  3. Alchemical imagery eventually became extravagant and difficult to understand.

B. Alchemy was also extended into medicine in the fourteenth century.
  1. John of Rupescissa, a native of southern France, promoted the production of "quintessences" of various materials, including metals and minerals, using newly discovered substances.
  2. John was a radical Franciscan; he argued that alchemy would provide the wealth and health necessary for Christians to withstand the anti-Christ.

III. Astrology and astronomy were closely related throughout the Middle Ages in both Latin and Arabic cultures.

A. For the purposes of these lectures, we can define *astronomy* as the study of the structure of the cosmos and its motions, and *astrology* as the study of the effects of the cosmos on the earth. Both were generally pursued by the same people, who did not necessarily see the distinction between them that we do.
  1. Recall that Ptolemy's "astronomical" *Almagest* was intended to be read alongside his "astrological" *Tetrabiblos*.
  2. In general, more people were interested in getting planetary positions right than in rationalizing how they got there.
  3. In order to calculate past and future planetary positions, tables were produced. Such tables ultimately date back to Babylon but were highly developed in the Islamic world and, later, in Europe.
  4. The "Alphonsine Tables," compiled about 1275 and dedicated to King Alfonso X ("El Sabio") of Castile, were the most important tables in the Latin world until the seventeenth century.

B. All of this interest in positional astronomy was geared toward astrological purposes.

C. Astrology contains several different subsets or pursuits.
  1. The most commonly known today deals with predicting the fates of individuals. This form of astrology was consistently condemned by the church because it potentially infringes on human free will.
  2. A more acceptable branch of astrology merely states that the planets have influence on the earth (after all, clearly, the moon causes the tides and the sun causes the seasons) and endeavors to understand and take advantage of these influences.
  3. The means by which the planets influence the earth was explained in many different ways; for example, Ptolemy said that the planets extend their own qualities to the earth: Mars promotes hot and dry qualities, for instance.
  4. This influx of qualities might potentially upset the balance of health in a person, or a combination of bad influences could cause plague.

D. Birth horoscopy was very important, because a child at birth is "imprinted" with a certain constitution by prevailing celestial influences.
  1. This constitution should be known because it may make the person susceptible to certain diseases, passions, or personality traits (good or ill).
  2. Thus, the medical use of astrology was very important (down until the seventeenth century).
  3. "The stars incline, but do not compel." We can compare the medieval view of astrological influence to the modern debates over "nature versus nurture" in forming behaviors. Curiously, the *one thing* medievals had to preserve—free will—is largely neglected by moderns involved in the nature/nurture debate.

E. One might ask why astrology was not repudiated sooner.
  1. Pre-modern people lived in a world of vast uncertainty, subject constantly to the mortal perils of plague, war, famine, and so on. Astrology offered hope of some warning about such dangers.
  2. Moreover, Ptolemy had said that the system of influences was enormously complex; it was relatively easy to predict planetary positions but very difficult to predict accurately what the net result would be.

IV. Subjects like alchemy and astrology, which we might be tempted to call "pseudo-sciences," were serious topics of inquiry by learned scholars in the Middle Ages (and after) and were endowed with theoretical underpinnings and methodologies as developed as any of the "sciences."

Essential Reading:

David C. Lindberg, *The Beginnings of Western Science*, chapter 11 and pp. 287–290.

John North, *The History of Astronomy and Cosmology*, chapter 10, pp. 248-71 (Latin astrology).

Supplementary Reading:

Ptolemy, *Tetrabiblos*.

William R. Newman, "Technology and Alchemical Debate in the Middle Ages," *Isis* 80 (1989): 423–445.

Questions to Consider:

1. Think about the difficulty of proving or disproving statements about the actions of very complex systems. In this lecture, we considered astrology, which most people today reject; think of current topics or issues of contention (global warming?) that remain unsolved partly or predominantly because of the complexity of the systems involved. How can resolution ever be reached? How do you expect resolution was reached in the case of astrology?
2. Why do you suppose that the crucial issue of free will has largely dropped out of modern scientific discourse on behavior? What are the scientific, moral, and other consequences of this omission?

Lecture Twenty-Three

Medieval Physics and Earth Sciences

Scope: This lecture looks at medieval developments in astronomy and the physics of motion. The examples used will show how medieval questions could have surprising results, how medieval natural philosophers used and disagreed with Aristotle, and how the results of medieval speculation and calculation laid the foundations of the modern science of kinematics.

Outline

I. In Europe, astronomy was significantly altered by the influx of Arabic and Greek works during the translation movement.

- **A.** The system of medieval astronomy was basically Ptolemaic and Aristotelian.
  1. The first popularizing text was that of al-Farghani (written in the ninth century, translated by John of Seville in 1137), which gave the basics of the Ptolemaic system.
  2. This astronomy and cosmology was popularized in Sacrobosco's *Sphere*, a text written at Paris circa 1250; this work remained a standard textbook until the mid-seventeenth century.
- **B.** The Middle Ages also inherited the tension between Ptolemaic astronomy and Aristotelian cosmology.
  1. There was a strong tradition of anti-Ptolemaic thought in Spain, for example, with the scholars Ibn-Bajja (known to the Latins as Avempace), Ibn-Rushd (Averroës), and al-Bittruji (Alpetragius). They argued that Ptolemy's system of eccentrics and epicycles was *physically impossible*.
  2. A solution proposed by Ibn al-Haytham (Alhazen) was to make Aristotle's celestial spheres solid and thick enough to contain the Ptolemaic deferent and epicycle.
  3. Ibn al-Haytham's solution was picked up especially by Roger Bacon and several other Franciscans.
  4. Attempts were also made to calculate the thickness of the heavenly spheres, that is, the distances of the planets from the earth.

II. If the celestial spheres (which carry the planets around the earth) exist, what makes them move in regular motions?

- **A.** Aristotle himself was self-contradictory.
  1. *On the Heavens* says that the quintessence (of which the heavenly spheres are composed) has a natural tendency to circular motion, just as earth has a natural motion downwards.
  2. *Physics* and *Metaphysics*, however, talk of "unmoved movers"—intelligences that are external to the orbs but cause them to move without being affected by them.
  3. Aristotle leaves us with the rather unsatisfying claim that the unmoved mover draws the orbs onward by "being loved by them." (Love makes the world go round!)
- **B.** Medieval scholars didn't think much of Aristotle's obscure claim; there was widespread disagreement about the cause of celestial motion.
  1. For some, God becomes the efficient and final cause of motion, a single unmoved mover.
  2. Such explanations tended to violate the principle of naturalism, however. God is, *of course*, the *ultimate* cause of the motion, but what is the *proximate* cause?
  3. Some cosmologists suggested the action of angels delegated by God to act like Aristotle's unmoved mover.
  4. Others, including the Englishman Robert Kilwardby (thirteenth century) stated that, at creation, God had imparted a natural motion to the spheres.
  5. Yet others, such as Jean Buridan, a Parisian master (c. 1300–c. 1358), argued that God had only to get the spheres going and they would keep moving eternally by virtue of their "impetus." With no resistance to their motion, they should never slow down.
  6. Nicole Oresme (c. 1325–1382) wrote that the celestial orbs were like a great clock—once it was prepared, it would run on its own.

III. Important developments in the history of physics—specifically, the dynamics of moving bodies—occurred in the fourteenth century.

- **A.** Interestingly, these developments in dynamics originated in a purely theological question.
  1. The twelfth-century theologian Peter Lombard asked a question based on Gospel verse about how grace or charity could be increased in a person.
  2. Peter's answer was that grace and charity—gifts of the Holy Spirit—were absolute; thus, an apparent increase in charity arose from increased participation in absolute charity. This solution has Platonic and Aristotelian backgrounds.
  3. An alternative answer was also proposed (probably by the Franciscan theologian John Duns Scotus, c. 1265–1308), namely, that charity could be added incrementally. Every quality was, thus, augmentable or diminishable; this notion was called the "intension and remission of qualities."
  4. Shortly thereafter, this notion was applied not only to Aristotelian "motions of quality" (e.g., an apple becoming increasingly red) but also to "motion of place" (e.g., an object moving from A to B or moving increasingly fast).
  5. A group known as the "Oxford Calculators" began to study local motion around 1330 and defined, for the first time, the notions of uniform velocity and uniform acceleration and the concept (important in modern dynamics) of "instantaneous velocity."
- **B.** These "Calculators" also devised the "mean speed theorem," which was proven geometrically by Nicole Oresme around 1350. Oresme's proof was well known thereafter and reappears as the fundamental axiom of the "new science" of motion in Galileo's *Two New Sciences* in 1638.
- **C.** This example shows how far a succession of ideas can move from its original source (a twelfth-century theological query eventually results in a fundamental axiom of kinematics) and, thus, how wide a view is necessary to understand the "history of science."

IV. The motion of the earth itself was raised again in the fourteenth century.

- **A.** The Parisian masters Jean Buridan and Nicole Oresme considered the possibility of the daily rotation of the earth.
  1. This issue was apparently a topic of discussion even in the twelfth century; William of Conches remarks on a "crazed philosopher" who maintained it.
  2. Buridan noted that we can observe only *relative motion*, so we cannot tell if it is we who are moving or the stars.
  3. Buridan eventually rejected a rotating earth on the basis of the fact that an arrow shot straight upward falls back to its place of origin, rather than being left behind by an earth in motion.
  4. Oresme argued that the arrow experiment does not prove anything, saying that the arrow also has impressed horizontal force, which would keep it moving along with the earth.
  5. Oresme noted that a moving earth would be more economical, because the motion of one body in twenty-four hours would dispense with the necessity of the rest of the cosmos moving around the earth once a day.
  6. In the end, however, Oresme rejected the possibility of diurnal motion. There is no way to decide between the two possibilities, so he goes with the commonsense answer.
- **B.** It is important to note that Oresme's motivation was to show that there are some cases in which the exercise of reason fails to give us an answer; therefore, reason should not be used to impugn articles of faith. (Of course, he's used argument to argue for the insufficiency of argument!)

Essential Reading:

Edward Grant, *The Foundations of Modern Science in the Middle Ages*, chapters 6 and 8.

David C. Lindberg, *The Beginnings of Western Science*, pp. 290–315.

Supplementary Reading:

John North, *The History of Astronomy and Cosmology*, chapter 9, "Western Islam and Christian Spain."

Questions to Consider:

1. Oresme noted that a rotating earth was a "more economical" way of explaining celestial diurnal motion, and indeed, sometimes "economy" is used as a way of deciding between rival explanations. (This principle is often invoked under the title of "Ockham's razor"—named after the fourteenth-century Franciscan theologian William of Ockham.) But how reliable a tool is this in evaluating scientific theories? Why should the world be minimalist rather than Baroque? Why would people tend to prefer (sometimes almost automatically) the "more streamlined" or more "economical"? What does that say about us, and how does that affect our pursuit of science?
2. Today, funding agencies bestow patronage of various sorts on projects conducted at universities, research institutions, and corporations. One criterion of evaluation for proposals is the expected result—that is to say, the successful acquisition of funding is closely tied to the projected outcome. Keeping in mind how Peter Lombard's theological questions and the subsequent commentaries are related to principles of kinematics, how wise is it to tie patronage to specific predicted products? How else might the scientific enterprise be maintained and funded?

Lecture Twenty-Four

The Middle Ages and the Renaissance

Scope: Trying to fit labels to historical periods is always tricky. Nonetheless, many thinkers from the fifteenth to the seventeenth centuries saw themselves as initiating a new period of civilization, including in scientific areas. The Italian Renaissance often claimed to be a clean break from the "Middle Ages"—a time so successfully demonized that some rhetorical extravagances about it are still heard today, 500 years later. This lecture looks at features that characterize the Italian Renaissance (and the subsequent Scientific Revolution) and what they meant in terms of worldview and scientific activity.

Outline

I. According to customary periodization, the Middle Ages was followed by the (Italian) Renaissance (roughly 1450–1550), then by the Scientific Revolution (roughly 1550–1700). But periodizations are often problematic.

- **A.** The term *Middle Ages* was derisive (like *Gothic* for architecture), devised by Italian Renaissance writers consciously to divide themselves from their immediate predecessors (or contemporaries).
- **B.** On the one hand, many of the changes often associated with the (Italian) Renaissance can be seen as continuations of changes begun in the twelfth-century Renaissance.
- **C.** The concept of the Scientific Revolution has been under heavy debate for the past twenty-five years—how revolutionary was this period?

II. The Middle Ages bequeathed several important developments to succeeding periods.

- **A.** Even if some early modern writers (and their followers) were loath to admit it, the amassed body of scientific, medical, and technological knowledge was far greater (with some exceptions) at the end of the Middle Ages than at the end of the classical period.
- **B.** An institutional, and largely independent, home for scholarship and natural philosophical inquiry, the university, had been created.
  - **1.** The university had also devised an orderly method of investigating questions (Scholasticism).
  - **2.** The university had fostered a disputative, inquisitive culture.
- **C.** Some significant questions about the natural world had been posed, but not answered conclusively (for example, the means and manner of the motion of the heavenly spheres).

III. Nonetheless, the period 1450–1550 witnessed several significant events or developments that changed the medieval world in various ways. We need to keep four developments in particular (humanism, printing, voyages of discovery, and Protestantism) in mind as we survey the history of science down to the seventeenth century.

IV. The rise of humanism deeply affected the world of learning in various—and somewhat ambiguous—ways.

- **A.** On the one hand, it redirected tastes and interests to new subjects and texts.
  - **1.** The humanist movement included love of antiquity (classical culture), a love of texts and elegant literary style, and greater interest in the "humanities" (history, literature, and so on).
  - **2.** Humanist views included strong critiques of late medieval notions. Humanists also preferred the ideal of an active civic life over the medieval ideal of contemplative scholarship.
  - **3.** Humanists assailed the traditional authority of the universities, claiming that they did not understand the ancients, wrote in bad Latin, and had (along with the Arabs) corrupted the classical heritage by introducing "barbarisms."
- **B.** The humanist love of antiquity was often expressed in a fervor for finding and editing ancient texts.
  - **1.** Many new texts, particularly Greek ones, were sought out and studied. New works of Plato, Ptolemy (his *Geography*), Lucretius, and several Hellenistic mathematicians and natural philosophers were rediscovered.
  - **2.** It was once claimed that the fall of Constantinople (1458) brought new texts and Greek scholars to the Latin West, sparking the Renaissance, but it is now clear that the revival of interest in Greek sources was already well established before that time.

3. The humanist love of the "purity" of ancient sources naturally led to a search for the oldest possible documents. Antiquity became a stamp of value and reliability. Older classical authors could "trump" later classical authors.
4. One group of such documents was the *corpus Hermeticum*, published in a Latin translation from the Greek in 1471 by Marsilio Ficino. These were supposedly authored by the Egyptian Hermes Trismegestus (believed to be a contemporary of Moses) but are actually much later.

C. Together with increasing leisure and wealth, humanism led to an increase of scholarship outside the universities and schools.

D. But humanism could be retrogressive, because (in its strong form) it tended to repudiate progressive intellectual developments made since antiquity as barbarous intrusions.

V. The invention of the printing press (c. 1450) created a print culture as never before.

A. More texts could be distributed to more people more quickly and cheaply.

B. The impact of the printing press would have been minor if there had not been a larger literate and more leisured populace to embrace and exploit it.

C. Humanism fed into a renewed interest in texts and reading.

D. Yet books remained largely luxury items due to their high price throughout the fifteenth and sixteenth centuries.

VI. Increased trade and improvements in navigation allowed for greater contacts with Asia and other cultures and, finally, for the discovery of the New World (1492) and its subsequent exploration.

A. Lands, peoples, plants, and animals were discovered that had no precedents in the classical/medieval tradition or that conflicted directly with traditional geographical knowledge.

1. The influx of new ideas and new scientific knowledge continued unabated to the eighteenth century and even beyond.
2. These voyages of discovery spurred innovations in technology, such as new methods for determining latitude and longitude, better gunnery for defense, and new mining technology for exploiting the New World.

B. Science and technology were needed to get to the new lands more quickly and reliably and for the exploitation of what was found there.

C. Changes in map-making encapsulated new views of the world.

1. The most common type of medieval map is the so-called T-O map, which shows the three continents (Europe, Asia, and Africa) separated by T-shaped waters (Mediterranean, Nile, and Don).
2. Such maps are schematic; they show relationships and symbols but not how literally to get from point A to point B.
3. Moderns expect maps to be grid-like and be literally representative, like a satellite photo; medievals did not share this expectation.
4. Some modern maps are similar: Subway and train-line maps are often drawn only to show stops along a straight line without reference to geographical "reality."
5. The lesson is extendable to much of medieval natural philosophy: If we look for what moderns expect, medieval "science" can seem disappointing. But medievals did not do their studies for our sakes; they had their own questions and motives.
6. Starting around 1300, portolan maps began to appear; these gave more literally true outlines of coasts.
7. In Europe, the portolan maps grew hand-in-hand with voyages of trade and exploration—voyages that would transform European culture through the fifteenth and sixteenth centuries and beyond.

VII. The Protestant Reformation (1518) fractured Western Christianity, altering the institutional framework in which natural philosophy had been previously pursued.

A. Theological disputation and emphasis shifted to either defining new Protestant doctrines or mounting responses to and refutations of them.

B. Protestantism affected the history of science in diverse ways, and its overall impact is still the subject of debate, especially after Protestantism itself began to splinter into sects.

C. The centrality of theological preoccupations to natural philosophy, so evident in the medieval world, largely persists through the Scientific Revolution, even if the manners of its expression change markedly.

D. In sum, the period from 1450 to 1700 saw the introduction of many new ideas and numerous challenges to older ideas. Intellectually, the period is one of *both* change and continuity. Rather than making blanket statements, it is better to watch for individual signs of change and continuity as we progress through the last twelve lectures.

Essential Reading:

Edward Grant, *The Foundations of Modern Science in the Middle Ages*, chapter 8.

David C. Lindberg, *The Beginnings of Western Science*, chapter 14.

Allen G. Debus, *Man and Nature in the Renaissance*, chapter 1.

Supplementary Reading:

Pamela O. Long, "Humanism and Science" in *Renaissance Humanism: Foundations, Forms, and Legacy*.

Frances and Joseph Gies, *Cathedral, Forge, and Waterwheel: Technology and Invention in the Middle Ages*, chapter 7.

Questions to Consider:

1. To consider the impact of the discovery of the New World, imagine that we were able to travel to another planet, and we find it full of life. How would this affect science, technology, and culture?
2. Compare the invention of the printing press to the creation of the Internet. Consider the positive and negative impacts on science and society. Who benefits (who does not) and in what ways? What changes and what remains the same?

Biographical Notes

Note: The dates of birth and death are unknown for many characters from antiquity. In these cases, it is common to place them chronologically with a *floruit* (abbreviated fl., literally, "he, she, or it flourished" in Latin) which expresses the date or dates when they were known to be alive.

**Abū Ma`shar**, known as **Albumasar** among the Latins (787–886): Born in Khorasan (now in Afghanistan), Abū Ma`shar was a leading astrologer of the Islamic Empire. His *Introduction to the Science of Astrology* was influential in the Latin West and studied alongside Ptolemy's *Tetrabiblos*.

Adelard of Bath (fl. 1116–1142): An early translator of Arabic texts into Latin, Adelard was also author of several logical and natural philosophical works. He traveled widely and as far as Palestine in search of texts.

Agricola, Georgius (1494–1555): Born in Saxony as Georg Bauer, Agricola studied in Leipzig, Bologna, Padua, and Venice and worked at the humanist Aldine Press. In 1527, he returned to Saxony and began practicing medicine and studying mineralogy and mining. He also served as *burgomeister* of Chemnitz (1546).

Agrippa von Nettesheim, Henrich Cornelius (1486–1535): Agrippa led a colorful life. He was born in Köln, spent time in Italy (1512–1518) and at the universities of Dôle and Pavia, practiced medicine in Geneva and the Netherlands and as physician to the queen-mother of France, and worked on military matters in Spain. His writings on natural magic are the best known of his many works, even though late in life (1531), he repudiated magic.

Al-Battānī, in full, **Abu `Abdullah Muhammad ibn Jābir ibn Sinān al-Battānī al-Harrānī aş-Şabī'**; known as **Albategnius** among the Latins (c. 858–929): Born into a Sabian family of Harran but a convert to Islam, al-Battānī was a prominent astronomer and mathematician, whose works were among the most well known and esteemed Arabic works in the Latin West down to the sixteenth century. His astronomical work included both careful observations and innovative calculation methods.

St. Albert the Great (c. 1193–1280): Called the "Universal Doctor." A Bavarian by birth, Albert studied at Padua, where he became a Dominican in 1223 and taught at numerous German Dominican schools, then at Paris (1245–1248); he was teacher of St. Thomas Aquinas. Albert was Provincial of his Order (1253–1256) and made bishop of Regensburg in 1260; the latter post he resigned in 1262 to return to the life of a scholar. Besides his massive summaries and commentaries on Aristotle, Albert wrote on alchemy, astrology, zoology, botany, and other topics and made numerous original observations in many fields. He was called "the wonder and miracle of our age" by a contemporary, and after his canonization in 1931, he was declared patron saint of natural scientists in 1941.

Alcuin of York (735–804): An Englishman by birth, Alcuin was invited to the court of Charlemagne at Aachen in 781, where he acted as a teacher and undertook educational and ecclesiastical reforms. Upon his retirement in 796, he was made abbot of St. Martin's at Tours, where he revitalized that Benedictine abbey and developed the Carolingian script to facilitate copying and reading.

Alexander the Great (356–323 B.C.): Son of King Philip II of Macedon and tutee of Aristotle, Alexander began his life of military conquest at an early age, conquering all of Greece, the Persian Empire, Egypt, and Asia as far as India and current Afghanistan. His unification (brief) of this vast area spread Greek language and culture far and wide and marks the beginning of the Hellenistic period.

Al-Khwārizmī, Abū `Abdullāh Muhammad ibn Mūsā (fl. 825): Born in Khwarizm, a village south of the Aral Sea in central Asia. Al-Khwārizmī's mathematical contributions are enormous. He introduced Indian decimal place notation ("Arabic numerals") to the Arab world, and his text in Latin translation (now lost in the original Arabic) introduced that number system to the Latin West. He developed algebraic and trigonometric methods and is immortalized in the word *algorithm*—a corruption of his name.

Al-Kindī, Ya`qūb ibn Is-hāq as-Şabah (died 870): Early Islamic philosopher, "the Philosopher of the Arabs," Al-Kindī flourished in Baghdad under several caliphs and wrote more than 270 works, including texts on Platonism, astrology, medicine, optics, and arithmetic.

**Al-Ma`mūn, Abū al-`Abbas `Abdullāh** (786–833): The son of Harūn ar-Rashīd, al-Ma`mūn became the seventh `Abbasid caliph in 813 after defeating his half-brother al-Amīn. He attempted to end Islamic sectarian rivalry and was notably well inclined toward Greek learning and, as such, was an important patron and promoter of the translation movement.

**Al-Mansūr, Abū Ja`far** (709–14 to 775): Born in Jordan, upon the death of his brother in 754, al-Mansūr became the second `Abbasid caliph and founded Baghdad as the new seat of the caliphate.

**Al-Mu`āwiyah (ibn Abi Sufyan)** (c. 602–680): Born a pagan at Mecca, he converted to Islam, was made governor of Syria in 640, and fought the fourth caliph `Alī (son-in-law of the Prophet), after whose assassination in 661, he assumed the caliphate, initiating the dynasty of the Umayyads, and set up the Islamic capital in Damascus.

Anaxagoras (c. 500–c. 425 B.C.): A Presocratic philosopher, he emphasized the guiding action of *nous*, or mind, in the origin of the world.

Anaximander (fl. 570 B.C.): A younger associate of Thales in Miletus, he studied astronomy and reportedly introduced the *gnōmōn* to Greece.

Anaximenes (fl. 550 B.C.): Last notable member of the Milesian school, followers of Thales, he chose air as the basis of all material objects.

Archimedes (c. 287–212 B.C.): Celebrated mathematician and engineer of antiquity, he studied at Alexandria but lived most of his life in his native city of Syracuse in Sicily. Numerous tales tell of his legendary feats of ingenuity, especially in defending Syracuse from the Romans. His works were revived and highly esteemed in the Italian Renaissance and were a particular inspiration to Renaissance engineers and to Galileo.

Aristarchus of Samos (c. 310–230 B.C.): A Hellenistic astronomer and mathematician about whom little is known save that he reportedly proposed a heliocentric system and made calculations of the relative distance to the sun and moon.

Aristotle (384–322 B.C.): Enormously influential Greek thinker, native of Stagira, student of Plato, and founder of the Lyceum at Athens. He wrote on everything from logic and poetics to cosmology, metaphysics, and natural history and was called simply "The Philosopher" in the High Middle Ages.

Ar-Rāzī, Abū Bakr Muhammad ibn Zakariyya (c. 865–925): Born at Rayy in Persia, he wrote on philosophy, medicine, and alchemy. He was chief physician at the hospital at Rayy and, later, at Baghdad. His surveys of medicine were well regarded in both the Arabic and Latin worlds, and his alchemical treatises became models for the genre in Europe.

St. Augustine of Hippo (354–430): Probably the most influential and important Christian theologian of all time. Born at Tagaste in North Africa (currently in Tunisia) of a Christian mother and pagan father, Augustine studied philosophy and rhetoric at Carthage; went to Rome and Milan, where he was baptized; and returned to North Africa, where he became bishop of Hippo and founded a monastery. A prolific and highly learned writer whose voluminous works were well known and esteemed throughout the Middle Ages, he effected a powerful synthesis of Christianity and Greek philosophical thought, oversaw important church councils, and laid the foundations for the accepted methods of biblical interpretation.

Bacon, Francis, Lord Verulam, Viscount St. Albans (1561–1626): Bacon studied at Cambridge and Paris (1576) and continued his legal education at Gray's Inn. He became a barrister in 1582, an M.P. in 1584, and although he was befriended by Lord Essex in the early 1590s, he denounced Essex as a traitor to Queen Elizabeth I in 1601. He became Lord Chancellor in 1618 and fell from power in 1621 amid charges of impropriety.

Bacon, Roger (c. 1219–1292): Called the "Marvellous Doctor." Despite his notoriety, Bacon's biographical details are cloudy. Born in England, Bacon studied at Oxford and Paris and began lecturing at Paris on Aristotle's *libri naturales* around 1237. He studied further at Oxford, became a Franciscan circa 1257, and at some point, began to prefer mathematical Neoplatonic approaches to nature over the logical methods of Aristotle. His most important natural philosophical works were written from 1266–1268 for Pope Clement IV. He also spent time in prison under mysterious circumstances.

Bellarmino, St. Roberto (1542–1621): A native of Montepulciano in Tuscany, Bellarmino distinguished himself as the preeminent theologian of the Counter-Reformation. He studied at the Jesuit college of his hometown and entered the Society in 1560. He then studied at Rome, Padua (1567–1569), and Louvain (from 1569); returned to Italy in 1576; and became a member of the Collegio Romano. He was made cardinal in 1599 and bishop of Capua in 1602; at the conclave of 1605, he was advanced as a candidate for pope, but he refused. He dealt with Galileo during the first phase of his inquiry (1612–1616). He gave away all his goods to the poor and died a pauper. His canonization occurred in the early twentieth century.

St. Benedict of Norcia (c. 480–c. 547): Founder of the Benedictine Order (at Monte Cassino in Italy), father of Western monasticism.

Biringuccio, Vannoccio (1480–c. 1540): Biringuccio was born in Siena, studied metallurgical practices in Italy and Germany, and was employed by several Italian rulers at Siena, Ferrara, Florence, and Rome. His only written work is the *Pirotechnia*, published posthumously.

Boethius, Anicius Manlius Severinus (c. 480–524): Government official under Theodoric the Ostrogoth (who executed him), philosopher and scholar, sometimes called the "last bilingual [Greek and Latin] scholar of antiquity," Boethius translated some of Aristotle's logical works and transmitted digests of classical learning to the Middle Ages.

Boyle, Robert (1627–1691): Seventh son and fourteenth child of the wealthy Richard, Great Earl of Cork. Boyle was schooled at Eton and tutored during a Continental Grand Tour. His first career was as a moralist, but around 1650, his interests turned to natural philosophy. He relocated to Oxford in the mid-1650s, where he participated in an "Experimental Club." There, he set the foundations of his scientific career. He later moved to London and took up residence with his sister, with whom he lived the rest of his life. He helped found the Royal Society in 1660, published a book (either on science or theology) nearly every year after 1659, and became the most celebrated natural philosopher in Britain. Unlike Newton, he was of a pleasant disposition and highly charitable and maintained correspondence with hundreds of savants across Europe. He was offered the Presidency of the Royal Society, the knighthood, and ordination as a bishop, but he refused. His legacy funds an annual lecture on Christianity and supported an "Indian college" at William and Mary.

Brahe, Tycho (1546–1601): Tycho, a member of the Danish nobility, studied law at the universities of Copenhagen (1559–1562) and Leipzig (1562–1565) but spent his spare hours in the study of astronomy. He returned to Denmark in 1570 and received the grant of the isle of Hven from King Frederick II, where he built his observatory-castle Uraniborg. He fell out of favor in the late 1590s upon the accession of a new king but went to Prague in 1600 at the invitation of Holy Roman Emperor Rudolf II to make prognostications regarding war and plague; there, he collaborated with Johannes Kepler and died the following year.

Buridan, Jean (c. 1300–c. 1358): Probably a native of Bethune in France, rector of the University of Paris in 1328, Buridan was a prolific commentator on Aristotle, particularly on the *libri naturales*.

Cassini, Gian Domenico (Jean-Dominique) (1625–1712): A native of Liguria in northern Italy, Cassini studied at the Jesuit college in Genoa and became professor of astronomy at Bologna in 1651. At Bologna, he constructed a meridian line in the church of San Petronio in order to improve solar theory. He observed eclipses of Jupiter's satellites and published tables of their times in 1668. In 1669, he was invited to Paris as a member of the Académie Royale des Sciences (at a huge salary) and assumed the leadership of the Observatoire, being succeeded in that post by his son, grandson, and great-grandson, who died in 1845.

Cassiodorus, Flavius Magnus Aurelius (485–580): Roman senator and scholar; founded a monastery at his villa in southern Italy (the Vivarium) in order to preserve classical culture and texts. Wrote historical, pedagogical, theological, and other works.

St. Clement of Alexandria (c. 150–211/15): Born at Athens, converted to Christianity, became leader of the Christian school at Alexandria, wrote numerous catechetical and theological works, eventually forced to flee to Jerusalem during the persecutions of Christians in 201–202, where lived out the rest of his life. He was deeply influenced by Neoplatonism, which he found consonant with and useful to Christianity; he strongly promoted the study of pagan philosophy by Christians.

Copernicus, Nicolaus (1473–1543): Born in Torun, Poland, Nicolaus was orphaned young and raised by his uncle, the bishop of Warmia. He studied at Krakow (1491–1495) first, then canon and civil law and medicine in Italy. He received the post of canon at Frauenburg from his uncle in 1497, where he took up residence (for the rest of his life) in 1510. He is best known for advancing the heliocentric theory, presented in his book *De revolutionibus* (1543).

Dee, John (1527–1608): Celebrated as a mathematician, astrologer, and magician, Dee is one of the most fascinating and enigmatic characters of the late sixteenth century. He studied at Cambridge and Louvain, traveled through Europe, and returned to England in 1551. He had good relations with Queen Elizabeth but eventually took up residence in Prague, connected to the court of Emperor Rudolf II. There, with the rather shady skryer Edward Kelly, he conducted the angelic conversations. He returned to England shortly before his death.

Democritus (fl. 420 B.C.): Follower of Leucippus, key promoter and developer of atomism, native of Abdera.

Descartes, René (1596–1650): Born at La Haye, Descartes was educated at the Jesuit college of La Flèche (1606–1614), then studied law at Poitiers (1614–1615). He left France for the Netherlands, where he conducted further personal studies, wrote and published profusely, and corresponded widely. His natural philosophical system attracted numerous adherents for a century, and his mathematical innovations (for example, "Cartesian coordinates") continue to be fundamental.

Empedocles of Agrigentum (fl. 450 B.C.): Presocratic philosopher who suggested the existence of four "roots" (or elements)—fire, air, water, and earth—out of which everything is produced and into which everything is resolved by the random actions of the opposing forces of Love and Strife.

Epicurus (born 341): Philosopher who used Democritean atomism as a basis of his moral philosophy, which dismissed fears of the gods, post-mortem punishments, and fate by arguing that the soul was mortal and that all occurrences good or ill were the result of the random motions of atoms.

Eratosthenes (c. 276–195 B.C.): Native of Cyrene and head of the Library at Alexandria, he is best known for his measurement of the size of the earth.

Euclid (fl. 300 B.C.): The most well known mathematician of antiquity. Euclid was active at Alexandria, and his *Elements* had remained a basic text for geometry ever since.

Eudoxus of Cnidus (c. 390–c. 337 B.C.): A student of Plato at the Academy and the first (known) to have taken up his challenge to try to explain observed planetary motions by means of a combination of uniform circular motions. His cosmological scheme consisted of a series of nested spheres carrying the planets, sun, and moon centered on the stationary earth.

Galen (129–c. 199): Galen was born in the Greek city of Pergamon, where he also studied medicine at the school affiliated with the shrine of Asclepius and sampled the various Greek philosophical schools current in his day. In 157, he became physician to the gladiators at Pergamon, then in 161, traveled to Rome to the court of Emperor Marcus Aurelius, and afterward (168–169), became physician to his son, the Emperor Commodius. Galen's medical works and theories became authoritative and endured as such to the Renaissance.

Galilei, Galileo (1564–1642). Born the son of Vincenzo Galilei, a noted composer and music theorist, Galileo began his education at the University of Pisa in 1580 but left without a degree in 1585. After work on Archimedean hydrostatics and the vibration of strings, he returned to Pisa in the chair of mathematics in 1589 and moved to Padua in 1592. After his celestial discoveries of 1609, Cosimo de' Medici gave him a sinecure chair at Pisa and a position as philosopher and mathematician in his Florentine court. In 1615, Galileo was questioned by the Inquisition and, although found not guilty of the original (serious) charges, was told not to teach Copernicanism as literally true. After a series of complicated events, Galileo was questioned again in 1633 and shown to have transgressed the ruling of 1616; he recanted the notion of terrestrial motion and remained under house arrest at his villa in Florence the rest of his life, during which time he wrote arguably his most important book, *Two New Sciences*.

Gassendi, Pierre (1592–1655): Gassendi was born in Provence, entered the priesthood, studied at Aix-en-Provence, then earned a doctorate in theology at Avignon in 1614. In 1634, he became provost of the cathedral of Digne and was appointed professor of mathematics at the Collège Royal in 1645. His massive natural philosophical work—aimed at replacing Aristotelianism with a revived atomic philosophy—the *Syntagma philosophica* was published posthumously in 1658.

Geber (13th century): The pseudonym (based on the Arabic Jābir) used by a Latin writer, probably the Franciscan lecturer Paul of Taranto, for his important alchemical treatise *Summa perfectionis* (c. 1280). "Geber" remained an alchemical authority down to the early eighteenth century.

Gerard of Cremona (c. 1114–1187). This most prolific of the translators of Arabic works into Latin was born in Cremona, Italy, and died in Toledo, Spain, after having translated more than seventy books.

Gilbert, William (1544–1603): Gilbert was born in Essex, attended Cambridge, then traveled widely on the Continent, possibly receiving a medical degree there. He began practicing medicine in London, was admitted to the College of Physicians around 1576, and became physician to Queen Elizabeth I in 1601, a post continued by James I, but cut short by Gilbert's death from the plague in 1603.

Grosseteste, Robert (c. 1168–1253): Grosseteste ("Big Head") was a native of Suffolk and studied at Paris and Oxford, becoming doctor of theology, an influential lecturer to the Franciscans at Oxford, and bishop of Lincoln in 1235. He wrote extensively on light and optics, using a strongly Neoplatonized Aristotelianism. His study of light, reflection, refraction, and optical phenomena was simultaneously both natural philosophical and theological. He exerted much influence on Roger Bacon and on the practice of natural philosophy in the High Middle Ages.

Halley, Edmond (1656–1742): Halley was born in London and attended Oxford starting in 1673. He voyaged to St. Helena to study the stars of the Southern Hemisphere. He was elected Fellow of the Royal Society in 1678, became Savilian Professor of geometry in 1704, and Astronomer Royal in 1721. He is best known for his work on comets, notably predicting the return of the great Comet of 1680 in 1756, a comet that ever since has borne his name.

**Harūn ar-Rashīd, ibn Muhammed al-Mahdī ibn al-Mansūr al-`Abbasi** (766–809): Born in Persia, son of al-Mahdi, he became the fifth `Abbasid caliph in 786 and ruled over a flourishing Islamic empire; the Baghdad of his reign is that portrayed in *A Thousand and One Nights*. He was a patron of the arts and learning, including the translation movement.

Heraclides of Pontus (c. 390–after 339 B.C.): A student of Plato's Academy about whom very little is known, except that he proposed the diurnal rotation of the earth as an explanation of the daily movements of the heavens.

Heraclitus of Ephesus (fl. 500 B.C.): Nicknamed "the dark" both on account of his obscurity and his occasionally gloomy utterances, Heraclitus was one of the most original of the Presocratic philosophers; he emphasized the constant change visible in the natural world, as well as its underlying stability.

Hippocrates (c. 460–c. 377 B.C.): Greek physician and medical writer, often considered the father of ancient medicine. The writings attributed to him are considerable and influential, although some are certainly compositions of his students at Cos.

Hooke, Robert (1635–1703): Hooke was involved in an astonishingly broad range of activities. An accomplished mechanic, in the late 1650s, he worked with Robert Boyle on the construction of an air pump and became demonstrator to the Royal Society in 1662 and a Fellow in 1663. He built telescopes; made astronomical discoveries (such as Jupiter's rotation and Great Red Spot); published an important study of microscopy; was a chief surveyor of London after the Great Fire of 1666; produced theories of color, light, and gravity; and designed improved clocks.

Hugh of St. Victor (died 1141): Hugh was either Flemish or Saxon by birth and, from 1120, was the master of the school at the Abbey of St. Victor in Paris. He wrote on philosophy, pedagogy, geometry, theology, and biblical exegesis.

Hunayn ibn Is-hāq, Abū Za'id, al-Ibādī; known as **Johannitius** to the Latins (808–873): A Nestorian Christian born in what is now Iraq and active in Baghdad, he is known for his numerous translations of more than 100 scientific, mathematical, and medical texts from Greek to Arabic.

Huygens, Christiaan (1629–1695): Huygens was born into a wealthy family, the son of an esteemed diplomat and poet. He studied at Leiden and Breda and, at the invitation of Colbert, became a founding and leading member of the Académie Royale des Sciences in 1666. He is best known for his work in astronomy, mathematics, optics, and pendulum clocks.

Ibn al-Haytham, Abū `Alī al-Hasan, known as **Alhazen** among the Latins (c. 965–1039): Born in Basra, Iraq, and active much of his life in Egypt, where he was connected to al-Azhar mosque in Cairo, Alhazen wrote on astronomy, optics, and mathematics and examined such phenomena as the rainbow, atmospheric refraction, mirrors, and lenses. His optical theories were widely distributed in Latin Europe and influential to at least the seventeenth century. Several manuscripts in his handwriting survive.

Ibn-Rushd, Abū al-Walīd Muhammad ibn Ahmad ibn Muhammad, known as **Averroës** among the Latins (1126–1198): Born at Córdoba, Spain, under the Umayyad caliphate, Ibn-Rushd studied law and medicine and gained renown as a philosopher and physician. He wrote important commentaries on Aristotle and on Plato (hence, he is known among Christian theologians as "The Commentator") and argued that reason and philosophy were superior to faith. His influence was greater on Christian and Jewish thought than that of his fellow Muslims. Many of his views on God, the soul, and faith were heretical in Islam (as well as in Christianity!) and, as a result, he was exiled, returning to Morocco only shortly before his death.

Ibn-Sīnā, Abū `Alī al-Husayn ibn `Abdullāh, known as **Avicenna** to the Latins (980–1037): A Persian by birth, Ibn-Sīnā became one of the most significant Muslim philosophers and physicians and wrote numerous treatises. He was deeply influenced by Aristotle, whose works he prized, and Ibn-Sīnā's commentaries on Aristotle were, in turn, influential in the Latin West. His medical writings include the massive *Qanun*, perhaps the most widely known and respected Arabic medical treatise in the Latin West, where it was accorded equal status with the texts of Galen and Hippocrates.

St. Isidore of Seville (c. 560–636): Bishop of Seville, doctor of the church, theologian, encyclopedist. His *Etymologies*, which contained a pastiche of classical and early Christian learning, became one of the standard sources for a wide variety of subjects throughout the Middle Ages. In 2001, he was declared patron saint of the Internet.

Johannes of Sacrobosco (John of Holywood) (first half of 13th century): Author of the most widely read textbooks on elementary astronomy and mathematics of the Middle Ages and teacher at Paris. His books continued to have wide readership until the sixteenth century.

John of Rupescissa (Jehan of Roquetaillade) (died 1362): A native of southern France, John studied at Toulouse and became a Franciscan at Orleans. He pursued alchemy and medicine and was the first to prescribe alcohol extracts of metallic compounds as medicines. His attachment to the "Spiritual" branch of the Franciscans, his wild prophetic and apocalyptic writings, and his abusive criticism of church authorities led to his imprisonment in 1345 and again in 1356.

St. Justin Martyr (c. 100–c. 165): Born in Flavia Neapolis (modern Nablus, Palestine), St. Justin studied Greek philosophy in his youth, became a Christian circa 130, and began teaching at Rome after 135, where he was eventually denounced to the Roman authorities and martyred by decapitation. Several of his writings survive. He was key in joining Christianity with Greek philosophical thought.

Kepler, Johannes (1571–1630): Kepler was born in Weil-der-Stadt, Württenberg, to a poor but noble family. He began seminary at Adelberg in 1584, but his talents enabled him to go on to the University of Tübingen in 1588, where he studied with Michael Maestlin. He accepted the job of astronomy lecturer at Graz in 1594. In 1600, he went to work with Tycho Brahe, who had recently transferred to Rudolf II's court in Prague; when Tycho died in 1601, Kepler inherited his post as Imperial Mathematician. For twelve years, he lived at Linz and was invited to London by James I and to a chair at Bologna, but declined both. Kepler's life was fraught with problems from the outset: His parents became bankrupt, his wife and three children died young, his mother was tried as a witch, his salary was rarely paid, and he seemed always caught in sectarian crossfire.

Leonardo da Vinci (1452–1519): Leonardo first apprenticed with the sculptor Verrocchio in 1481, then went to Milan (1482–1499), where he worked in his many capacities as artist, engineer, and scholar. He returned to Florence in 1500, then went back to Milan in 1506, then to Rome, and finally, at the invitation of King Francis I, to France in 1516, where he spent the remainder of his life. A remarkable character, Leonardo became the archetype of the "Renaissance Man," known equally for his design of flying machines, his anatomical studies, and his *Mona Lisa* and *Last Supper*.

Leucippus (fl. 430 B.C.): Presocratic thinker, earliest known proposer of atomism.

Lucretius, full name Titus Lucretius Carus (first century B.C.): Roman popularizer, via his poem *On the Nature of Things* (*De rerum natura*), of the atomic theory and atheistic philosophy of the Greek Epicurus.

Newton, Sir Isaac (1642–1727): Son of a yeoman farmer, Newton studied at Cambridge from 1661 to 1665; became Lucasian Chair of Mathematics in 1669, Fellow of the Royal Society in 1671, Master of the Mint in 1696, and president of the Royal Society in 1703; and received the knighthood in 1705. His discoveries in calculus, optics, and celestial motion date from the 1660s. His famed *Principia* was published in 1687 at the urging of Edmond Halley and was followed by texts on optics, ancient chronology, and prophecy. By all accounts, Newton was a difficult, and occasionally erratic, man.

Oresme, Nicole (c. 1325–1382): A native of Normandy, Oresme entered the University of Paris in 1348, where he became doctor of theology. He later was tutor to Charles V and held several church offices, including bishop of Lisieux from 1377. He wrote significant treatises on theology, cosmology, astrology, and coinage and made French translations and commentaries on Aristotle.

Osiander, Andreas (1498–1552): An evangelical Lutheran minister who spread Protestantism to Nürnberg and became professor of theology in Königsberg in 1549, where he was embroiled in controversies because of his stubborn views and condemned by several Lutheran synods. He is infamous for having prefixed an unsigned note to Copernicus' 1543 *De revolutionibus* (when charged with completing its publication by Rheticus), which declared that its contents were models, contrary to the belief of Copernicus.

Paracelsus, Philippus Aureolus Theophrastus Bombastus von Hohenheim (1493–1541): Born at Einsiedeln in Switzerland, Paracelsus, it is claimed, studied at over half a dozen universities in Germany and Italy, but much of his biography is hearsay and legend. He was an army surgeon in Italy in 1521, and he lectured on medicine at Basel in 1527–1528. His erratic and volatile temperament meant that he was often forced to move about. Only a few of his writings were published during his life, such as his work on syphilis—the "French disease"—then (possibly) a new disease. He died at forty-eight in the service of the prince-archbishop Duke Ernst of Bavaria.

Parmenides of Elea (fl. 450 B.C.): Founder of the influential Eleatic school in southern Italy, he argued that all change is a mere illusion—nothing comes into being or passes away.

Pascal, Blaise (1623–1662): A native of Clermont, Pascal distinguished himself early with an essay on conic sections, published when he was seventeen. To help his father, a tax intendant, he designed and built the first adding machine at twenty-one. In the early 1650s, he wrote treatises on hydrostatics and the weight of the air and performed experiments with the barometer. In 1655, Pascal entered the convent at Port-Royal (Paris). He wrote on theology, morals, geometry, physics, and other subjects, and his writings are considered models of French literature. He died at the young age of thirty-nine.

Peter Lombard (c. 1100–c. 1162): Called "The Master of the Sentences." A native of Novara, Italy, Peter studied successively at Bologna, Rheims, and Paris; he was made bishop of Paris in 1158 or 1159 but held the office only a short time. His most important work, the *Four Books of Sentences* (c. 1145–1151), a set of theological disquisitions, became the standard, and required, text for theology students to comment on throughout the High Middle Ages.

Peter of Spain (c. 1215–1277): Born in Lisbon, educated first at the cathedral school of Lisbon, then at the University of Paris, Peter studied natural philosophy under St. Albert the Great and medicine under the Franciscan John of Parma and was made professor of medicine at Siena in 1247. He wrote a widely used text on logic, as well as books on medicine and alchemy. On 20 September 1276, he was elected pope, taking the name John XXI and soon initiating investigations of teaching at Paris, which eventually led to the Condemnation of 1277. On 14 May 1277, his hastily constructed study at the papal palace in Viterbo collapsed on him, and he died from his injuries six days later, having been pope exactly eight months.

Plato (c. 428–348 B.C.): Born of a noble Athenian family, Plato became the disciple of Socrates. After Socrates' execution in 399 B.C., Plato traveled though Greece, Egypt, and Magna Graecia (the southern Italian Greek colonies). Plato founded the Academy at Athens, which counted Aristotle among its first students. Plato's numerous writings form a major foundation of Western thought and civilization.

Pliny, the Elder; in full, Gaius Plinius Secundus (23–79). Roman administrator and encyclopedist, author of the *Natural History* (*Historia naturalis*), one of the most widely known natural philosophical texts of antiquity throughout the Middle Ages. He was killed on 24 August 79, during the eruption of Mt. Vesuvius that buried Pompeii.

Ptolemy, Claudius (fl. 150 A.D.): Extremely influential Hellenistic natural philosopher, best known for his astronomic/astrological work contained in the *Almagest* and *Tetrabiblos*, but also active in geography, optics, and other areas. The Ptolemaic system was the most comprehensive and accurately predictive cosmological system, and although generations of subsequent astronomers labored to improve it, its general outline was accepted down to the seventeenth century.

Pythagoras (c. 580 B.C.): Mysterious founder of the mystery school of the Pythagoreans in southern Italy. A contemporary of Thales and native of Samos, he purportedly studied mathematics and musical harmonies.

Rheticus, Georg Joachim (1514–1576): Born in Feldkirch as Georg Joachim von Lauchen, he took the name Rheticus (from Rhetia, the Latin name of his native Austrian province) after his father was executed for witchcraft. Rheticus went to Wittenburg in 1532, earned his M.A. in 1536, and became professor of mathematics there. He traveled to study with Copernicus in 1539, became a believer in heliocentrism, published a summary of Copernicus' ideas in 1540, and received Copernicus' permission to publish his full work. In the last stages of publishing

Copernicus' text (1542), Rheticus took an appointment at Leipzig and consigned the rest of the task to Osiander. He stayed at Leipzig until 1551, at which time he fled after charges of having an affair with one of his students.

Sosigenes the Alexandrian (first century B.C.): Hellenistic astronomer-mathematician commissioned by Julius Caesar to devise an accurate calendrical system for the Roman Empire. The resulting Julian calendar, begun in 44 B.C., was used until 1582 when it was replaced by the Gregorian calendar in use today.

Starkey, George (1628–1665): Born in Bermuda the son of a Scottish minister, Starkey was orphaned at a young age and sent to the Massachusetts Bay Colony, where he enrolled at Harvard, earning an A.B. in 1646. He went to London in 1650 and set up a laboratory and medical practice. His writings include Helmontian medical treatises published under his own name and extremely influential works on transmutatory alchemy published under the pseudonym of Eirenaeus Philalethes (Greek for "Peaceful Lover of Truth"). He died in the Great Plague of 1665 after dissecting a plague victim.

Strato of Lampascus (died 268 B.C.): Known as "the physicist" (*ho phusikos*), Strato was the third leader of Aristotle's Lyceum; among other things, he studied falling bodies and the possibility of the vacuum.

Tertullian, Quintus Septimius Florens (c. 155–c. 230): Native of north Africa, a lawyer by profession, convert to Christianity by 197, thereafter a priest, Christian apologist, theological controversialist, and eventually heretic. His writings are vivid and pungent, both those against paganism and the later ones against orthodox Christianity.

Thābit ibn-Qurra (836–901): An Arab Sabian born in Harran, Syria, of a noble family; by some accounts, his first career was as a money-changer, but he is known as an active astronomer, mathematician, and trilingual (Greek, Arabic, and Syriac) translator in Baghdad at the court of the caliph Mu`tadid. His astronomical works and translation of Greek works continued to be influential in the Latin Middle Ages.

Thales of Miletus (fl. 600–580 B.C.): Earliest philosopher of the Milesian school, he is generally considered the first of the Presocratics. Thales postulated that everything was made of water.

Theophrastus (c. 371–286 B.C.): Aristotle's student and first successor as leader of the Lyceum. Wrote on plants and stabilized the Lyceum financially.

Thierry of Chartres (died after 1156): A scholar and teacher at the cathedral school of Chartres. Wrote an important Hexameral treatise using Neoplatonic notions and a commitment to naturalism.

Van Helmont, Joan Baptista (1580–1644): Born in Brussels of a Flemish noble family, Van Helmont studied at Louvain (but initially refused to accept his degree), practiced as a physician, and developed one of the most influential frameworks for chemistry and medicine of the seventeenth century. His early tract on the weapon salve brought him into conflict with the Jesuits, and charges of heresy dogged him for the rest of his life, although his widow (also a noble Fleming) had him exonerated. Most of his writings were published posthumously (1648) by his son Francis Mercury.

Vitruvius (Marcus Vitruvius Pollio) (fl. first century B.C.): Roman architect and engineer; author of *De architectura*, a manual of Roman architecture rediscovered and highly admired in the Italian Renaissance.

Willem of Moerbeke (c. 1215–1286): A Flemish Dominican who first translated Aristotle from the Greek original into Latin, he was a friend of St. Thomas Aquinas, chaplain to several popes, and eventually, bishop of Corinth.

William of Conches (c. 1090–after 1154): Born in Normandy, which he calls "a country of mutton-heads and dense skies," William studied at Chartres under Bernard, then began teaching there himself in the early 1120s. He seems to have had a special interest in natural philosophy. He retired early from the school and became tutor to the sons of Geoffrey Plantagenet (one of whom became England's King Henry II); Geoffrey is one of the interlocutors in William's superb survey of natural philosophy, the *Dragmaticon philosophiae*.

History of Science: Antiquity to 1700

Part III

Professor Lawrence M. Principe

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Professor of History of Science, Medicine, and Technology and of Chemistry,
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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.

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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. **4.** Gilbert's ideas are probably the inspiration behind Kepler's *anima motrix* (which is reprised by Galileo).
5. **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. **3.** Van Helmont's system was a highly influential combination of mechanism and vitalism.
4. **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. **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. **1.** The *archeus* oversees digestion, the assimilation of food, and other maintenance roles in the body.
2. **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. **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. **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. **2.** The "seeds," or seminal principles, are *active principles* implanted in matter by God; their action radically transforms water into all other substances.
3. **3.** The Helmontian *semina* can be traced back to St. Augustine's seminal reasons.
4. **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. **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. **1.** The *semina* and other objects could extend their power for organizing and changing matter radially without transfer of material substance.
2. **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. **3.** The cure occurred at a distance by "sympathy" or, as Van Helmont preferred (borrowing a term from Gilbert), by "magnetic" cure.
4. **4.** The weapon-salve was also treated by Gassendi (and many others), who explained its action mechanically.
5. **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?

Bibliography

Essential Readings:

Note: The following texts can be considered the general "textbooks" and important primary sources for the course; they are intended to provide a set of more or less continuous readings relating to the lectures. However, the material covered in some of the lectures does not appear in these books; the supplementary readings below furnish more specific information—usually at a somewhat higher level.

Barnes, Jonathan. *Aristotle: A Very Short Introduction*. Oxford: Oxford University Press, 2000. This is the best quick introduction to Aristotle available; excellent overview and analysis.

Debus, Allen G. *Man and Nature in the Renaissance*. Cambridge: Cambridge University Press, 1978. A slim work intended as a textbook, covers material for Lectures Twenty-Four to Thirty-Three.

Finocchiaro, Maurice A. *The Galileo Affair: A Documentary History*. Berkeley: University of California Press, 1989. Contains not only translations of *all* the documents relating to Galileo's trials, but also an introduction with the most concise and balanced overview of the whole affair.

Galileo. *Sidereus Nuncius*, trans. Albert van Helden. Chicago: University of Chicago, 1989. Galileo's announcement of his telescopic discoveries; highly readable way to encounter primary sources.

Grant, Edward. *The Foundations of Modern Science in the Middle Ages*. Cambridge: Cambridge University Press, 1996. A clear and comprehensive textbook for the Latin medieval section of the course, Lectures Thirteen and Seventeen through Twenty-Three; especially good on the subjects of the Latin translation movement, universities, and medieval physics and cosmology.

Gutas, Dimitri. *Greek Thought, Arabic Culture*. London: Routledge, 1998. There are no textbooks in English dealing with the history of Arabic science; however, this book gives an excellent, up-to-date, and insightful analysis of the adoption of Greek learning in the Islamic world, even though the level of discussion is somewhat high for a beginning student.

Henry, John. *The Scientific Revolution and the Origins of Modern Science*, 2nd ed. London: Palgrave, 2002. An outstanding and very short survey of seventeenth-century science. It is massively and unobtrusively referenced with the most up-to-date sources and, thus, can be a jumping-off point for further study of specific topics. Because it does not run in the same order as the lectures, I suggest that listeners read the whole thing through after Lecture Thirty-Five as a summary review of Lectures Twenty-Four to Thirty-Five.

Lindberg, David C. *The Beginnings of Western Science*. Chicago: University of Chicago Press, 1992. A good and thorough textbook designed for undergraduates, used here as a mainstay of the first two units (Lectures One through Twenty-Four).

Lloyd, G. E. R. *Early Greek Science: Thales to Aristotle*. New York: Norton, 1970. The author is the accepted authority on ancient Greek scientific thought; excellent introduction to the content of Greek thought about the natural world.

———. *Greek Science after Aristotle*. New York: Norton, 1973. See the previous comment.

Plato. *Timaeus and Critias,* trans. Desmond Lee. New York: Penguin Classics, 1977. Good readable translation of the *Timaeus*.

Westfall, Richard S. *The Construction of Modern Science: Mechanisms and Mechanics*. Cambridge: Cambridge University Press, 1977. Parts of this work are quite dated now, but it still contains a good presentation of the essentials of the mechanical philosophy.

William of Conches. *A Dialogue on Natural Philosophy* (*Dragmaticon Philosophiae*), ed. Italo Ronca and Matthew Curr. South Bend, IN: University of Notre Dame Press, 1997. A very readable translation that provides a fine sense of the style and motivation of a (non-Scholastic) medieval treatise on natural philosophy.

Supplementary Readings:

Applebaum, Wilbur, ed. *Encyclopedia of the Scientific Revolution: From Copernicus to Newton*. New York: Garland Publishing, 2000. An extremely useful reference source for the third unit of this course, hundreds of concise, up-to-date entries written by leading scholars and intended for students. If you want to acquire one reference source for the history of the Scientific Revolution, this is it.

Aristotle. His entire corpus appears in the Loeb Classical Library editions where the translations run the gamut from good to bad in terms of readability and accuracy. There are a slew of Aristotle translations out there, and it is probably best to buy or borrow them like shoes—try them on, walk around a bit, and, if they seem uncomfortable, there is probably another one to try on. Also try a "reader" which contains "key" selections from Aristotle's writings; there are quite a few available, see below, for example, Irwin and Fine.

Ashworth, William B., Jr. "Natural History and the Emblematic World View," in *Reappraisals of the Scientific Revolution*, edited by David C. Lindberg and Robert S. Westman, pp. 333–365. Cambridge: Cambridge University Press, 1990. A clear exposition of the changes in the way the natural world and its objects were viewed in the Renaissance.

Augustine. *The Confessions*, trans. by R. S. Pine-Coffin. New York: Penguin Books, 1961. Most readable translation of this important work; easily available. Follow St. Augustine on his circuit of the late classical world. Between the pious exclamations, this book gives a vivid view of the intellectual/ philosophical marketplace of 400 A.D. and St. Augustine's real indebtedness to classical thought.

Bacon, Francis. *Selected Philosophical Works*, ed. Rose-Mary Sargent. Indianapolis, IN: Hackett, 1999. Good translation and collection, containing selections from most of Bacon's works that deal most closely with his method and his impact on the history of science.

Benson, Robert L. and Giles Constable, eds. *Renaissance and Renewal in the Twelfth Century*. Toronto: University of Toronto Press, 1999. A recent and lengthy work updating the classical study by Haskins. It consists of twenty-six papers which cover the broad range of subjects which underwent dramatic change during the twelfth century.

Cadden, Joan. "Science and Rhetoric in the Middle Ages: The Natural Philosophy of William of Conches," *Journal of the History of Ideas* 56, (1995): 1–24. Fine contextualization and exposition on the primary reading listed above from William of Conches.

Casson, Lionel. *Libraries in the Ancient World*. New Haven: Yale University Press, 2001. Very readable overview of the development of libraries in antiquity.

Copenhaver, Brian P. "Natural Magic, Hermeticism, and Occultism in Early Modern Science," in *Reappraisals of the Scientific Revolution*, edited by David C. Lindberg and Robert S. Westman, pp. 261–301. Cambridge: Cambridge University Press, 1990. Important analysis of how natural magic functioned in the Renaissance and clarification of the role of the Hermetic corpus; fairly high level but fascinating.

———. *Hermetica: The Greek Corpus Hermeticum and the Latin Asclepius in a New English Translation with Notes and Introduction*. Cambridge: Cambridge University Press, 1992. Best translation of the Hermetic corpus, with an extremely detailed and expert introduction.

Copernicus, Nicolas. *On the Revolutions*, tr. by Edward Rosen. Baltimore: Johns Hopkins Press, 1978. An excellent translation of *De revolutionibus*, including all the important front matter and with a helpful introduction and annotations.

Crombie, A. C. *Robert Grosseteste and the Origins of Experimental Science, 1000–1700*. Oxford: Clarendon Press, 1953. Slightly dated at some points but still a clear exposition of Grosseteste's work and influence.

Dawson, Christopher. *Mission to Asia*. Toronto: University of Toronto Press, 1998. Very readable translations of the original accounts compiled by the Franciscan friars who journeyed to Mongolia in the middle of the thirteenth century. Absolutely fascinating.

Dear, Peter, ed. *The Scientific Enterprise in Early Modern Europe: Readings from Isis*. Chicago: University of Chicago Press, 1996. A collection of over a dozen articles from *Isis*, the journal of the History of Science Society. The volume makes a good "reader" for those interested in more advanced and detailed discussions of particular events or characters of the Scientific Revolution. (See the similar reader volume by Shank, ed., below.)

Dhanani, Alnoor. *The Physical Theory of Kalam: Atoms, Space and Void in Basrian Mu`tazili Cosmology*. Leiden: Brill, 1994. Fascinating analysis of atomistic doctrines among the early *mutakallimūn*; a difficult text to be sure (it began as a Ph.D. dissertation), but so is the topic. Provides considerable reward to a patient and committed reader.

Dibner, Bern. *Moving the Obelisks*. Norwalk, CT: Burndy Library, 1991. Short and entertaining study of the moving of obelisks from antiquity to the modern era; profusely illustrated, including fold-out plates that are facsimiles from Fontana's sixteenth-century account of moving the Vatican obelisk.

Dick, Steven J. *Plurality of Worlds: The Origins of the Extraterrestrial Life Debate from Democritus to Kant*. Cambridge: Cambridge University Press, 1982. Fascinating account of the varied historical views on the possibility of extraterrestrial life.

Dobbs, Betty Jo Teeter. *The Janus Faces of Genius: The Role of Alchemy in Newton's Thought*. Cambridge: Cambridge University Press, 1991. An attempt to synthesize the disparate elements of Newton's interests and activities into a unified portrait of his scientific motivations.

———. "Newton as Final Cause and First Mover," *Isis* 85 (1994): 633–643. The text of the Distinguished Lecture given by this expert on Newton's alchemy to the History of Science Society in 1993. This short paper is extremely readable for all students of this course and does a fine job of summarizing the ground-breaking reevaluation of Newton's position in the history of science (particularly in regard to his alchemy and theology) advanced by Dobbs.

Eamon, William. "Technology as Magic in the Late Middle Ages and the Renaissance," *Janus* 70 (1983): 171-212. A very interesting view of the "wonderful" aspect of technology, with excellent examples and illustrations, written in an engaging style.

Galileo. *Dialogue on the Two Chief World Systems*. There are two translations currently available. The older one by Stillman Drake is *Dialogue Concerning the Two Chief World Systems, Ptolemaic and Copernican*. New York: Modern Library, 2001. A newer translation and abridgement along with helpful up-to-date commentary is by Maurice Finocchiaro, *Galileo on the World Systems: A New Abridged Translation and Guide*. Berkeley: University of California Press, 1997.

Galileo, *Two New Sciences*, tr. Henry Crew and Alfonso de Salvio. New York: Dover, 1954. An older translation, but readable and widely available in many editions.

Gies, Frances, and Joseph Gies. *Cathedral, Forge and Waterwheel: Technology and Invention in the Middle Ages*. New York: Harper/Collins, 1994. A fine work for the general reader covering late classical and medieval technology.

Gilbert, William. *On the Magnet*. New York: Basic Books, 1958. An older translation but readable and widely available in many editions.

Grafton, Anthony. *Cardano's Cosmos: The Worlds and Works of a Renaissance Astrologer*. Cambridge, MA: Harvard University Press, 1999. View of the life and thought of an important Renaissance figure.

Grant, Edward, ed. *A Source Book of Medieval Science*. Cambridge, MA: Harvard University Press, 1974. May be a little difficult to find but contains more than a hundred translated excerpts from medieval authors (Latin and Arabic) with annotations and commentary. Particularly strong in cosmology and physics.

Hare, R.M. *Plato*. Oxford: Oxford University Press, 1996. A very brief survey of Plato's ideas. The author is a moral philosopher, and so his analysis centers more on aspects of Plato's thought than on topics strictly of interest to the historian of science.

Haskins, Charles H. *The Renaissance of the Twelfth Century*. Cambridge, MA: Harvard University Press, 1927. The classic work on the subject. Frequently reprinted and easily available; covers a wide range of topics in twelfth-century history, not just history of science.

Hellman, C. Doris. *The Comet of 1577: Its Place in the History of Astronomy*. New York: AMS Press, 1971. Analysis of the importance of comet observations by Tycho and others and how they affected the prevailing Aristotelian view of the cosmos.

Hugh of St. Victor. *Didascalicon*, ed. Jeremy Taylor. New York: Columbia University Press, 1991. Good primary source in which to sample the heights reached by the Platonic strain of Christian thought and the emphasis placed on education by the medieval Christian schools. Can be a bit difficult to penetrate at points, but rewarding (and provocative!) to the patient modern reader.

Huizinga, Johan. *The Autumn of the Middle Ages*. Chicago: University of Chicago Press, 1996. A classic, dealing predominantly with art history yet useful for the student of this course in terms of creating the cultural atmosphere at the end of the "Middle Ages."

Hutchison, Keith. "What Happened to Occult Qualities in the Scientific Revolution?" *Isis* 73 (1982): 233–253. Provides an excellent description of the meaning and identity of "occult qualities" in late Aristotelian thought and their often-surprising fate in the Scientific Revolution, including the co-opting of such qualities by the mechanical philosophy. (Also reprinted in the Dear collection, above.)

Irwin, Terence and Gail Fine. *Aristotle: Selections*. Indianapolis: Hackett Publishing, 1995. Reading all the way through any one work by Aristotle on one's own takes a bit of fortitude; this book provides important selections from about fifteen of Aristotle's books. The range includes his logic and ethics, but also selections from some of *libri naturales* (but, unfortunately, nothing from *On the Heavens*). The translations are generally good and readable.

Kahn, Charles H. *The Art and Thought of Heraclitus*. Cambridge: Cambridge University Press, 1979. Detailed analysis and text (Greek and English) of each fragment surviving from my favorite Presocratic philosopher.

Kargon, Robert H. *Atomism in England from Harriot to Newton*. Oxford: Clarendon Press, 1966. Analysis of the various atomistic views in England with brief biographical sketches of their promoters—excellent for following the history of this important idea in England up to Newton.

Kirk, G. S., J. E. Raven, and M. Schofield. *The Presocratic Philosophers*. Cambridge: Cambridge University Press, 1983. One of the classic works on the Presocratics: texts, translations, and analyses. Hard to read through, more a work of reference. (See Wheelwright, below.)

Landels, J. G. *Engineering in the Ancient World*. Berkeley: University of California Press, 1981. Emphasis on hydraulic engineering, weapons, and modes of transport in the ancient world. Overview of the technological work found of Hero, Vitrivius, Frontinus (first century A.D. waterworks engineer for the city of Rome), and Pliny.

Lawrence, C. H. *The Friars*. London: Longmans, 1994. Account of the origin and work of the Dominicans and Franciscans in the Middle Ages.

Leff, Gordon. *Paris and Oxford Universities in the Thirteenth and Fourteenth Centuries*. Huntington, NY: Krieger Publishing, 1975. The standard work on the medieval university; detailed analysis of the origins of the northern universities, fascinating detail about curricula and student life, as well as intellectual developments at each locale.

Lindberg, David C. *Roger Bacon's Philosophy of Nature*. Oxford: Clarendon Press, 1983. Critical editions and translations of Roger Bacon's works *On the Multiplication of Species* and *On Burning Mirrors*, together with biographical material on Bacon and analysis of his intellectual development and contributions. Bacon's text can be quite challenging for a twenty-first century reader, but brush up on your medieval Aristotelian terminology and optics and plunge in!

Lindberg, David C., ed. *Science in the Middle Ages*. Chicago: University of Chicago Press, 1978. A collection of essays by eminent scholars on medieval history of science; essays cover technology, the translation movement, the universities, mathematics, physics, cosmology and astronomy, optics, medicine, natural history, magic, and more.

Lindberg, David C., and Robert S. Westman. *Reappraisals of the Scientific Revolution*. Cambridge: Cambridge University Press, 1990. A collection of essays by eminent scholars intended to reevaluate common views of the development of sixteenth- and seventeenth-century science. Generally at a high level, but most articles are quite accessible and are very useful for further developing points brought forth in the lectures.

Lindberg, David C., and Ronald L. Numbers. *God and Nature: Historical Essays on the Encounter between Christianity and Science*. Berkeley: University of California Press, 1986. Collection of essays on the relationship between science and religion from the Patristics to twentieth-century creationism.

Long, Pamela O. "Humanism and Science" in *Renaissance Humanism: Foundations, Forms, and Legacy*, ed. Albert Rabil, Jr. Philadelphia: University of Pennsylvania Press, 1988, vol. 3, pp. 486–512. Readable and erudite overview of the role of humanism in early modern science, analyzing the various scholarly views of the role of humanism in science.

———. *Technology, Society, and Culture in Late Medieval and Renaissance Europe, 1300-1600*. Washington, D.C.: SHOT/AHA, 2000. An excellent, brief (77 pages), illustrated, and highly readable text on aspects of early modern technology—from mining and gunnery to textiles, agriculture, and sculpture. Part of a series of short monographs on technology (priced at just $8!) available at www.theaha.org.

McEvoy, James. "The Metaphysics of Light in the Middle Ages," *Philosophical Studies* 26 (1979): 126–145. High-level text but important in terms of an introduction to a difficult but important feature of medieval thought—in natural philosophy and elsewhere.

Neugebauer, Otto. *The Exact Sciences in Antiquity*. New York: Dover, 1969. A classical work dealing with Babylonian, Egyptian, and Greek mathematical and astronomical texts. This book can be tough slogging, most useful for those with a good grasp of astronomy and mathematics to start with. Emphasizes scientific content over cultural context.

Newman, William R. “Technology and Alchemical Debate in the Middle Ages,” *Isis* 80 (1989): 423–445. A fascinating article that argues for alchemy’s bold (and modern-sounding) claims for the power of human artifice over nature. (Also in the Shank reader, below.)

North, John. *The History of Astronomy and Cosmology*. New York: Norton, 1995. An outstanding survey of the history of astronomy from prehistory to the modern era. Lucidly organized and written, exhaustive in coverage, and masterful in presentation, North’s work has become a standard source. If you want one book to use as reading and reference in the history of astronomy, choose this one.

Osler, Margaret J. “How Mechanical Was the Mechanical Philosophy? Non-Epicurean Aspects of Gassendi’s Philosophy of Nature,” in *Late Medieval and Early Modern Corpuscular Matter Theories*, edited by Christoph Lüthy, John Murdoch, and William Newman, pp. 423–439. Leiden: Brill, 2001. A very clear and interesting analysis of Gassendi’s mechanical system and its “non-mechanical” elements.

———. *Rethinking the Scientific Revolution*. Cambridge: Cambridge University Press, 2000. A collection of essays dealing with various aspects of the current reevaluation of the concept and content of the Scientific Revolution, beginning with a spirited debate between Westfall and Dobbs, scholars cited in various places throughout this course.

Plato. *Republic*. There are a huge number of translations of this important work available, many with commentaries of greater or lesser value. The most important section for historians of science is Book VII, which contains the “Parable of the Cave,” a key exposition of Plato’s ontology and epistemology.

Pliny. *Natural History*. New York: Penguin, 1991. Representative selection of some of the more entertaining sections of Pliny’s encyclopedic work. If you want the whole thing, try the Loeb Classical Library edition.

Principe, Lawrence M. *The Aspiring Adept: Robert Boyle and His Alchemical Quest*. Princeton, NJ: Princeton University Press, 1998. Treatment of the previously oft-hidden alchemical preoccupations of Boyle; includes two provocative (and hitherto unpublished) texts by Boyle on alchemy.

Principe, Lawrence M., and William R. Newman. “Some Problems in the Historiography of Alchemy,” pp. 385–434 in *Secrets of Nature: Astrology and Alchemy in Early Modern Europe*, edited by Anthony Grafton and William Newman, pp. 385–434. Cambridge, MA: MIT Press, 2001. Debunks four widespread popular misconceptions about the subject of alchemy and shows the origins of these misconceptions.

Ptolemy. *Tetrabiblos*, trans. Frank Egleston Robbins. Cambridge, MA: Harvard University Press, 1980. Part of the Loeb Classical Library series, presented with Greek and English on facing pages. This is the classical source for the astrological tradition and is surprisingly readable.

Ross, Sydney. *Nineteenth-Century Attitudes: Men of Science*, chapter 1: “Scientist: The Story of a Word.” Dordrecht: Kluwer Academic Publishers, 1991. Amusing history of the coinage and slow acceptance of the word “scientist”—will greatly surprise most readers.

Sabra, A. I. “Greek Science in Islam,” *History of Science* 25 (1987): 223–243. Thoughtful piece on the translation movement and the fate of Greek science in the Arabic world.

———. “Situating Arabic Science: Locality versus Essence,” *Isis* 87 (1996): 654–670. Probes the reasons behind the Arabic embrace of Greek learning and briefly explores the cause of the decline of Arabic science, with a plea for more scholarly attention to be paid to this important and understudied area.

Shank, Michael H., ed. *The Scientific Enterprise in Antiquity and Middle Ages: Readings from Isis*. Chicago: University of Chicago Press, 1996. A collection of twenty-two articles from *Isis*, the journal of the History of Science Society. The volume makes a good “reader” for those interested in more advanced and detailed discussions of particular events, topics, or characters from antiquity and the Middle Ages. (See the similar reader volume by Dear, ed., above.)

Stahl, William Harris. *Roman Science: Origins, Development, and Influence to the Later Middle Ages*. Madison, WI: University of Wisconsin Press, 1962. There’s not a great deal of material on Roman science available; this is the classic study.

Stroup, Alice. *A Company of Scientists: Botany, Patronage, and Community at the Seventeenth-Century Parisian Royal Academy of Sciences*. Berkeley, CA: University of California Press, 1990. An excellent view of this important scientific society during its early years of the seventeenth century. The first five chapters give a fine overview of the structure and founding of the Académie; the balance deals with more specific issues—particularly in botany and chemistry—as illustrations of the society.

Theophilus. *On Divers Arts*, trans. John G. Hawthorne and Cyril Stanley Smith. New York: Dover, 1979. Want to know how to cast a bronze censer, build an organ, or construct a stained-glass window starting with sand, ashes, and lead? Then this eleventh-century text from a monastic workshop is the book for you.

Thoren, Victor E. *The Lord of Uraniborg: A Biography of Tycho Brahe*. Cambridge: Cambridge University Press, 1990. Can be difficult to read at times, but the standard biography of the Great Dane.

Westfall, Richard S. *Never at Rest: A Biography of Isaac Newton*. Cambridge: Cambridge University Press, 1980. Most complete and up-to-date biography of Isaac Newton. This is quite a massive volume; for those not wishing to read the whole thing, there is an abridged version at about a third the length.

Westman, Robert S. "Three Responses to the Copernican Theory: Johannes Praetorius, Tycho Brahe, and Michael Maestlin," in *The Copernican Achievement*, edited by Robert S. Westman, pp. 285–345. Berkeley and Los Angeles: University of California Press, 1975. Important study of how Copernicus' work was interpreted and used in the sixteenth century.

———. "Proof, Poetics, and Patronage: Copernicus' Preface to *De revolutionibus*," in *Reappraisals of the Scientific Revolution*, edited by David C. Lindberg and Robert S. Westman, pp. 167–205. Cambridge: Cambridge University Press, 1990. Interesting study of the publication of *De revolutionibus* and Copernicus' humanism.

Wheelwright, Philip. *The Presocratics*. Indianapolis, IN: Bobbs-Merrill, 1960. Emphasis here is given to the fragments of the Presocratics themselves. The brief introductions to each author and his school are particularly useful. A better first book on this topic than Kirk and Raven, in my opinion.

Wilken, Robert L. *The Christians as the Romans Saw Them*. New Haven: Yale University Press, 1984. A book that "turns the tables" since the popular view of the Romans is often through Christian eyes; here, the (pagan) Romans get their turn. Interesting description of the development of early Christian theology as a response to learned pagan criticism.