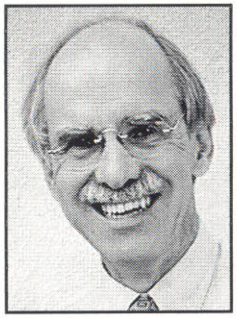

Professor Frederick Gregory is Professor of History of Science at the University of Florida, where he has taught for 25 years. He holds a seminary degree from Gordon-Conwell Theological Seminary, a Master's degree from the University of Wisconsin, and a Ph.D. from Harvard University in the history of science. His teaching awards include the John Mahon Undergraduate Teaching Award and the Wilensky Graduate Teaching Award.

Guidebook Contents

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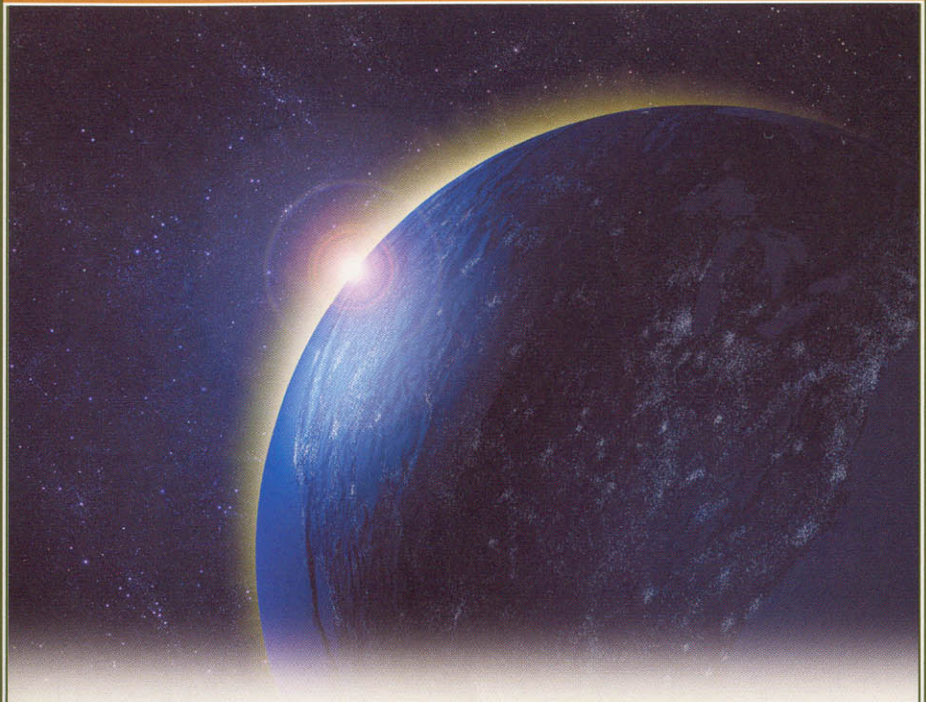

The History of Science: 1700-1900

Taught by: Professor Frederick Gregory,
University of Florida

Part 1

Course Guidebook

THE TEACHING COMPANY®

Frederick Gregory, Ph.D.

Professor of History of Science, University of Florida

Frederick Gregory is Professor of History of Science at the University of Florida, where he has taught for 25 years. He holds an undergraduate degree from Wheaton College in Illinois, where he studied mathematics. After graduating with a seminary degree from Gordon-Conwell Theological Seminary in Wenham, Massachusetts, he entered the University of Wisconsin at Madison to begin his study of the history of science. On completing a master's degree from the University of Wisconsin, he went on to Harvard University for his Ph.D. in history of science. Professor Gregory's research interests have focused on German science in the 18th and 19th centuries, particularly as it reflects the larger cultural setting in which it is embedded. His past publications have ranged widely over disciplines from both the physical and biological sciences and include major studies of German scientific materialism and of the interaction of natural science and religion in the 19th century.

Dr. Gregory is a past chairman of the Department of History at Florida and served as president of the History of Science Society of North America in 1996 and 1997. He has received numerous grants for research in his field, including an Alexander von Humboldt grant from the German government and a fellowship from the Dibner Institute for the History of Science at MIT.

Dr. Gregory is a veteran lecturer on the history of science, both in this country and abroad, serving as a designated lecturer for the Visiting Lecture Program of the History of Science Society. He provided commentary for the American production of the television series *The Day the Universe Changed* and has been a winner of both undergraduate and graduate teaching awards at the University of Florida. At present, Professor Gregory is one of four scholars engaged in a three-year collaboration between German and American investigators on the subject "Mysticism and Modernity," an effort sponsored by the Volkswagen Foundation in Germany. He is also engaged in writing a two-volume undergraduate textbook on the history of science.

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"Science in the Enlightenment"

The History of Science: 1700 – 1900

Scope:

In the wake of the success of the "new science" of the 17th century, many in the subsequent era wished to extend the spirit of discovery into new areas. Experimental and theoretical investigations into a host of new subjects helped to shape the period that has come to be known as the Enlightenment, or the Age of Reason. By deliberately cutting across scientific disciplines, this course attempts to provide a glimpse into the spirit of excitement and exploration that enabled many to question accepted opinion on a number of different issues. In the process, we shall see that concepts no longer regarded as tenable in the 21st century, such as ideas of weightless matter and preformed embryos, proved to be extremely useful to earlier natural philosophers. Eighteenth-century science, then, is particularly instructive concerning the complex way in which natural science develops. It also illustrates that the investigation of nature is never pursued in a vacuum. We shall encounter examples of how science is embedded in and affected by its cultural context and even its political context, especially as we approach the French Revolution at the end of the century. The conclusions of 18th-century natural philosophers also contributed to the growth of a new attitude about the relevance of natural knowledge to religion. Continuing the 17th-century assumption that the investigation of nature provided a testimony to the wisdom of the creator, some presumed to regard their findings as suggestions of the natural means God had employed in his role as ruler of the cosmos. We shall see several examples of how freely some natural philosophers presumed to provide explanations for matters previously attributed to direct divine action.

The mechanical view of nature that had been developed in the wake of Newton's achievement proved to be highly successful in the Enlightenment, but in the19th century, a new science of living things came into existence and, with it, a romantic version of natural science. The question immediately arose whether there was something irreducible about life, whether organism was prior to mechanism. To complicate matters further, discoveries of fossil remains forced humankind to acknowledge the existence of an entire prehistoric world, demanding a complete reorientation to the past and to the place of humans in the natural world. These were no small issues; they implied that the commonly accepted view of the past needed to be altered. Some suggested that the present resulted from a natural process of development over a long time, asserting, in the manner of their forerunners, that they had uncovered the natural means God had employed to produce the present diversity of living things. These issues were forced onto the public in the years before Darwin, so that the appearance of *The Origin of Species* continued a discussion that was well underway. Theories about the history of organisms fascinated those in the late 19th century, as did claims about the relevance of these theories for pressing social, political, and medical issues. Always in the background hovered the question of what the new claims of natural science meant for people of faith.

Physical science also presented the 19th century with its storehouse of marvels. No one realized, in 1796, that forces were at work undermining the perfect machinery of the heavens celebrated by Pierre Simon Laplace that year. If forces were as interconvertible as they seemed to be at the beginning of the century, signs that things were more mysterious than Newton had anticipated appeared, with the curious properties of electromagnetism and a new understanding of the role of heat in the 1820s. From there, the world of science became more and more intriguing. By 1854, Hermann Helmholtz forecasted a new vision of the future of the world based on irreversible physical processes. The universe was running down and doomed to a tragic end. When popular writers on the Continent latched on to the latest science to support a materialistic view of reality, north British physicists employed the new science of energy to oppose them. A concomitant clash about the meaning of physical science occurred when unexpected claims about the possibility of extraterrestrial life erupted before a public already fascinated with the latest observations of new and extremely powerful telescopes. If electromagnetism had introduced curiosities earlier in the century, it continued to mystify in James Maxwell's treatment at mid-century. Not only was light somehow involved, but experiments conducted in the wake of Maxwell's work just did not make sense. Nevertheless, the amazing accomplishments of physical scientists during the century permitted some not only to be undaunted but to predict confidently that the end of science was near. Developments at the end of the century showed, however, that natural science is an ongoing enterprise much bigger than the outlook of any specific era.

Lecture One

Science in the 18th and 19th Centuries

Scope: This first lecture considers the time period of the course as a whole and the place natural science occupied in it. After orienting ourselves to the 18th century, the era in which the course commences, we consider the special challenge facing anyone who wishes to understand and learn from the natural sciences of the past. We are then introduced to key institutions of natural science in Britain, France, and Germany and end with an introduction to the major scientific subjects and themes that will be covered in the course.

Outline

I. The prize question for the *Berlin Monthly* of 1783 was "What is Enlightenment?"
  - **A.** The question itself reveals something important about the age: its self-awareness of its status as an enlightened age compared to previous eras.
    - **1.** The Enlightenment marks the beginning of a longer period of Western history called the *modern era*.
    - **2.** The modern era is distinguished by a commitment to discover truth and by a confidence in reason as the means of finding truth.
  - **B.** One of the entries in the prize competition was by Immanuel Kant.
    - **1.** Kant, who characterized enlightenment as the awakening to a realization that we humans have created realms separate from ourselves on which we then have become dependent, said that enlightenment further involves having the courage to discern this and act on it by getting rid of this self-imposed dependency.
    - **2.** Kant respected the power and the limitations of natural science to give us knowledge about nature.
  - **C.** The thinkers of the age were impressed with the human capacity for reason.

II. A preliminary question is: Does an examination of the science of the past pose any special challenges to the historian?
  - **A.** We must be careful to realize that it would be a mistake to assume that the natural philosophy of the past necessarily resembles the natural science of today.
  - **B.** This lesson has been brought home by the historian of science Thomas Kuhn.
  - **C.** It is extremely easy to impose present standards onto the past, where they do not belong and do not help us understand the past.

    1. If we use the word *scientist*, for example, we all know what we mean by the term.
    2. But can we accurately call a man from the 17th century, for example, Isaac Newton, a *scientist*, when the word was not even coined until the third decade of the 19th century?

  D. We will do our best to avoid such mistakes, although it is very hard, in fact impossible, to refrain completely from taking our own perspective with us as we investigate the past.

III. To begin our consideration of these centuries, we note the role of institutions shaping the natural science of the 18th century.

  A. In Britain, the Royal Society, established in the 17th century, was waning in its influence.

  B. By mid-century, the major focus in natural philosophy was in France.
    1. The Academie des Sciences enjoyed government support.
    2. The King's Garden, founded in the 17th century, provided access to natural science for the public through lectures and exhibits.
    3. Disruptions in the major organizations of natural science caused by the French Revolution led to a reestablishment of their central place by 1795.

  C. In the German states, a general cultural upsurge was accompanied by an increasing role for the natural sciences.
    1. In the second half of the century, German writers ceased deferring to France and began to establish an indigenous literary tradition.
    2. With the rise of an "ideology of scholarship," the faculty of philosophy in the German universities and the natural sciences themselves achieved new importance and new status.

IV. What will we examine in this course?

  A. We will follow individual natural philosophers of the 18th and 19th centuries who were inspired by their predecessors to push the limits of knowledge in a diversity of areas.

  B. In Part I, which is concerned with the 18th century, we will consider issues from both the physical and biological sciences.
    1. Because of the variety of subject matter we will examine, we will follow a theme to its conclusion rather than slavishly observing chronological development.
    2. Our procedure will be to do several passes over the century as we look into individual themes.

  C. Parts II and III are devoted to the life sciences and the physical sciences of the 19th century, respectively.

V. What themes will the course investigate?

  A. Inquiries about the history of the cosmos challenged the limited time scale of previous times.

  B. The realm of living things fascinated natural philosophers over the two centuries.
    1. Similarities among various species of living things suggested that they could be arranged on a scale of being.
    2. The development of the embryo from a formless mass to a fully formed adult raised a basic question: What determines the direction the development will take?
    3. In the 19th century, natural philosophers uncovered the prehistoric world of creatures that roamed the Earth in a distant past.

  C. We will assess the largely successful attempts to break away from occult explanations of chemical phenomena.
    1. The 18th century saw attempts to distinguish rational chemistry from alchemy.
    2. The development of new experimental techniques and the discovery of oxygen later in the century made possible a new quantitative approach in chemistry.
    3. Part of this story, we will see, involved national rivalries.
    4. Distancing chemistry from alchemy, however, resulted in the recognition that the future of chemical explanation lay in periodicities.

  D. Not all endeavors to explain natural phenomena avoided appealing to supernatural or mysterious powers and forces.
    1. The world of medicine included a wide array of healers, from outright quacks to those who claimed to base their cures on theoretical knowledge.
    2. The appearance of Mesmer's explanation of animal magnetism exposed how a "rational" explanation of nature's forces could be affected by the interaction of social, intellectual, and especially political factors.

  E. The number and kind of physical forces proliferated, especially around the turn from the 18th to the 19th centuries.
    1. Investigations in static electricity produced a quantitative account of electrical phenomena.
    2. The discovery of animal electricity led to the invention of the battery and linked the physical and biological sciences.
    3. Electromagnetism quickly found practical application, plainly visible to nonscientists.
    4. Considerations of the nature of heat led to sweeping generalizations about all forces that contained dire consequences for the future of the cosmos.

        5. As natural science became more and more associated with materialism, natural scientists took sides.
    - **F.** A common theme that will reappear throughout the course concerns the relation of God to nature.

Essential Reading:

Outram, *The Enlightenment.*

———, "The Enlightenment: Our Contemporary."

Supplementary Reading:

Hankins, *Science and the Enlightenment*, chapter 1.

Kuhn, *The Structure of Scientific Revolutions.*

Questions to Consider:

1. Exactly what harm to history is done by using the term *scientist* for such figures as Galileo Galilei, Gottfried Leibniz, and Isaac Newton?
2. If the two centuries that define this course, the 18th and 19th centuries, make clear what is meant by the modern era, which defining features have led some to claim that we are currently living in a *post*-modern period?

Lecture Two

Consolidating Newton's Achievement

Scope: The conclusions Newton presented were not acceptable to many in his day. Although he had many defenders among the British, his system contained central assumptions that flew in the face of some of the best thinking on the Continent. This lecture explains how Newton's thought was received by leading thinkers in France and Germany and describes the events that led to the eventual creation of a worldview that claimed Newton as its hero. By the end of his life in 1727, Newton had begun to win adherents outside Britain, in Holland and in France. A Newton party began to grow especially among young Frenchmen, who found his mathematical approach to explaining natural phenomena intriguing. Several specific problems that arose in the decades after 1730 presented opportunities for these French Newtonians to demonstrate the power of Newton's approach. These included attempts to solve the so-called three-body problem, the return of Halley's comet, and the so-called secular acceleration of the moon. The establishment of Newton's system of by the end of the century made possible a new conception of the cosmos as a place different from Newton's own idea of it.

Outline

- **I.** Isaac Newton's book *Mathematical Principles of Natural Philosophy* appeared in 1687 to great acclaim in Britain.
- **II.** Why was Newton's book so impressive?
    - **A.** The book was presented in the imposing format the ancient Greek mathematician Euclid had used in his famous book on geometry.
        1. Many of the problems and their proofs were complicated, requiring considerable mathematical skill.
        2. Newton had invented a new mathematical technique, the calculus, to help him solve the difficult problems he addressed.
    - **B.** Newton claimed he was presenting a system of the world.
        1. To attempt to explain why the heavens moved as they did was a bold undertaking.
        2. Newton's explanation of the motion of the heavenly bodies was cast as the application of a general law that referred to all matter.
    - **C.** Newton declared that all matter was attracted to all other matter by a special force.
        1. To avoid materialism, Newton held that the force was not intrinsic to matter.
        2. Newton claimed to know that the force depended on the size of matter and that it weakened as the inverse square of the distance.

3. He had become convinced about this attractive force while working on the problem of the moon's motion.
4. His original solution as a youth had been preliminary. Now, in his book, it was complete.

III. How was Newton's book received?

A. In Britain, he won immediate fame.

B. On the Continent, there were critics among the followers of René Descartes.

1. Earlier in the 17th century, Descartes had explained the motions of the heavens by rigidly separating reality into two realms, matter and mind.
2. For Cartesians, such as the Dutchman Christian Huygens, Newton inappropriately mixed mind and matter when he allowed the force of attraction to be imposed onto matter.
3. For Cartesians, the idea that matter could "attract" other matter over a space was saying that matter possessed a kind of hidden, or occult, force.

C. The German natural philosopher Gottfried Leibniz also criticized Newton's idea of attractive force.

1. Leibniz noted Newton's failure to refer to an intervening material medium as the vehicle to transmit the attractive force.
2. Leibniz criticized Newton's belief that God's intervention was necessary to guarantee the system's stability.

IV. What events led, over the course of the 18th century, to the establishment of Newton's view among leading natural philosophers of the Enlightenment in France?

A. Soon after Newton died in 1727, his views began to be encountered by the educated public in France more frequently.

1. Voltaire published a favorable description of Newton's philosophy in 1733.
2. He and Madame du Châtelet wrote an expanded popularization of Newton's system some years later.

B. A challenge to Newton's inverse square law in the 1740s led to its vindication.

C. The return of Halley's comet in 1758 was seen as a testimony to the power of Newton's system.

V. By the end of the century, Newton's system had acquired almost godlike power.

A. Pierre Simon Laplace's "Newtonian" explanation of an irregularity in the moon's motion appeared to rescue the stability of the solar system.

B. The same author's *System of the World* of 1796 dispensed with the need for any divine supervision to account for the heavens.

C. Just as natural philosophers subjected the heavens to the rule of natural law over the course of the 18th century, so too, did they scrutinize the Earth and its past with the same intent.

Essential Reading:

Dear, *Revolutionizing the Sciences*, chapter 8.

Hankins, *Science and the Enlightenment*, chapter 2.

Supplementary Reading:

Westfall, *Never at Rest*, chapters 10, 14.

Terrall, "Émilie du Châtelet and the Gendering of Science," and *The Man Who Flattened the Earth: Maupertuis and the Sciences in the Enlightenment.*

Questions to Consider:

1. Given that Newton did not claim to explain what gravity was or the mechanism by which it worked, how is it that he became so famous?
2. If nature was regarded as a deterministic machine in the Newtonian worldview that emerged in the 18th century, how "Newtonian" was Newton himself?

Lecture Three

Theories of the Earth

Scope: Just as natural philosophers subjected the heavens to the rule of natural law over the course of the 18th century, so too, did they scrutinize the Earth and its past with the same intent. Although the majority of people simply accepted the Genesis account of the Earth's origin, natural philosophers in France and Scotland speculated in this era on the physical means God might have employed in creating the universe. These speculations became known as *theories of the Earth*—conjectures about the causal means God might have used to create the Earth and to shape it over the course of time. By introducing causal agencies that required long periods of time to mold the Earth into its present condition, these writers challenged the commonly accepted age of the Earth and, with it, the duration of history itself. This development illustrates that some natural philosophers had come to believe that God exercises control over nature through the action natural laws require. Nowhere was the clash between 18th-century natural philosophy and received wisdom more focused than on the question of the Earth's past.

Outline

I. The attitude of deists was likely to cause problems where the history of the Earth was concerned.

- **A.** Although not atheists, deists were interested in naturalistic explanations.
- **B.** Naturalistic explanations of how the Earth originated became known as *theories of the Earth.*

II. The tradition of speculating on the means God might have employed in creating the Earth emerged in both the 17th and 18th centuries.

- **A.** In the older theories of the Earth of the 17th century, the intent was to support the Genesis account.
- **B.** In the 18th century, natural philosophers were willing to free themselves from the confines of the commonly understood implications of biblical references.

III. Between 1692 and 1718, France's ambassador to Egypt, Benoît de Maillet, composed what he called "a new system on the diminution of the waters of the sea."

- **A.** As a traveler in the Mediterranean region, de Maillet possessed great curiosity about the area.
- **B.** De Maillet became convinced that his grandfather's theory about the waters of the sea diminishing was correct.
- **C.** He determined to write a book that laid out his idea.
  - **1.** De Maillet cast the work as a conversation between a Christian missionary and an Indian philosopher named Telliamed.
  - **2.** In this "Indian" understanding of the Earth's past, the Earth was originally covered with water, which gradually decreased, exposing, first, mountains, then more dry land.
- **D.** Telliamed maintained that various forms of aquatic animals had changed during the time the sea was gradually receding in accordance with natural processes.
  - **1.** Fish found that their fins became feet and served them to walk on land.
  - **2.** From structures in ancient Carthage, he estimated that the rate the sea level had dropped from earlier times to his day was three feet every thousand years.
- **E.** The work appeared in 1748, a decade after de Maillet himself died, and produced outrage.

IV. In 1749, the Comte de Buffon published the first three volumes of his *Natural History,* a multivolume work that set out to organize all that was known about the natural world.

- **A.** In the first volume, Buffon included a history of the Earth.
  - **1.** He suggested that the Earth and other planets had originated as the result of a comet that had struck the Sun at an oblique angle.
  - **2.** The Faculty of Theology of the Sorbonne in Paris condemned 14 propositions from *Natural History.*
- **B.** In 1778, Buffon republished his thesis about the comet in a widely read book entitled *Epochs of Creation.*
  - **1.** By this time, the atmosphere in France had changed from a quarter century earlier.
  - **2.** The unprecedented developments that would lead, in a decade, to the outbreak of the French Revolution meant that Buffon could safely publish his old radical ideas.
  - **3.** Buffon depicted seven epochs of formative activity that took a long time.
  - **4.** Life appeared only after 33,000 years. By the time humans appeared in the final epoch, some 70,000 years had passed.

V. In 1795, James Hutton published ideas communicated earlier to the Royal Society of Scotland about the Earth's past.

- **A.** Hutton invoked operations of nature that were not sudden and dramatic but "equable and steady." He found a causal agency for these slow changes in the interior heat of the Earth.

B. He believed that the development of the Earth he had described was just a part of a larger cyclical process.

VI. All these authors of theories of the Earth believed that God was still responsible for creation. But they had adopted the conviction that God acted on nature by establishing natural laws that dictated nature's course.

Essential Reading:

Bowler, *Evolution*, chapter 2, pp. 26–39.

Laudan, *From Mineralogy to Geology*, chapter 6.

Supplementary Reading:

Haber, *Age of the World*, chapter 3.

Questions to Consider:

1. What was it that prompted natural philosophers to ask themselves what means God had employed to create the Earth?
2. Why was it the extended time scale, rather than the implicit evolution of life, that was so offensive in the 18th century?

Lecture Four

Grappling with Rock Formations

Scope: At the end of the 18th century in Germany, there emerged an approach to the study of the Earth that contrasted in an important respect with the formation of speculative theories of the Earth's development based on universal causal laws. The German mineralogical tradition emphasized the gathering of empirical information about minerals, primarily because of its usefulness to the mining industry. In the 18th century, the scope of German mineralogy expanded to include more than merely the mineral content of the Earth's crust. The primary German mineralogist of the late 18th century, Abraham Werner, continued to emphasize careful observation and created a geological system based on the time of formation of rocks that proved enormously influential, especially on the Continent. Werner's work left an indelible imprint on those who established geology as a science in the decades after him.

Outline

I. In the last lecture, we examined attempts by natural philosophers in the 18th century to explain how the Earth and its creatures came to have the features they do through an appeal to causal natural laws.

- **A.** As in astronomy, it was a case of creation by natural law; that is, in place of God as the direct cause, they placed the operation of natural laws God had imposed on nature.
- **B.** These explanations were not atheistic, because God was necessary as the creator of the laws. God operated on nature, not directly by fiat, but by remote control through the laws. This conception has been called *deism*.

II. In this lecture, we consider another 18th-century approach to understanding the Earth and its history. Its most distinguishing feature was its reluctance to search for grandiose and universal causal laws to explain the present features of the Earth's surface.

- **A.** This approach emerged in Germany with roots in the German mineralogical tradition.
  - **1.** The presence of rich deposits of ore drew primary attention to metals and accounted for the long-established mining tradition in such regions as the Erz Mountains of Saxony.
  - **2.** Mining officials wanted practical information about the location and properties of valuable metals, including lead, copper, and silver.

        3. In the 18th century, state officials established technical schools, separate from the universities, for the purpose of training the officials they required.
    B. Rather than searching for universal causal laws, German mineralogists preferred to gather information about the various forms of solid materials found on Earth. They were, therefore, more empirically oriented.
        1. Their focus remained on the Earth and its features, not as much on the development of life.
        2. They did, however, make inferences from the data they gathered about the Earth's past.
    C. This mineralogical tradition is interesting in its own right and is of central importance for later developments.
        1. Many early 19th-century thinkers, especially on the Continent, identified with the empiricism of this tradition, shunning the more speculative traditions of the theorists of the Earth.
        2. Key notions in later geology, such as the importance of rocks and the idea of rock formation, emerge from this work.

III. By far, the central figure in this 18th-century story is Abraham Werner (1749–1817), who studied and later taught at the mining academy in Freiberg.

- **A.** First, we need to know what Werner inherited from his predecessors in the German mineralogical tradition.
- **B.** Then, we will examine what Werner contributed that earned him an international reputation.

IV. There were many different ways of classifying what were known as minerals.

- **A.** One common classification scheme in the 18th century included four classes: earths, metals, salts, and sulfurs.
- **B.** German mineralogists gathered information about these various forms of solid materials found on Earth.
- **C.** We're interested here primarily in earths.
- **D.** For earths other than rocks, mineralogists preferred an analysis called the *wet way*, which involved both tests for solubility in water and, where possible, precipitation from solutions, such as at hot springs and health spas.
    - **1.** Chemists contributed their understanding of interactions of earths with acids and bases.
    - **2.** From numerous investigations, experimenters differentiated a whole range of earths, based on their solubility.
- **E.** In the 18th century, German scholars began to subject rocks, previously regarded as mere conglomerations of individual minerals not worthy of study in their own right, to classification.
    - **1.** They categorized rocks according to the effect heat had on them, the so-called *dry way*.
    - **2.** They began to gather more information than just the mineral content of the rocks.
    - **3.** Where the history of the Earth was concerned, there was widespread acceptance among 18th-century mineralogists that the original ocean referred to in Genesis had been a thick, gelatinous, aqueous fluid made up of minerals in solution.
    - **4.** Rocks and most other solid minerals formed over time by a process of consolidation, that is, the transition from fluidity to solidity.
    - **5.** This was the major problem to be tackled until the end of the 18th century.

V. Abraham Werner drew on the collected wisdom of his predecessors to create a geological system that made him famous across Europe in the late 18th century and after.

- **A.** Werner's most important contribution was to make the *time* of formation of rocks, not their mineralogy, their most important feature.
    - **1.** It was Werner who gave to geology the historical entities he called "formations" for rocks that had been formed at the same period.
    - **2.** Werner focused on the *variety* of information gathered about rocks.
    - **3.** Unlike his predecessors, his goal was to develop a systematic knowledge of all the data gathered about individual regions to determine when and how their rocks had been laid down.
    - **4.** He called his new approach *geognosy*, based on the Greek word for "abstract knowledge."
- **B.** Werner used his approach to draw conclusions about the Earth's history.
    - **1.** The oldest rocks from the calm waters of the primeval ocean consolidated in successive individual formations to form a "primitive class."
    - **2.** Next came a small class of formations he called "transition" rocks, some of which had formed in turbulent waters.
    - **3.** The third class of formations he called "stratified" rocks, some of which resulted from mechanical pressure, while others consolidated by chemical means.
    - **4.** The final class of formations, the "recent" class, came from eroded material deposited by moving water and from the extruded material of volcanoes.
- **C.** Contrary to a widespread impression, Werner did not appeal to sudden and dramatic events to explain how the Earth had developed.

    1. He held that the primeval ocean had gradually retreated over time and that there was evidence to indicate that the retreat had occasionally reversed itself.
    2. Werner preferred not to endorse speculations about where the retreating water had gone, believing it was sufficiently clear that the waters *had* retreated.
    3. Late in his life, he invoked the new knowledge that water was composed of gases to suggest that primal waters had decomposed when forming the atmosphere.

- **D.** Werner joined others who were willing to extend the history of the Earth far beyond the 6,000 years inferred from a literal reading of the Old Testament.
    1. His preference was not to speculate about matters that did not easily lend themselves to precise determination, but he conceded that there was a time "when the waters, perhaps a million years ago, completely covered the earth."
    2. Werner came from a devout pietistic background, but he appears not to have allowed any traditional religious views he may have had to determine his geological considerations.
    3. The effect of Werner's work was to add to those who argued that the Earth was a cosmic body whose past had been shaped by natural processes.
    4. Because of the enormous influence Werner exerted through his celebrated teaching at Freiberg, he helped shape the immediate future into the third decade of the 19th century.

Essential Reading:

Bowler, *Evolution*, chapter 2, pp. 39–49.

Laudan, *From Mineralogy to Geology*, chapters 4–5.

Supplementary Reading:

Porter, *Making of Geology*, chapter 6.

Questions to Consider:

1. Why was it so obvious to thinkers in the German tradition that rocks had formed by a process of consolidation from a primitive fluid into solids?
2. Although Werner never published much, students came from all over Europe to study with him. Exactly what was it about Werner's system that attracted so many to Freiberg?

Lecture Five

Alchemy under Pressure

Scope: The alchemical understanding concerning the interactions among various material substances was challenged in the 18th century by the attempt to define a rational approach to chemistry. Part of the motivation was to dissociate the emerging investigative techniques of chemical experimentation from the craft tradition associated with alchemical practice. In the analysis of combustion, Georg Stahl, in Germany, drew on developments in the 17th century to create a coherent explanation of combustion based on *phlogiston*, the weightless substance of fire. By the middle of the century, new developments in the analysis of salts resulted in an increased emphasis on quantitative measurement that had not been emphasized in alchemy.

Outline

- **I.** In the analysis of rocks, natural philosophers concerned with mineralogy in the 18th century stood close to those interested in chemistry.
    - **A.** By the end of the 18th century, chemistry had taken on a new status from what it had earlier.
    - **B.** In this lecture, we will examine how this new status emerged from its older links to alchemy.
    - **C.** We will see how, in spite of alchemy's continued presence, the Enlightenment emphasis on reason allowed chemists to differentiate themselves from alchemists.
- **II.** The 17th century included a mixture of approaches to understanding how material substances combined.
    - **A.** The meanings of the terms *alchemy* and *chemistry* are not cleanly distinguishable in the 17th century.
        1. *Chymistry* is the more inclusive term, involving an understanding of the elements and essential principles that combined to form bodies.
        2. Chemists sought to extract such principles and elements from bodies, then later to add them back to reconstitute the bodies.
        3. Such knowledge could also be helpful in purifying substances of impurities or in attempts to transmute one material into another.
        4. Chemical knowledge could be useful; for example, a frequent goal was to find applications of chemical knowledge to find medicines or stronger metals.

        5. But to the extent chemistry was associated with the "merely" practical arts, it could not enjoy the higher status rendered to philosophy.
    - **B.** The classical alchemical pursuit of transmutation waxed strong during the 17th century.
        1. This is seen in the great number of works published on the subject.
        2. Numerous leading natural philosophers, including Robert Boyle and Isaac Newton, investigated the possibility of alchemical transmutation.
        3. Increasingly, alchemical experimentation was pursued with a view to advancing natural philosophy, albeit the pre-Enlightenment form of natural philosophy.

III. From before the beginning of the 18th century, there were signs that chemistry was beginning to be differentiated from alchemy.

- **A.** Chemistry had begun to see itself as a separate investigative enterprise.
    1. Experimentation in the chemistry of salts led to a replacement of older conceptions of composition based on elements and principles with the more practical notions of acids and alkalis.
    2. Chemistry was incorporated as a major activity in the French Academy of Sciences from its founding in 1666.
    3. In 1718, Etienne Geoffroy, prominent professor of chemistry at the Jardin du Roi, published tables of the affinities observed between different chemical substances.
    4. Growth in the chemistry of salts, especially in France, marked chemistry as an investigative science.
- **B.** Some chemists began to expand the craft traditions with which they had been associated to include a rational intellectual focus.
    1. Those engaged in craft traditions were often regarded as artisans who were primarily concerned with making a livelihood.
    2. Such individuals generally stood lower on the social scale than those who dealt with intellectual or spiritual truth.
    3. By incorporating into chemistry an intellectual concern to make it a rational enterprise, chemistry could be differentiated from alchemy.

IV. In Germany during the early decades of the 18th century, Georg Stahl, professor of medicine at Halle and later court physician in Prussia, attempted to create "rational chemistry," as opposed to alchemy.

- **A.** Stahl insisted that the meaning of the words *alchemy* and *chemistry*, long used interchangeably, had recently come to denote two completely different undertakings.
    1. He identified alchemy as the mostly confused and largely vain attempt to make gold.

        2. Chemistry was different, because it was devoted to rational experimentation as a means of expanding fundamental knowledge of natural substances.
        3. Stahl did not define what he meant by *rational.*
- **B.** Although he did not deny that transmutation was possible, Stahl and his followers criticized alchemy severely for its negative impact on society.
    1. It nourished swindling and promoted longing for gold and fantastic medicines.
    2. It distracted its enthusiasts from their obligations to God.
    3. There were no teachers capable of giving rational instruction in alchemy.
- **C.** Stahl continued to identify with medicine and the craft traditions while attempting to define "true chemistry."
    1. It was inspired by "rational enthusiasm for research."
    2. It came from a desire to know the true knowledge of material composition for its own sake, not for material wealth.
    3. It resulted from rational chemical process, the knowledge of which could be used to understand how to improve medicine, mineral processing, distilling, brewing, glass making, and other useful endeavors.

V. Stahl also tried to construct a chemical system that revealed the intimate composition of substances. The best known feature of the system was Stahl's treatment of combustion.

- **A.** Stahl drew on the work of Joachim Becher, a predecessor in the 17th century.
    1. Becher created a system of elements and principles that drew on Paracelsus and Aristotle.
    2. An Earth, *terra pinguis* or "oily earth," was regarded as the constituent present in all bodies that could be burned.
- **B.** In 1702, Stahl introduced his interpretation of combustion, which was based on that of Becher.
    1. Stahl adopted the name *phlogiston* for Becher's combustive principle.
    2. Phlogiston, for Stahl, was an imponderable substance; that is, it was substantial but it did not weigh anything. By itself, it could not be detected by the senses.
    3. Phlogiston is found loosely present in some substances. Combustion, in fact, occurs when these bodies lose their phlogiston.
    4. Such substances as charcoal and oils are especially rich in phlogiston; incombustible bodies have either already lost or do not contain phlogiston.

    5. Phlogiston is not the same as fire, which is sensible, but it is the motive power of fire particles.

  - **C.** Stahl, and especially his many followers, used this basic understanding to explain why metals rust.
    1. Stahl explained the rusting of metals, called *calcination*, as their loss of phlogiston.
    2. Stahl never discussed the fact that metals gained weight on rusting.
    3. An early convert to Stahl's phlogiston theory, Johann Juncker, misinterpreted Stahl's phlogiston as something material.
    4. He introduced the idea that phlogiston buoys up the metals that contain them so that when the metal loses its phlogiston to become calx, the heavier weight emerges.
  - **D.** Phlogiston could be used to supply a coherent account of more forms of combustion than merely calcination.
    1. A burning candle placed under a bell jar goes out because the enclosed space is saturated with phlogiston, preventing any further release of additional phlogiston.
    2. If digestion of food involves "burning," then a mouse placed under a bell jar should die when the air become saturated with phlogiston-rich exhaled air.

VI. Over the course of the 18th century, the phlogiston theory continued to gain adherents in Germany, France, Sweden, and Britain, who found it useful in their continued exploration of chemistry.

  - **A.** Before the middle of the 18th century, Stahl's approach was most well known in Germany.
  - **B.** Increasing demands of industry, especially metallurgy, aroused greater interest in German chemical texts, many of which were translated between 1750–1760.
  - **C.** By 1770, when an important new saga in the history of chemistry was about to unfold, phlogiston theory had enjoyed wide popularity in France and Britain for 20 years.

Essential Reading:

Smith, *Business of Alchemy*, chapter 4.

Supplementary Reading:

Holmes, *Eighteenth Century Chemistry as an Investigative Enterprise*.

Hufbauer, *Formation of the German Chemical Community*, chapter 1.

Questions to Consider:

1. In explaining the eventual separation of chemistry from alchemy in the 18th century, how sufficient is it to appeal to the emerging social perceptions of the two enterprises?
2. Why did it take longer in chemistry than in astronomy for natural philosophers to insist that observations be measured in precise quantitative terms?

Lecture Six

Lavoisier and the New French Chemistry

Scope: In the 1780s, a number of investigators in Britain, Germany, and France were conducting experiments to identify the properties of new "airs" (gases) and to explore the different ways chemical substances interacted. Of special significance among these experimenters was Joseph Priestley in England, who developed the phlogiston theory of combustion to its zenith in the late 18th century. Priestley's discovery of the gas later called oxygen set in process a series of events that led to the creation of a new explanation of combustion by Antoine Lavoisier in Paris. The new French approach claimed to base itself on a principle of the conservation of matter, thereby stressing the role of weighing reagents before and after a chemical reaction. The ensuing debate over the new French chemistry eventually settled the matter in favor of Lavoisier's quantitative approach.

Outline

I. In the last lecture, we looked at an attempt in the first half of the 18th century to identify chemistry as a rational science, thereby differentiating it from alchemy, with which it had long been associated.

II. Two other factors should be mentioned before turning to the subject of this lecture, which is the new French system of chemistry that arose in the last three decades of the century.

- **A.** First was the work of Stephen Hales in England during the 1720s. Hales was interested in the fumes produced when various substances, such as plants, were heated in a flask.
  - **1.** Because an "air" resulted, it was assumed that air was "fixed" in the plant and had been set free by the heating process. It became known as "fixed air."
  - **2.** Hales was interested in the amounts of air he could release from its fixed state in various substances. He did not inquire about the properties of the air he obtained.
- **B.** Second was the realization that weighing the fixed air released in a reaction could be important.
  - **1.** Traditionally, experimenters were uninterested in the air (gas) produced in chemical reactions. It simply disappeared up the chimney.
  - **2.** One investigator at mid-century who realized the importance of weighing was the Scot Joseph Black. He was investigating the value of magnesia as an antacid.
  - **3.** Black noticed that the exact same weight loss occurred in two different experiments involving magnesia alba (calcium carbonate). In one, he heated the magnesia alba, and in the other, he added an acid to it.

    $\text{Magnesia alba} + \text{acid} \rightarrow \text{residue}_1 + \text{weight loss}$
    $\text{Magnesia alba} + \text{heat} \rightarrow \text{residue}_2 + \text{weight loss}$
  - **4.** Subtracting the second line from the first (because heat does not weigh anything) gives

    $\text{acid} \rightarrow \text{residue}_1 - \text{residue}_2$

    Therefore,

    $\text{acid} + \text{residue}_2 = \text{residue}_1$
  - **5.** Black assumed that the weight loss was the result of the fixed air produced in both cases.
  - **6.** The equality of the weight loss in the two different experiments led him to investigate the properties of the fixed air.
  - **7.** Black was able to show that the air was different from ordinary air.
  - **8.** By identifying a new individual air with its own properties, Black opened up chemistry to the possibility that there may be many new airs.
  - **9.** Chemists quickly began devising means for producing and investigating the properties of new airs.

III. One particularly successful gas chemist was the Englishman Joseph Priestley, who identified numerous new airs during the latter part of the 18th century.

- **A.** Priestley was convinced of the phlogiston theory of combustion and used it to help explain the results of his experiments.
  - **1.** He explained the heating of a metal to produce a calx (rusted metal) as the loss of phlogiston from the metal.
  - **2.** Heating the calx further "reduced" the calx back to the metal. This was the result of the recombination of the calx with phlogiston. For that, he would need a source of new phlogiston.
  - **3.** Priestley assumed the new phlogiston was supplied by the charcoal used to produce the heat.
  - **4.** Thus,

    $\text{metal} + \text{heat} \rightarrow \text{calx} + \text{phlogiston}$
    $\text{calx} + \text{more heat} \rightarrow \text{metal}$
- **B.** In the summer of 1774, Priestley acquired a 12-inch burning lens he could use to heat substances.
  - **1.** He used it to heat mercury calx and noticed, to his surprise, that the calx turned into the metal without a source of phlogiston being present.

    2. In addition, he noticed that an air was produced that readily supported combustion. He assumed that it was laughing gas, an air he had discovered earlier that supported combustion.
    3. On a trip to France that fall, Priestley explained his puzzling results to French natural philosophers.
    4. After returning home, Priestley conducted further tests and realized that his new air was not laughing gas but a new air.

IV. Among the French chemists who heard Priestley describe his puzzling results was Antoine Lavoisier, a gifted experimenter, who two years earlier, had been promoted to an associate in the French Academy of Sciences.

- **A.** Earlier that same year (1774), Lavoisier had translated and become familiar with the work of Joseph Black, whose careful quantitative approach he appreciated.
- **B.** Two years earlier, in 1772, Lavoisier had been investigating why metals gain weight when they rust.
    1. He expressed dissatisfaction with Stahl's phlogiston theory, which he characterized as seriously flawed, because he suspected that the metal was fixing air into itself as it gained weight, yet phlogiston was allegedly being lost at the same time.
    2. Lavoisier resolved to conduct extensive additional experiments on both the fixing of air by and the release of air from various substances.
    3. One of the experiments he tried in early fall of 1774 was with mercury calx, the same substance Priestley had experimented with earlier that summer. But Lavoisier did not notice anything unusual about the air produced.
- **C.** Priestley's visit spurred Lavoisier to redo the experiment with mercury calx.
    1. This time, he did the experiment using two different means of heating the calx: with a burning lens and with a charcoal fire.
    2. A check of the airs produced in the two cases revealed that they were different: Using a burning lens gave an air that supported combustion; using charcoal gave Black's fixed air, which did not support combustion.
    3. Lavoisier reported to the Academy in the spring of 1775 that when metals rust to form a calx, their gain in weight is the result of the addition to the metal of "the purest part of the very air which surrounds us, which we breathe."
    4. He added that when fixed air was produced, it was because of the presence of charcoal.
- **D.** The aftermath of the story contains several ironies.
    1. It was Priestley who realized that the air produced using a lens was not pure common air but a new gas. Yet it was Lavoisier who named the new gas *oxygen* ("acid-maker"), because he thought it was present in all acids.
    2. Lavoisier's account of combustion as the addition of oxygen dispensed with the weightless fluid called phlogiston.
    3. He insisted that matter may change forms during a chemical reaction, but it cannot be created or destroyed. He is known for having announced this principle as the conservation of matter.
    4. Although Lavoisier became known as the father of modern chemistry, Lavoisier himself believed that heat was a weightless element that was combined with the air. During combustion, it is released as the air becomes fixed in the metal. The release of heat did not disturb the conservation of matter, because heat does not weigh anything.
    5. The presence of a weightless substance in both the old and new chemistries of the late 18th century meant that it would take some time for the new oxygen-based understanding of combustion to become the consensus.

V. This episode shows us that major changes in our views of nature often do not occur suddenly as the result of a single person's insight in which all is clear.

Essential Reading:

Donovan, *Antoine Lavoisier*, Part II.

Supplementary Reading:

Hufbauer, *Formation of the German Chemical Community*, chapters 7–9.

Questions to Consider:

1. Who discovered oxygen, Priestley or Lavoisier?
2. Lavoisier is often called the father of modern chemistry, because he rejected the weightless element phlogiston and insisted that matter is conserved. Yet he believed that heat was a weightless elemental substance that entered into chemical reactions. Why, therefore, is he seen as so modern?

Lecture Seven
The Classification of Living Things

Scope: In the view of living things inherited in the 18th century, species existed as God had originally created them. The number and kind of species were fixed—therefore, not subject to change—and each organism took its place in an orderly arrangement that ascended from the lowest form to the most complex. During the century, Carl Linnaeus developed a system of botanical classification that, because it did not attempt to appeal to all the characteristics of a species, was easier to use and led to a standardization of nomenclature. Through long study of thousands of plants, Linnaeus came to doubt the absolute fixity of species over the course of his career. His conclusions, as well as those that Georges Buffon drew about animal species, add to those from geology that were challenging the accepted view of the past.

Outline

I. In an earlier course on history of science prior to 1700, Professor Principe from Johns Hopkins University described the explosion in the number of plants and animals recognized during the 16th and 17th centuries.

- **A.** He noted that the invention of the microscope made possible new knowledge of the internal structure of plants and animals.
- **B.** He emphasized that natural history emerged during this period as a part of natural philosophy in which plants and animals represented a collection of individual objects of interest in their own right, as opposed to being regarded as emblematic of some religious or moral truth, as they had been earlier in the Middle Ages.
- **C.** In this lecture, we will investigate what became of all this knowledge in the 18th century.

II. Other aspects of the heritage from the past also shaped the context in which 18th-century naturalists attempted to organize the wealth of new knowledge about the living world.

- **A.** From the Greek conception of the cosmos, as articulated in the Platonic tradition, it was understood that the cosmos had a divine origin. As such, it was complete, which could only be if, as Plato said in the *Timaeus*, it contained "all sorts of living creatures."
  - **1.** In the Latin West, this understanding came to mean that everything that could exist did exist, that God's creation, arranged in a staircase of being (*scalae naturae*), was complete.

  - **2.** To say that this was *not* the case would imply that God had erred, that God had neglected to create some beings that could have taken their place among living things.
  - **3.** Some time ago, the historian Arthur Lovejoy characterized the view of the world of organisms that resulted from this perspective as a "great chain of being," proceeding from the simplest form of life upward until it reached the godhead itself.
  - **4.** John Locke, in the 17th century, located human beings in the middle of this ascending chain.
- **B.** Accompanying this assumption was another: that the perfection of the original creation had not changed since the creation.
  - **1.** To suggest, for example, that some species had come into being subsequent to the original creation implied that God had forgotten to include them, that there had been a gap in the original chain that only later was filled.
  - **2.** This notion has been called the *doctrine of the fixity of species.*
  - **3.** As it came down to the 18th century, this doctrine meant that species, being fixed in place, did not go out of existence, did not come into existence, and did not change from what they originally were.
- **C.** Naturalists asked themselves whether it was possible to specify a taxonomy that reflected accurately how organisms related to each other, perhaps even the plan God had followed.

III. Among those who took up this question of a natural order in the 18th century was a Swede named Carl Linnaeus.

- **A.** Carl's parents hoped that he would go into the Swedish Lutheran ministry, but he disappointed them.
- **B.** After a year at Lund University, Linnaeus moved to Uppsala, where there was a herbarium of 3000 species.
  - **1.** Even this early in his training, Linnaeus determined that the botanical work he had been reading was inadequate.
  - **2.** He would take on the task of describing all flowers accurately and "bring them into new classes, reform name and genera, in a completely new way."
- **C.** The occasion for his decision to erect a new system was his reading about the French botanist Sébastien Vaillant's work on plant sexuality.
- **D.** In the early 1730s, the young student wrote out his first thoughts on a sexual system of plant classification. He argued that nature itself proclaims sexuality should be the basis for classification, because fruiting occurs so consistently.
  - **1.** In his system, he used the number of stamens and their relation to each other as the basis of the major divisions of plants into classes.

2. By 1735, he had written the first edition of his *System of Nature*, a slim book that grew, in later editions, into a multivolume classic that made Linnaeus famous.
3. Linnaeus conceded, however, that his system was not the natural order he and others ideally sought.

E. In various writings from around the middle of the century, Linnaeus introduced a refinement to his system that eventually would standardize botanical nomenclature.

1. At the time, identifying plants from the names they were given was extremely difficult, because it required consulting one of the several books containing enormous lists of names.
2. Linnaeus insisted that the species name should do more than merely describe the plant; it should differentiate it from other species in the same genus.
3. Linnaeus's success in accomplishing this binomial classification scheme became evident from its widespread acceptance.

IV. At Uppsala, Linnaeus saw himself as an agent of change, as one who would improve understanding for the benefit of his fatherland.

A. He undertook much of his research as an expression of his commitment to improving the Swedish economy by making it more self-sufficient.

B. Among his more famous endeavors were the attempts to acclimatize plants from elsewhere, even from tropical regions, to the Swedish climate.

1. He sent students all over the world as his emissaries to gather information and to bring back products for acclimatization experiments.
2. His assumption was that a plant species exposed to a colder climate would develop into a stronger variety.

V. Linnaeus and other naturalists also began to think that species were not as fixed as most people believed.

A. In Linnaeus's case, his exhaustive study of new plants over two decades brought him to a different understanding of God's work at the creation.

1. Having observed plants with unusual features, Linnaeus first considered the possibility that the emergence of varieties was the result of natural hybridization, not of differences in soil.
2. By the 1760s, he had come to the conclusion that God had originally created only a small number of species, which through hybridization, gradually produced primordial genera.

B. Georges Buffon, who was critical of Linnaeus's "artificial" system of classification, also concluded that species were not as fixed as most commonly assumed.

1. Working on animals, as opposed to plants, Buffon concluded that what Linnaeans would call different species were really variants of an original ancestral form.
2. The ancestral form had "degenerated" when individuals changed locations because of differences in external conditions, such as climate.
3. Practical reasons make it impossible for these degenerations to interbreed at present, but if the external conditions that caused the degeneration to occur were removed, the ancestral form would reemerge as quickly as it had degenerated.

VI. As in the case of the novel ideas about the Earth and its history, considerations of the world of living things brought with it certain challenges to widely accepted ideas.

A. The easy understanding of living things as the result of God's direct creative decree was complicated by conclusions that God may have employed natural processes to accomplish his ends.

B. The nature of these natural processes, especially in Buffon's understanding of degeneration, required much more time than was conventionally conceived.

Essential Reading:

Koerner, *Linnaeus*, chapters 1, 2, and 6.

Glass, *Forerunners of Darwin*, chapter 4.

Supplementary Reading:

Frängsmyr, ed., *Linnaeus*: *The Man and His Work,* essay by Lindroth.

Questions to Consider:

1. In your mind, is a natural order of classification a theoretical possibility?
2. Given that Buffon agreed with Linnaeus that species were not fixed, why was he so critical of Linnaeus's system?

Lecture Eight

How the Embryo Develops

Scope: During the second half of the century, a famous debate occurred concerning the knotty problem of embryonic development. How do embryos of different organisms, which seem in the earliest stages to resemble each other, know how and when to follow different paths to produce different adult forms? After reviewing the wisdom handed down to those in the 18th century on this question, we will follow the development of the two major answers considered, concluding the treatment with an investigation of the extended debate between Albrecht von Haller and Caspar Friedrich Wolff, beginning in 1758. Noting that each of their respective positions depended on close empirical observation, we conclude by asking how best to explain their different readings of what they saw.

Outline

I. In the last lecture, we looked at the emergence, in the 18th century, of a new system of classification for the diverse *kinds* of living things that were known at the time.

II. In this lecture, the focus is not on groups of living things, but on individuals and their development.

- **A.** In particular, we're going to ask questions especially about reproduction in animals, which requires the presence of males and females. How did naturalists explain what goes on during growth?
- **B.** How does one embryo know to develop into a rabbit and another into a horse?

III. What was the inherited wisdom on these matters that came to naturalists of the 18th century from their predecessors?

- **A.** According to Descartes, in the 17th century, male and female semen was mixed in procreation.
  - **1.** The particles of the mixed semen underwent a fermentation that slowly formed the heart and other parts of the animal body.
  - **2.** Descartes simply asserted that the formation occurred without indicating why or how different adult forms came about.
- **B.** Nicolas Malebranche soon criticized Descartes's mechanical explanation.
  - **1.** In 1674, he proposed that adult forms were encased, preformed, in the eggs of animals; the sperms unleashed a gradual expansion of the form as it grew to adulthood.

  - **2.** The miniature adult forms contained in each egg, in turn, contained even more minute adult forms and so on, thereby accounting for all future adults that would come in that line.
  - **3.** Because all adults that would ever live were already formed in miniature, one did not have to explain how the embryo knew the final form into which it was to develop.
- **C.** At the beginning of the 18th century, preformation was widely accepted among natural philosophers, who allowed that God had encased adult forms at the original creation.
  - **1.** Preformationists did not deny that mechanical laws were involved, just that they could not by themselves explain how the embryo unfolded.
  - **2.** Although some preformationists argued that it was the sperm that contained the encased adult forms, the great majority believed that the egg played this role.
- **D.** In the 1740s, preformation was supported by the discovery of parthenogenesis.
  - **1.** Charles Bonnet in France showed that female aphids, also known as tree lice, could reproduce themselves for several generations without fertilization by a male.
  - **2.** Bonnet became convinced that miniature forms had to be stored in the females.

IV. Around this same time some opposition to preformation theory emerged.

- **A.** The discovery by the Swiss Abraham Trembley of the freshwater polyp in 1741 raised questions about preformation.
  - **1.** He initially thought that the polyp was a plant but observed that it was capable of independent motion and concluded that it was an animal.
  - **2.** He also discovered that the polyp was capable of regenerating a complete organism after having been cut in two.
  - **3.** Apparently no complete miniature adult form was necessary to produce an intact adult form.
- **B.** Georges Buffon, the celebrated natural philosopher we have met in other lectures, also criticized preformation.
  - **1.** If one examines the developing embryo, it shows no change at all for some time, then the formation occurs gradually.
  - **2.** Given that offspring resemble *both* parents, the mixing of the seminal fluids of both parents must be necessary to form a composite entity.
  - **3.** Buffon did concede that nature must have provided what he called an internal mold that directed the development of the embryo.

4. The claim of Buffon and others that the embryo was a formless mass and that its development proceeded from material that was *previously unorganized* has been called *epigenesis*.

V. A famous debate between preformationists and epigeneticists took place in the 1760s and 1770s.

A. Albrecht von Haller, a Swiss physician, journal editor, and general polymath, wrote a book in 1758 on the formation of the heart in chickens.

1. As a student back in the 1720s, Haller had learned preformation theory from his teacher Hermann Boerhaave.
2. When he heard about Trembley's polyp in the 1740s, he changed his mind and became an epigeneticist.
3. When Buffon published epigeneticist ideas about generation in 1749, Haller reconsidered questions of generation.
4. For three summers in the mid-1750s, Haller conducted a series of experiments on incubated chicken eggs.
5. He observed that the membranes of the yolk were like the membranes of the intestines of the embryo. From this, he concluded that the yolk was but an expansion of the small intestine of the chicken.
6. Haller announced his reconversion back to preformation in a letter to Bonnet in September of 1757, publishing his conclusions to the wider world the next year.

B. The reply to Haller's announcement came quickly from a young German physician in Berlin named Caspar Friedrich Wolff.

1. Wolff strongly supported epigenesis, which he had just defended in his doctoral dissertation, a copy of which he sent to Haller.
2. Wolff argued that the embryo developed as a result of the solidification of fluids; that is, fluids are secreted that then solidify into structures.
3. After a part is formed, the flow of new fluids into it produces vessels that define its organization.
4. Wolff claimed that his numerous careful observations of embryonic development confirmed the kind of process he described, denying that fully formed parts emerged as expansions of preformed structures.
5. Haller and Wolff both appealed to empirical observations to substantiate their respective claims.

VI. How do we explain the different ways in which Haller and Wolff read the same empirical data? The different interpretations Haller and Wolff made of the same empirical observations stemmed from their differing philosophical positions.

A. Haller's position is entirely consistent with the Newtonianism he inherited from his teacher Boerhaave.

1. Very much like Newton, he employed mechanical laws to describe nature, but he did so within limits.
2. Again like Newton, Haller believed it was dangerous to attribute active forces directly to matter; rather, matter is itself passive.
3. If matter possessed active forces on its own, then godless materialism was not far behind.
4. Haller allowed for mechanical expansion of embryos but insisted that God was responsible for the original organization that expanded to form adult individuals.
5. In this way, Haller reconciled his belief in mechanism with his religiously motivated opposition to materialism.

B. Wolff saw his position as a natural outgrowth of the Leibnizian heritage he embraced, even though his epigeneticist view was not required by this heritage.

1. Leibniz, a contemporary and rival of Newton, allowed matter itself to possess active agency in the course of putting together an elaborate metaphysical system.
2. Wolff determined to be the first person to apply the principles of rationalism to embryology.
3. In his defense of epigenesis, Caspar Friedrich Wolff denied that embryonic development is guided by the soul, insisting that physical processes of secretion and solidification are sufficient to explain embryonic development.

C. In the end, the conception each had of God's role provides a helpful means of distinguishing their views.

1. For Haller, God had to be directly involved. In this, he again resembled his predecessor Isaac Newton.
2. Wolff objected to the preformationists' direct appeal to God.
3. Although the preformation theory, as enunciated in the 18th century, passed from the stage, the issue of God's relation to nature remained very much alive.

Essential Reading:

Richards, *Meaning of Evolution*, chapter 2.

Roe, *Matter, Life, and Generation*, chapters 3–4.

Supplementary Reading:

Clark et al, eds., *Sciences in Enlightened Europe*, chapter 6, essay by Hagner, pp. 186–199.

Questions to Consider:

1. To the modern eye, preformation theory seems absurd. How was it that it was so widely persuasive in the early 18th century?
2. Does today's natural science accept the idea of a formative force directing the way the embryo develops from an unorganized state?

Lecture Nine

Medical Healers and Their Roles

Scope: In this lecture, we will examine the general understanding of health and disease of the 18th century, as well as the bewildering array of medical healers that graced the countryside. A distinguishing feature of both medical knowledge and practice is that it was not confined by the law, nor did it necessarily follow the contours of social rank to the extent one might expect.

Outline

I. In the last two lectures, we entered the world of animate nature.

- **A.** We examined, first, how natural philosophers in the 18th century came to arrange the great variety of all living things into a system of classification.
- **B.** We then brought our attention down to animal life in particular and considered the perplexing question, with its two fascinating alternative answers, of how animal life develops from its embryonic beginnings into its many different adult forms.

II. In this lecture, the focus narrows even more onto one specific organic being—homo sapiens. The goal changes from the 18th-century understanding of how our body develops to how to maintain and repair it when it gets out of whack.

- **A.** We ask, first, about how health and disease were understood in the 18th century, then examine the intriguing world of medical healers.
- **B.** Preliminary to pursuing this agenda, we'll make an observation about how this subject differs from many of the other topics we have considered.
  - **1.** Most of the other subjects we have considered generally involved esoteric knowledge, of interest to a limited segment of society.
  - **2.** This is not the case with knowledge about healing.
- **C.** An important observation to make is that we cannot accurately describe healing practices of the 18th century if we impose on them an assumption common to our own day: that there is an accepted standard practice dominated by physicians, whose knowledge of health and disease differs drastically from that of a world of alternative practitioners.
  - **1.** The understanding of what health and disease are was basically the same among physicians and other kinds of healers in the 18th century.

   2. When the sick sought out healers, they could go back and forth from one kind of healer to another, even when that involved crossing social boundaries.

III. What was the common understanding of health and disease?

- **A.** Health depended mainly on the notion of balance, an ancient notion that endured throughout the medieval and Renaissance periods into the 18th century.
  - **1.** Health required that there be equilibrium, for example, among the four humors, or fluids, in the body that corresponded to the four elements of earth, air, fire, and water. The corresponding humors were black bile, yellow bile, blood, and phlegm.
  - **2.** Disease, then, arose when an imbalance occurred in the normal distribution of the humors. A modified form of humoralism persisted into the 18th century.
- **B.** In the 18th century, the art of living a healthy life, of actively pursuing balance among factors we can control, fell under the idea of *dietetics*, which was understood in the sense of "regimens."
  - **1.** Factors we can control were called the *non-naturals*, or things not given by nature: *fresh* air, food, movement (exercise), sleep, excretion, passion.
  - **2.** The watchword here was moderation—not to permit excess in any area.
  - **3.** Healers paid particular attention to food and excretions. Hampered evacuations (sweat, urine, feces) was the most common diagnosis for illness.
- **C.** To maintain moderation, the most common remedies were bleeding and purgatives.
- **D.** What's crucial to realize here is that healers of all kinds agreed about this.
  - **1.** This was the message reinforced in the increasing popular literature that appeared on medicine during the 18th century, written by physicians.
  - **2.** It also marked the general views of non-physician healers, of which there were many kinds.
  - **3.** We can distinguish physicians from non-physician healers but not according to the basic content of the medical knowledge they possessed. The distinction is much more a social one.

IV. Who were the healers of the 18th century?

- **A.** The life of most physicians was not easy.
  - **1.** New graduates from a medical faculty who hung out a shingle found things especially tough.
  - **2.** A physician might become a district *physicus*. This position carried administrative duties of overseeing medical practice, but because the physicus answered both to a higher medical board *and* local political authorities, it was often a no-win situation.
  - **3.** Best if one could become a court physician or, even better, the personal physician of the duke or king.
- **B.** Officially approved healers also included apothecaries, midwives, and surgeons, who had to complete an apprenticeship before they could practice legally.
  - **1.** Where physicians had rights to internal medicine, only apothecaries could prepare and sell medicines.
  - **2.** First-class surgeons did major surgery, but barber surgeons cut hair and performed cupping.
  - **3.** Childbirth was the prerogative of midwives.
- **C.** Unlicensed healers included an array of folks: bath masters, oculists, dentists, peddlers, executioners, knackers, corn doctors, wise women, cowherds, and so on.
- **D.** What about quackery?
  - **1.** Quacks were those who poached on territory where they did not belong, undercutting the livelihood of others.
  - **2.** Those with official sanction to practice resented the many healers who practiced without permission.
  - **3.** One could be accused of quackery even if one had an official sanction in one area but poached onto another's territory.
- **E.** People who could pay tended to go to a physician, but most people went to whomever they thought might help.

V. When did things begin to change in medicine and why?

- **A.** The historical consensus is that the turn from the 18th to the 19th century was a pivotal time.
  - **1.** The noted French historian/philosopher Michel refers to this time when what he calls the firm web of our modern experience was set in place.
  - **2.** Foucault equates modern medicine with the "anatamo-clinical perception," in which the physician's goal was to replace the patient with her body.
- **B.** It should be noted, as well, that around the turn of the 19th century, the very understanding of what it meant to be "scientific" was emerging.
- **C.** The transition to what would become known as "scientific medicine" would take time.
  - **1.** It would be another half century before the physician began to aspire to be regarded as a scientist.
  - **2.** Then, with the development of the germ theory of disease, the blending of medicine with experimental science was irresistible.

3. It also involves the complicated question of the emergence of a practitioner of science, of professionalization, a subject we shall return to when discussing the 19th century.

Essential Reading:

Lindemann, *Health and Healing in Eighteenth-Century Germany*, chapters 2–4.

Supplementary Reading:

Conrad, et al., *The Western Medical Tradition*, chapter 7.

Questions to Consider:

1. How does our basic understanding of disease today agree and differ from the basic understanding of healers in the 18th century?
2. What aspects of 18th-century medical quackery, understood as it was primarily in economic terms, remain true today?

Lecture Ten

Mesmerism, Science, and the French Revolution

Scope: In the years before the French Revolution, Franz Anton Mesmer solicited the approval of the Paris Academy of Sciences for his theoretical claims about an imponderable fluid that was present in living things. This lecture introduces Mesmer and his theory, details his sensational successes and failures, and analyzes the reactions to Mesmer among academicians as they differed from those of the general population. Mesmer's career illustrates that natural science is not pursued in a political vacuum. Rather, in terms made particularly vivid by a charged political atmosphere, it displays the enduring tendency, among those interested in explaining nature, to create alternative explanations to those that enjoy acceptance among officially established powers.

Outline

I. In this lecture, we continue our investigation of medicine in the 18th century.
   A. In Lecture Nine, we looked at the general understanding of health as maintaining a balance in the body and disease as the upsetting of that balance.
   B. One mark of the new medicine was its possession of scientifically validated theory from which it claimed to derive concrete practices.

II. In this lecture, we examine an early attempt—before the 19th century—to associate medical practice with science. It came with the work of an Austrian physician named Franz Anton Mesmer.
   A. Mesmer's claims of a scientific status for his medical theory did not succeed for two main reasons.
      1. There was not yet a consensus about what a "science" of medicine might or ought to be.
      2. His assertions were made in a highly politicized context: the years leading up to the French Revolution.
   B. Much about Mesmer's theory of disease resembled other theories of the time, especially electrical theory.
   C. We will see how Mesmer's story illustrates who claimed to speak for science during this period.

III. Who was Franz Mesmer?
   A. The son of a forester, he went to Catholic school and, later, to a Jesuit school in Konstanz.
   B. We see two opposing tendencies in the succeeding years.

    1. From 16 to 20 years of age, his study at the Jesuit university at Dillingen brought him into direct contact with mystical and magical traditions.
    2. From 20 to about 25, he continued studies in philosophy at the university at Ingolstadt, where he encountered opposition to Jesuit thought from followers of the rational philosophy of Christian Wolff.

- **C.** Around age 25, Mesmer decided to go to Vienna, where things began to come together.
    1. Eventually, he studied medicine there with students of Hermann Boerhaave, whose defense of experiment and reference to mechanical operations as a means of understanding the body were widely known in Europe.
    2. He married a wealthy widow, Maria Anna von Posch, at the beginning of 1768, which gave him entry into Vienna's society.
    3. His house became a meeting point for those interested in natural science and the arts, especially music.

IV. What was Mesmer's understanding of health and disease?

- **A.** He already began to develop it in his dissertation, defended successfully before the medical faculty in Vienna in 1766.
    1. It asserted the influence of planetary forces that affected the innermost matter of living things. Mesmer called this influence *animal gravity*, because it interacted with the parts of living things so fine that they no longer qualified as matter.
    2. This universal fluid, which serves as a medium for the animal gravity, flows unimpeded through living things when they are healthy. Illness results if the flow is blocked.
    3. Evidence of its reality can be seen in the influence on health of the moon and its phases.
- **B.** By 1774, Mesmer had become convinced that the best analogue for what he had called animal gravity was in fact the action of magnetism.
    1. He took into his home a 29-year-old woman named Franziska Osterlin, who suffered from various conditions, including convulsions.
    2. Mesmer successfully used magnets to restore the flow of what he now called animal magnetism, bringing the convulsions to a halt.
    3. He found that he could elicit tremulous responses from the woman without touching her and that he did not require direct communication of magnetic force.
    4. Mesmer then worked out a system in which various points on the body were key loci for applying magnetic force when removing blockage and restoring unimpeded flow of animal magnetic force.

V. What was the response to Mesmer's claims?

- **A.** His initial success in Austria led to a certain amount of fame.
    1. He was called on as an expert to evaluate the claims of Father Johann Joseph Gassner, who was healing through exorcism.
    2. Mesmer judged Gassner's belief in the devil to be theologically confused self-deception.
    3. This incident shows that Mesmer regarded his explanation as a rational understanding of the mechanistic forces of nature.
- **B.** The unconventional nature of Mesmer's approach also elicited hostile reactions among many in socially established institutions.
- **C.** One case, in particular, made it impossible for Mesmer to stay in Vienna.
    1. In 1777, Mesmer consented to treat a young girl of 18 named Maria Theresie Paradis, who had gone blind overnight when she was 3½ years old and had subsequently become a celebrated pianist.
    2. Mesmer made progress through magnetism to help her regain some sight. But regaining sensitivity to sight also disoriented the girl and affected her playing.
    3. The girl's father accused Mesmer of deception and mistreatment of his daughter for experimental purposes. There were also rumors of Mesmer's possible relationship with her.
- **D.** Mesmer went to Paris early in 1778, where he hoped his theory of animal magnetism would be validated by the Academy of Sciences.
    1. He was invited to outline his theory to the Academy, but its members ignored it.
    2. He set up a unique practice in which groups of people received treatments that produced sensational cures and achieved a substantial following among people from all social classes.
    3. As his fame grew, so did the hostility of established physicians in France and Germany to what they asserted was charlatanism.
    4. Converts in the pre-revolutionary days included political radicals, who embraced his theory as one more challenge to established powers.
    5. In 1784, a Royal Commission was appointed to evaluate Mesmer's claims.

VI. What can we learn from this episode?

- **A.** Clearly, Mesmer wanted his ideas to be regarded as based on sound mechanical principles.
    1. He rejected appeals to occult forces, claiming that the force he was manipulating was like gravity and magnetism.

2. The action of animal magnetism resembled that of electricity in that it flowed, it could be built up by blocking the flow, and its release produced dramatic results.
3. Mesmer was apparently utilizing hypnotic effects, which he had learned how to manipulate.

B. Mesmer's behavior, however, violated some of the emerging practices among natural philosophers.

1. After his initial address to the Academy was ignored, he insisted on keeping the details of his cures secret, passing them on only to chosen initiates.
2. Like alchemists, Mesmer's concern to profit from his theory subjected his motive to suspicion.

C. The charged political atmosphere of pre-revolutionary Paris accentuated the clash between the powers of the establishment and outsiders, including Mesmer, who were trying to join it.

D. Mesmer represents the enduring tendency in the history of science to resist the authority of those who claim to be official spokesmen.

1. Mesmerism did not die with the Paris Commission's report. It continued to flourish on the Continent and in Britain throughout much of the 19th century.
2. As consensus gradually developed in Western society about how science was to be understood and who the authoritative spokespeople were, Mesmer's claims took their place with others among the so-called "alternative" approaches to official science.

Essential Reading:

Darnton, *Mesmerism and the End of the Enlightenment in France*.

Supplementary Reading:

Crabtree, *From Mesmer to Freud*, chapter 1.

Questions to Consider:

1. There were close parallels between the behavior of Mesmer's fluid and that of the electrical fluid understood in the 18th century. Why was Mesmer's fluid rejected and electrical fluid accepted?
2. How do you explain the affinity that grew between some Mesmerists and the revolutionary movement in France?

Lecture Eleven

Explaining Electricity

Scope: During the first half of the 18th century, natural philosophers began to make real headway in explaining the bewildering phenomena associated with static electricity. The creation of new instruments and techniques made possible the more effective production of fascinating results that captured the attention even of kings. The discovery of how to store the electrical fluid led Benjamin Franklin to devise a widely recognized theoretical explanation of the nature of electricity. As in the case of chemical change, Franklin appealed to the idea of a special imponderable fluid to account for the effects produced. Here, the disruption of an equilibrium that existed between the electrical fluid's attraction to material bodies and its repulsion of itself provided the basis for Franklin's explanation

Outline

I. Mesmerism appealed to the flow of an imponderable fluid to explain disease.

A. In this lecture, we will meet another imponderable fluid whose flow purportedly explains electricity.

B. A major difference here is that this imponderable fluid is accepted without question as the basis of electrical phenomena.

C. We will see how and why this came about as we explore inherited ideas about electricity and follow the success of such thinkers as Benjamin Franklin during this time.

II. Before the 18th century, natural philosophers studied the attractive power amber exhibited when rubbed.

A. Materials that exhibited the so-called "amber effect" were named *electrics*. Magnetic attraction was exhibited only in iron.

B. Some believed the attraction to be occult, but most natural philosophers insisted on explaining it as an interaction among different kinds of matter.

III. In the early 18th century, the invention of new electrical instruments helped natural philosophers to produce impressive electrical effects more efficiently.

A. Francis Hauksbee became the chief experimenter of the Royal Society when Newton became president in December of 1703.

1. Hauksbee's means of producing electrical attraction using rubbed glass quickly became standard.

2. Hauksbee was able to produce stronger attractive forces than his predecessors had.

B. In the third decade of the century, Stephen Gray discovered that the electrical effect could be communicated to adjacent bodies.

1. Rubbing a glass tube with a cork stopper in one end, he noticed that a feather was attracted to the cork.
2. He inserted a stick into the stopper and attached an ivory ball to the other end of the stick. He showed that the feather was attracted to the ivory ball.
3. Gray discovered that communicating lines had to be insulated from contact with the ground, for example, by silk cords.
4. Such discoveries revealed two categories of substances: electrics one could rub, such as amber, glass, and silk, and conductors, such as wood, thread, or even the human body, that communicated and exhibited the attractive effect.

C. In France, Charles Dufay discovered how to produce electrical discharge in the form of both sparks and shocks.

IV. Interest in electricity spread to Germany in the late 1730s and early 1740s.

A. One example is Georg Bose at the University of Leipzig.

1. He produced electrical attraction by rubbing a spinning glass globe.
2. He enhanced the effect produced by suspending an iron bar from the ceiling using silk cords and communicated to it the electrical effect from the spinning glass globe.
3. Bose and others used the iron bar to produce dramatic effects that entertained spectators, including nobility and royalty.
4. Bose also electrified water in an insulated drinking glass, from which he then drew sparks.

B. Bose's experiments inspired others to make a new and important discovery, the *Leyden jar*, or condenser.

1. In Leyden in Holland, experimenters tried duplicating Bose's water experiment in early 1746. They replaced the drinking water with a glass jar containing water. The jar had a cork stopper from which a nail protruded.
2. An experimenter once tried the experiment while alone, which forced him to hold the flask while electrifying it. Touching the nail, he received a powerful shock.
3. In addition to increasing the power of discharge, the Leyden experimenters realized they could also store electricity in the jar.

V. A convincing explanation of the Leyden jar was provided by Benjamin Franklin.

A. Franklin asserted that electricity was a weightless substance that adhered to the surfaces of material bodies.

1. The amount of "electrical fire" that adhered was proportional to the mass of the body.
2. But the weightless electrical fire repelled itself.
3. Under normal conditions, an equilibrium is set up between the attraction of electrical fire to the surfaces of the jar and the electrical fire's repulsion of itself.
4. The jar, therefore, has a characteristic equilibrium amount of electrical fire on its surfaces.

B. Franklin used electrical fire to explain properties of electrics, such as glass, and conductors, such as wire.

1. Electrics, such as the glass globe, surrendered electrical fire from their surfaces more easily than others when rubbed.
2. Conductors permitted electrical fluid to flow through them.
3. The Earth possessed an unlimited amount of electrical fluid in equilibrium with its enormous mass.
4. Electrical fire cannot penetrate *through* glass.

C. In the arrangement of the Leyden jar, it was the disruption of equilibrium that accounted for its amazing effects.

1. Electrical fire was stripped from the revolving glass globe by rubbing and conducted through wire to the iron bar, then to the nail and into the glass jar.
2. Because the electrical fire could not penetrate through the side of the jar, it piled up inside the jar on the surface of the water and the inside surfaces of the jar.
3. Although the excess electrical fire inside the jar could not penetrate through the sides of the jar, the excess repulsive *force* it created could penetrate through glass.
4. This excess repulsive force repelled the normal amount of electrical fire on the *outside* surface of the jar, causing it to flow into the ground through the body of the person holding the jar.
5. The jar now had an excess of its normal amount of electrical fire on its inside surface and a deficiency of its normal amount on the outside surface.
6. The jar could be carried away from the apparatus with the excess electrical fluid stored inside.
7. If the person holding onto the outside surface touched the nail leading to the inside of the jar, a route was established for the excess fluid inside to pass through the person's body back to the outside surface of the jar, giving a shock to the person en route.

VI. For Franklin, the explanation of lightning was similar.

A. In the sea, salt particles (an electric) rub against those of water (a conductor), causing an excess of electrical fire to gather on the surface of the sea.

B. Evaporation of the water carries the excess weightless electrical fire to the clouds. When a cloud comes close to a sweetwater cloud, an exchange occurs as lightning, and the cloud deposits its water.

C. Any projecting object, such as a church steeple or tree, entices such an exchange.

D. Franklin became famous because he promoted the use of lightning rods and conducted his kite experiment.

E. The next major development, much later in the century, involved electrical discharge and living things; we will turn to that in the next lecture.

Essential Reading:

Cohen, *Benjamin Franklin's Science*, chapters 5–6.

Hankins, *Science and the Enlightenment*, chapter 3, pp. 50–71.

Supplementary Reading:

Heilbron, *Electricity in the Seventeenth and Eighteenth Centuries*, chapters 13–15.

Questions to Consider:

1. Electrical fluid is the third example of an imponderable substance, the other two being phlogiston and Mesmer's fluid, which natural philosophers used to explain natural phenomena. What function did these imponderable substances supply?
2. Why does Franklin's theory of electricity not explain why two negatively electrified substances (substances with a deficiency of electrical fluid) repel each other?

Lecture Twelve

The Amazing Achievements of Galvani and Volta

Scope: In the waning decades of the 18th century, Luigi Galvani concluded that animals are a source of electricity separate from both the artificially produced electricity of the new electrical machines and the naturally occurring electricity in the atmosphere. His announcement in 1791 was heralded all over Europe, eventually provoking a counter-claim from his fellow countryman Alessandro Volta. It was, argued Volta, contact between metals that produced the muscular contractions in Galvani's experiments. Volta's invention of the *pile*, or battery, in 1800, while an important development in the history of science, has often been misrepresented in histories of this debate between the two famous Italian natural philosophers of the late Enlightenment.

Outline

I. In this lecture, we will look into a question that arose in the late 18th century: Do animals possess electricity?

   A. The issue is important for several reasons.

      1. It opened up a new area of research.
      2. It was the context in which the battery was invented, which made current electricity possible.
      3. It linked electricity to life itself, as Mary Shelly's *Frankenstein* would confirm in 1815.

   B. The discoveries illustrate an important lesson about how science often develops.

II. The first phase of the story centers on the work of Luigi Galvani, lecturer in anatomy at the University of Bologna and professor of obstetrics at the separate Institute of Arts and Sciences.

   A. Galvani began doing experiments on the relationship between electricity and physiology in the late 1770s.

      1. In 1786, an assistant of Galvani, most likely his wife, Lucia Galeazzi, was amazed to observe that a frog's leg convulsed violently when the tip of a scalpel accidentally touched the crural nerve.
      2. A question immediately arose about whether the work of another assistant, who was producing sparks with an electrical machine across the room, played any role in bringing about this surprising result.
      3. It was soon confirmed that this was the case, that electricity discharged from a sparking machine could affect muscles even when not applied directly to them.

B. Galvani also experimented with natural electricity in lightning, which led him to a mysterious result.
  1. He showed that contractions occurred in the frog's leg when lightning from a thunderstorm was led to it.
  2. Galvani noticed that frog preparations hung by copper hooks from the iron railings surrounding a balcony of his house contracted, not only during thunderstorms, *but occasionally even in fine weather*.
  3. He found that he could cause the contractions outside by pressing the copper hook against the iron trellis.
  4. He took the frog inside, out of the weather, where he reproduced the same contractions as he had seen outside.
  5. He concluded that this result could not be due to atmospheric electricity, and it was clearly not due to a sparking machine.

C. Galvani explained his results by suggesting that he had discovered a third kind of electricity, different in origin from natural atmospheric electricity and from the artificially produced electricity of a Leyden jar, which also were known to produce contractions in muscles.
  1. This new "animal electricity," he reasoned, was stored in the muscles of animals in miniature Leyden jars.
  2. In Franklin's terms, the internal parts of muscles contained an excess of electrical fluid, while on the outside, there was a corresponding deficiency.
  3. According to Galvani, this imbalance was created in the body by the brain, which regulated the *creation* of an imbalance and its *discharge* to produce contractions when needed while the animal was alive.
  4. It did so by permitting the nerves, which ran from the inside to the outside of the muscle, to carry what had been thought of as *nervous fluid*.
  5. Galvani now sided with those who claimed that nervous fluid was really electrical fluid, arguing that the outer sheath of the nerves insulated the fluid from the muscle as it flowed from inside to outside.

D. Without the brain's presence, as in the case of the frog's leg, an artificial means of producing a discharge was necessary.
  1. If one connected a metal contact with the inside of the nerve (which ran to the inside of the muscle), then attached another metal lead to the outside of the muscle, one could, by joining the two metal leads, create a route for the excess fluid inside to flow to the outside and restore a normal balance.
  2. This contact between two metal leads, Galvani concluded, was what had occurred when he pressed the copper hook against the iron plate to produce a contraction.

E. Galvani's announcement of his discovery of animal electricity in a publication of 1791 was regarded by many as nothing short of path-breaking.

III. Alessandro Volta, a professor of physics, took Galvani's line of experimentation in a different direction.

A. He drew on the work of others who had experimented with contact between metals.
  1. He knew that one could produce a bitter taste on the tongue by joining two different metals that were both in contact with the tongue.
  2. Volta began to think that Galvani was wrong to regard the metal leads as mere conductors of electrical discharge. He pursued the idea that different metals in contact somehow were involved in the generation of the electricity.

B. It was not long before a heated controversy ensued between Volta and Galvani's nephew and defender, Giovanni Aldini, about *galvanism*, a name first used as a synonym for Galvani's animal electricity.

C. In a letter written on March 20, 1800, to Sir Joseph Banks, president of the Royal Society in London, Volta announced a new invention that became known as *Volta's pile*—what we call the battery.
  1. Volta compared his discovery to the Leyden jar, because it produced electrical discharge, although a weak one. Its advantage was that it produced electrical discharge as a continuously flowing current.
  2. Volta had imitated the arrangement of metals in contact on the tongue: He brought together zinc and silver, both of which were in contact with brine-soaked cloth.
  3. To magnify the effect, he piled up sets of silver and zinc discs in contact, silver on top and zinc beneath, each set separated by a paper soaked in a brine solution.
  4. Volta had shown that two metals in contact could, under the right conditions, produce electric current.

IV. Historians have sometimes allowed their wish to celebrate scientific heroes to distort the historical record.

A. Volta's discovery has been cast as a correction of Galvani's theory of animal electricity.
  1. The invention of the battery did confirm his view that contact between metals can produce electrical current.
  2. This has been assumed to mean that Volta established that contact between metals was the only source of electrical discharge in Galvani's earlier experiments.
  3. Some historians have seen the outcome this way, casting Volta as the "winner" in the debate over animal electricity.

B. But the situation is not nearly as simple as that.
   1. First, the invention of the battery was not regarded at the time, even by Volta himself, as the deciding factor in his disagreement with Galvani.
   2. The pile was seen as an amplified form of galvanism, which occurred in both metals and animals.
   3. In fact, investigators at the time were dealing with two possible sources of the electricity that produced the contraction in muscle tissue; one was the contact between two different metals and another was the source stored in muscles.

C. The development of science frequently demands that investigators make sense of a host of conflicting information.
   1. Admittedly, the successful scientist learns how to focus on the central clues and identify minor contradictions for what they are.
   2. Before the fact, however, it is virtually impossible to identify winners and losers; that only becomes clear over time.

Essential Reading:

Hellman, *Great Feuds in Medicine*, chapter 2.

Purrington, *Physics in the Nineteenth Century*, chapter 3, pp. 32–38.

Supplementary Reading:

Pancaldi, *Volta*

Pera, *The Ambiguous Frog*.

Questions to Consider:

1. Why was Galvani so quick to suppose that animals themselves were a source of electricity?
2. Historians have tended to pit Volta and Galvani in a contest against each other and declare Volta the winner. Why do you think they have done this?

Timeline

1686	Newton completes *Principia*; Leibniz publishes critique of Descartes's measure of the force of motion.
1702	Stahl introduces the imponderable substance phlogiston to explain combustion.
1727	Death of Newton.
1733	Voltaire's *Philosophical Letters* praises all things English, including Newtonian philosophy.
1735	First edition of Linnaeus's *System of Nature*, containing his scheme of classification based on plant sexuality. Edition of 1766 removes the claim that no new species have originated.
1741	Trembley observes regeneration in freshwater polyp and uses it to criticize the widely accepted idea that adult forms are preformed in the embryo.
1746	Leyden jar for storing electrical charge invented in Holland.
1748	De Maillet's *Telliamed* appears posthumously and outrages scholars with its implications for the age of the Earth; Franklin's explanation of the Leyden jar. His famous kite experiment was done four years later.
1749	Buffon's initial speculations on the origin of the Earth appear. Four years later, they are retracted as a result of pressure from Paris theologians.
1756	Black's experiments with magnesia alba underscore the importance of weighing reagents.
1757	Haller affirms his conversion to the preformation theory, setting off his debate with the epigeneticist Christian Wolff.

1774	Priestley produces a dephlogisticated gas from mercury calx and communicates his result to the French during a visit.
1775	Lavoisier argues that combustion consists of the addition of oxygen, not the release of phlogiston.
1778	Buffon reasserts his prolonged estimation of the age of the Earth and of life in *Epochs of Creation*; Mesmer arrives in Paris and begins a campaign to have his theory of animal magnetism accepted.
1781	First edition of Kant's *Critique of Pure Reason* sets limits on human knowledge of the world; Herschel discovers the planet Uranus.
1783	Berlin journal poses prize question on "What is Enlightenment?" reflecting public awareness of an enlightened era.
1784	Paris Commission rules against Mesmer's theory.
1786	Werner publishes his classification of rocks based on his theory of consolidation from primal fluid.
1789	Beginning of the French Revolution with the convening of the Estates General.
1791	Galvani announces his theory of animal electricity.
1793	Kielmeyer endorses the notion that laws governing organisms differ from the mechanical laws of the inorganic; Paines's *Age of Reason* attacks Christianity's acceptance of extraterrestrial life.
1795	Hutton communicates his ideas on prolonged gradual geological change to the Royal Society.
1796	Laplace's *System of the World* dispenses with God's supervision of the cosmos; Cuvier demonstrates the extinction of the mastodon.

1797	Schelling's *Ideas for a Nature Philosophy* opens his program to move beyond Kantian limits of knowledge.
1800	Volta invents the *pile*, or battery; von Humboldt departs for a four-year scientific expedition to explore the new world; Herschel discovers infra-red "light."
1802	Playfair and Murray champion Vulcanism and Neptunism, respectively; Young's first slit experiments establishing the wave theory of light.
1806	Goethe formulates his critique of Newton's theory of color.
1807	Dalton's *New System of Chemical Philosophy* revives interest in atoms.
1809	Lamarck's *Zoological Philosophy* lays out a systematic theory of evolution.
1811	Avogadro distinguishes atoms of an element from molecules, which may have more than one atom of an element.
1812	Cuvier elaborates his theory of catastrophes to explain the history of fossils.
1817	Founding of *Isis* by Oken, one of the first journals of natural science intended to educate the public.
1818	Fresnel's prediction of a bright spot based on the wave theory of light shown correct.
1820	Oersted discovers electromagnetism as a "circular" force surrounding a current-carrying wire; Ampère interprets magnetism as electricity in motion.
1822	Founding of the first modern scientific society, the German Society for Natural Investigators and Physicians; Fourier's theory of heat, in which heat flow is irreversible, is finally published after several years of unacceptance.

1823	Buckland's analysis of cave fossil remains brings the Earth's physical past into the study of world history.
1824	Carnot's theoretical analysis of the steam engine opens a new science of thermodynamics.
1831	Darwin leaves for a five-year trip around the world on HMS *Beagle*; Faraday demonstrates that cutting magnetic lines of force produces electricity; founding of the British Association for the Advancement of Science, modeled on the earlier German society; Somerville's translation of Laplace's *Celestial Mechanics.*
1841	Feuerbach's *Essence of Christianity* argues that religious doctrines are projections of human needs.
1842	Mayer's paper on the indestructibility of force.
1843	Joule begins experiments that will show that heat has a mechanical equivalent; the Great Disruption of the Scottish Church divided those unhappy with modernism from those happy with the latest science.
1844	Anonymous publication of the sensational book *Vestiges of the Natural History of Creation*; Darwin tentatively shares his ideas on transmutation with Lyell and Hooker.
1845	World's largest telescope resolves the nebula in Orion into stars, a blow to the nebular hypothesis.
1846	Vogt's *Physiological Letters* portrays thought as a secretion of the brain; Leverrier successfully predicts the location of a new planet, Neptune, winning the race with English astronomers.
1847	Helmholz's classic announcement of the conservation of force.
1848	Revolution breaks out in Paris, followed later by revolutions in other European capitals.
1850	Clausius agrees that heat has a mechanical equivalent but argues that it is proportional to the fall in temperature—not all heat is converted into work; Moleschott's *Theory of Nutrition: For the People* continues to popularize scientific materialism.
1851	Thomson affirms that "energy" cannot be lost but that it can become unavailable to humans.
1853	Whewell's *Of the Plurality of Worlds* shocks Britain with its rejection of extraterrestrial life.
1854	Helmholtz describes the heat death of the universe to a Königsburg audience.
1855	Büchner's *Force and Matter*, the Bible of scientific materialism, appears.
1857	Spencer articulates his *laissez faire* application of general evolutionary ideas to social and political questions; Clausius's use of statistical means to measure speed of molecules advances study of the kinetic theory of gases.
1859	Darwin, whose hand was forced by a letter from Wallace containing ideas similar to his own, rushes his *Origin of Species* into print.
1860	Maxwell's mechanical model relates electrical and magnetic phenomena. A mathematical depiction of the model led to the incorporation of light as an electromagnetic phenomenon.
1861	Thomson begins his critique of evolution on thermodynamic grounds.
1864	Pasteur critiques Pouchet's defense of spontaneous generation based on experiments.

1867	Jenkin's review of *Origin* raises major problems with Darwin's theory.
1869	Mendeleev arranges elements according to atomic weights in a periodic table.
1870	Büchner's ideas on evolution and society attempt to merge individual freedom and social responsibility; German states unite into a nation under Prussian leadership.
1872	Hodge's *What Is Darwinism*? answers that it is atheism.
1877	Schiaparelli's map of Mars identifies "canals" on the surface.
1879	Herrmann calls for the radical separation of science from religion, arguing that neither supplies metaphysical truth.
1881	Pasteur dramatically demonstrates a vaccine for anthrax; in 1885, he cures two patients with a vaccine for rabies.
1887	Michelson collaborates unsuccessfully with Morley to measure the relative velocity of the Earth through the ether.
1894	Michelson predicts that no original far-reaching discoveries in physics will be made over the next hundred years.
1900	Planck introduces the idea that energy is radiated and absorbed in discrete amounts he called *quanta*.
1905	Einstein formulates his theory of special relativity.

Glossary

Abiogenesis: The spontaneous appearance of living forms from inorganic matter.

Animal electricity: Electrical charge stored in the muscles of animals. Its discharge is responsible for muscle contraction, and it can be artificially discharged in freshly dissected parts.

Artificial classification: Classification of living things based on an arbitrarily selected organ or part.

Binomial nomenclature: Identification of living things using a designation containing species and genus names. Used by Linnaeus in his *System of Nature*.

Blending inheritance: Common understanding of heredity in Darwin's day in which the hereditary material from each parent is averaged in the offspring.

British Association for the Advancement of Science: First professional association of natural science in Britain, founded in 1831 and modeled on the earlier Society of German Natural Investigators and Physicians.

Calcination: Process in which a metal loses its phlogiston and becomes a calx, as happens when a metal rusts.

Caloric: Weightless material element of heat that, when combined with gross material bodies, makes them warm. Its density determined the body's temperature.

Catastrophism: Appeal to singular large-scale events to explain natural phenomena, as in the case of Cuvier's explanation of changes in the history of the Earth through floods and land elevation.

Classical mechanics: Name for the maturation of the Newtonian mechanical tradition in the 19th century. Commonly understood to entail a view of nature as a machine, determined in every respect by the mechanical laws governing its parts, large and small. In this view, energy is radiated and absorbed continuously, that is, at all possible frequencies.

Coherence theory of truth: Belief that the truth of a proposition consists not in its correspondence with a reality independent of what may be believed about it, but in its coherence with an existing set of beliefs.

Conservation of energy (force): Law according to which energy (force) can neither be created nor destroyed but may be transformed from one form into another. Also known as the First Law of Thermodynamics.

Conservation of heat: Understanding in which heat, when used to produce mechanical force, is not consumed but, as asserted by Sadi Carnot, is merely moved from a higher temperature to a lower one.

Conservation of matter: Matter can neither be created nor destroyed but can be changed from one form into another.

Consolidation: Process in which rocks have congealed over a long time from a primal gelatinous fluid to solid objects.

Correspondence theory of truth: Belief that the truth of a proposition consists in its correspondence between our idea of reality and reality itself.

Degeneration: Process by which Buffon believed a species had been altered over time by external conditions away from its original form into derivative forms. For example, contemporary lions and tigers were degenerations of a primitive cat.

Deism: Belief that God is necessary to establish morality and to create the world and its natural laws, but that once this has been done, God withdraws and no longer interferes with creation.

Dephlogisticated air: A gas that has no phlogiston in it. Priestley's name for the gas later called oxygen by Lavoisier.

Displacement current: The electrical current produced by changes in a magnetic field in regions of space where no conducting wire is present. First postulated by James Maxwell from his model of electrical and magnetic phenomena.

Dissipated energy: Kelvin's term for energy that had become unavailable for use by humans, the gradual accumulation of which leads to heat death.

Electrical fire: Franklin's name for the imponderable fluid whose presence, absence, and movement he used to explain electrical phenomena.

Electrics: The name given to substances that display the capacity to attract light objects, such as feathers, when rubbed.

Electrodynamics: Forces that arise from the motion of electricity; used by Ampère to explain the creation of magnetism from electricity.

Electromagnetism: Magnetism created in the vicinity of a current-carrying wire, first observed by Oersted, who depicted its action as circular forces surrounding the wire.

Enlightenment: Philosophical movement emphasizing the human rational capacity as a means of comprehending nature and the human condition.

Epigenesis: The unfolding of the embryo, viewed as an unorganized mass, into its adult form.

Ether: Weightless medium of great elasticity and subtlety, waves in which were responsible for the transmission of light; believed to permeate the whole of planetary and stellar space.

First Law of Thermodynamics: See **conservation of energy**.

Fixed air: Air present in substances that is released when the substance is burned. Later, Black's name for carbon dioxide.

Fixity of species: The notion that the species originally created by God cannot be added to, subtracted from, or altered over time.

Force of motion: The force an object exerts by virtue of its being in motion.

Galvanism: Name first given to the "animal electricity" discovered by Galvani; later used to refer to current electricity, as well.

Geognosy: Abraham Werner's name for his systematic study of minerals; his focus on close empirical observation and careful reasoning contrasted with speculative theories of causal agencies of terrestrial change.

Great Disruption: The split in the Church of Scotland in 1843 in which a segment of those dissatisfied with compromises with modernism left to form the Free Kirk.

Heat death: Projected end of the physical universe due to the gradual elimination of temperature differences necessary for heat to be used to produce mechanical motion. When no more temperature differences exist, no more mechanical motion can be produced.

Heterogenesis: The spontaneous appearance of living forms from organic debris, that is, organic material that has been rendered lifeless.

Humoralism: Assertion that balance among the body's four humours (blood, bile, black bile, and phlegm) accounts for health, while imbalance produces disease.

Ideal heat engine: Heat engine in which parts are considered weightless and no heat is lost to friction or by conduction.

Induced current: Production of a current by magnetism, accomplished by Faraday in 1831 when he discovered that changing lines of magnetic force produces electrical current.

Inheritance of acquired characteristics: The passing on to offspring of characteristics that an organism acquires during its lifetime (as opposed to those with which it is born).

Inverse square law: Law derived by Newton based on the assumption that the moon is affected by the same force that makes apples fall. The strength of the force between two masses drops off as the square of the distance between the masses.

Isis: First journal devoted to natural science and its implications for society, founded by Lorenz Oken in 1817.

Jardin du Roi ("Garden of the King"): Botanical institute, nursery, and laboratory over which Buffon presided from 1739 to his death in 1788. Contained a popular park accessible to the public and was the site of public lectures on natural science. Renamed during the revolution (see **National Museum**).

Karlsschule: The institution of higher learning set up by Grand Duke Karl Eugen of Württemberg in the 1770s as an alternative to the flagging university at Tübingen, which the grand duke had been unable to revitalize. Training ground for Kielmeyer and Cuvier.

Kinetic theory of gases: Explanation of properties of gases based on the assumption that atoms and molecules move freely through space and are not confined to motions of vibration around fixed positions.

Lamarckian evolution: The understanding of changes in species over time brought on by a natural tendency to complexity in their organization, complemented by the inheritance of characteristics acquired during the lifetime of organisms through over or under use of organs.

Law of definite proportions: Law of chemical combination stating that when atoms combine to form a compound, the number of combining atoms of the different elements form simple, definite ratios.

Leyden jar: Device invented in the 18th century that can store electrical charge.

Lines of force: Faraday's visualization of the circular pattern according to which the magnetic forces surrounding a current-carrying wire act.

Materialism: Belief that everything that occurs in nature can be explained as the result of matter in motion. Because it appeared to usurp God's role, it was historically associated with atheism.

Mechanical equivalent of heat: The amount of mechanical force that may be obtained from a certain amount of heat, measured experimentally by Joule in 1843.

Mechanical worldview: The assumption that nature behaves as a huge machine and that an understanding of nature consists in knowledge of the machinery's parts and how they go together.

Miracle of Canaan: The miracle worked by Jesus when he turned water into wine at a wedding celebration.

National Convention: Name of the revolutionary assembly that ran from the fall of 1792 to the summer of 1795 during the French Revolution. Most radical phase of the revolution, responsible for declaring France a republic and for executing the king.

National Institute: French replacement for the French Academy of Sciences, which had been closed in August of 1793. The Institute was created in 1795 and did not, as in the old Academy, retain a distinction based on class. It contained more than the natural sciences, including sections of moral and political science, as well as literature and the fine arts.

National Museum: New name for the old Jardin du Roi ("Garden of the King"), over which Buffon had presided from 1739 to his death in 1788. Site of public lectures by Cuvier on fossil bones in the late 1790s.

Natural classification: Classification scheme that would reveal the divine order of creation by allowing an organism's characteristics to determine its place in the larger scheme.

Natural selection: The principle specified by Darwin according to which an individual organism's survival is determined by how well the characteristics with which it is born respond to the demands of the environment in which it finds itself.

Naturalism: The worldview that rejects appeals to supernatural agency as part of attempts to understand history and the world and emphasizes natural causes operating according to law.

Nature philosophy (*Naturphilosophie*): Monistic German philosophical system in which the one reality shows itself in polarities of mind and nature, making it possible to recognize in nature the attributes of life and mind.

Nebula: Fuzzy objects in the heavens catalogued by the astronomers since antiquity. As part of the nebular hypothesis, they represented the primal hot nebulous matter from which the solar system was formed.

Nebular hypothesis: The conjecture that the solar system originated from hot nebulous matter that contracted into individual masses that began to revolve around a center and cool.

Neptunism: Geological view according to which the Earth has been shaped primarily by forces associated with moving water, which acted both over the long term to erode and over the short term in floods.

Newtonianism: View of nature and the cosmos as machinery governed by invariable natural laws that determine its motions.

Non-electrics: Substances that do not attract light objects when rubbed but that can conduct the electrical effect from one electric to another.

Noumenal realm: Kant's name for that part of reality whose existence we infer from encountering the limits of reason but whose contents are inaccessible to reason. The source, according to Kant, of the sensations that come to us from the world in itself.

Organic worldview: The assumption that nature behaves as an organism and that an understanding of nature consists in drawing on the aspects of experience that human organisms share in common with nature.

Pantheism: Belief in a deity who is identified as coexistent with nature.

Paradigm: The framework, including conscious and unconscious assumptions, within which thinking occurs.

Paris Commission: Special commission appointed by the French Academy to investigate the claims of Franz Mesmer. In its report of 1784, the commission ruled that Mesmer's fluid did not exist.

Periodic table: Table of chemical elements grouped according to similarities in chemical properties.

Phenomenal realm: Kant's name for that part of experience we encounter by means of the senses. The laws of natural science pertain to this realm.

Phlogiston: Imponderable substance whose release from a substance constitutes combustion.

Phrenology: Study of the laws thought to govern human character and mental capacities as revealed in the appearance of external features, such as the shape of the head. A popular science in Britain in the 1830s and 1840s.

Physicus: The district physician in charge of making sure that ordinances governing the practices of healing are abided by.

Pluralism: Belief in the existence of other worlds.

Power of life: Lamarck's phrase for the natural tendency of the physical organization of living things to become more complex.

Preformation: The doctrine that an embryo exists as an adult form in miniature that expands in growth.

Public sphere: The emergence of public opinion as a factor shaping public life. The assumption is that rational public discourse replaces autocracy as the legitimizing source of power. Although it emerges at different times in different countries, it was a reality in European life by the early 19th century.

Quackery: The presumption on the livelihood of others by performing their duties without appropriate permission.

Quanta of energy: Packets of energy called *quanta* by Max Planck, whose size is determined by the frequency of the radiation.

Quantum mechanics: Name for the view of mechanics that replaced classical mechanics. In quantum mechanics, energy is not radiated and absorbed continuously but only in discrete amounts.

Rational chemistry: Chemical investigations in which explanations rely on reasons and are not content with mere description of what occurs.

Recapitulation: Idea, endorsed by Kielmeyer, that the development of the species follows the same order as development of the individual organism. A theme present in German biology down through the time of Darwin.

Reign of Terror: The period of the French Revolution from the summer of 1793 to the summer of 1794 marked by a wave of executions of all enemies of the revolution by the Committee of Public Safety.

Scalae naturae: The ladder of creation or the arrangement of living things from the most simple to the most complex forms.

Scientific materialism: The defense of metaphysical materialism based on the claims of natural science. Endorsed in the popular writings of Karl Vogt, Jakob Moleschott, and Ludwig Büchner during the second half of the 19th century in Germany.

Second Law of Thermodynamics: Physical law according to which the amount of available energy in the universe (the energy that can be used to do work) decreases as energy transformations occur.

Social Darwinism: Name given to the alleged extension of Darwin's theory into the social and political realm by Herbert Spencer and others. Characterized by Spencer's phrase "survival of the fittest," which promises to improve humankind. A misnomer insofar as it is intended to apply to Darwin's notion of natural selection, which does not guarantee survival or progress.

Society of German Investigators and Physicians (*Gesellschaft Deutscher Naturforscher und Ärzte*): First modern association of natural science, established in 1822 with a meeting in Leipzig. Held annual meetings that convened in different cities and included both meetings of individual scientific disciplines and general social fraternization.

Special relativity: Theory of Einstein that resulted from his insistence that the laws of physics, including electromagnetism, be the same for all observers in uniform motion. For that to be true, the speed of light had to be made independent of the speed of the observer.

Spontaneous generation: The sudden appearance of life from non-life, either from inorganic matter or from organic material that had become lifeless.

Steady state theory of the Earth: Lyell's understanding of the Earth's past, in which basic conditions had not developed from a primitive state to that of the present. Were one transported back in time, the Earth's features would have been recognizable as similar to those of the present.

Subordination of characters: Cuvier's principle according to which the conditions of existence were so interconnected with organisms that came into existence that the relations among anatomical parts of living things were determined. By becoming familiar with the correlations among the parts of organisms (both living and fossil), he could then use what he learned to make inferences about an organism when all he had to go on was a few remains.

Survival of the fittest: Spencer's summary of Darwin's concept of natural selection. Darwin adopted the phrase in

Theory of the Earth: Speculative theories of causal agencies of terrestrial change, such as those offered by de Maillet (diminution of water), Buffon (cooling of a piece of the Sun), and Hutton (pressure from interior heat).

Transformism: French term for evolution at the time of Cuvier and Lamarck.

Unity of composition: The homologous similarity among organisms, attributed by Darwin to their common origin.

Use and disuse: First of Lamarck's secondary causes of evolution, by which an organ of an individual will enlarge or begin to atrophy over its lifetime from repeated use or prolonged disuse. Only important for species change when such acquired characteristics are passed on to offspring.

Vis viva: Literally "living force," the name given by Leibniz to the quantity mv^2, his alternative measure of the force of motion to Descartes's mv.

Vulcanism: Name given to Hutton's theory that the changes in the Earth's surface are due primarily to pressures caused by subterranean heat.

Wissenschaft: Sometimes translated as "science," but more broadly, the German idea of systematic study in which one establishes objective truths by deriving them from the essence of general truths that are grounded in one another. There are, accordingly, as many *Wissenschaften* as there are ways in which general truths, or truths of one kind, are examined as grounded in one another. An ideology of *Wissenschaft* emerges in the late 18th century.

Bibliography

To the Student/Reader: Readings marked "essential" in the outline are generally available, meaning that they can be purchased or ordered at a bookstore. My test for essential books has been that they will be shipped by national online vendors within 24 hours or, at worst, within two to three days. Readings listed as "supplementary" include books that may no longer be available in bookstores but that should be obtainable through libraries. It is sometimes difficult to identify printed materials covering various aspects of the lectures; in such cases, I have tried to list works that at least include the subject matter within a larger context.

Essential Reading:

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Burkhardt, Richard W. *Spirit of System: Lamarck and Evolutionary Biology*. Cambridge: Belknap Press, 1995. An excellent intellectual biography of Lamarck, with emphasis on his work and his changing position among the French savants of the day.

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Franz Anton Mesmer and the French establishment in the years leading up to the French Revolution.

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Haber, Francis C. *The Age of the World: Moses to Darwin*. Baltimore: John Hopkins Press, 1959. A classic study of the development of ideas about the age of the Earth from antiquity to the 19th century.

Hankins, Thomas L. *Science and the Enlightenment*. New York: Cambridge University Press, 1985. Part of the Cambridge History of Science Series, this time-tested synthetic survey of the physical and biological sciences has worn extremely well.

Heilbron, John L. *Electricity in the Seventeenth and Eighteenth Centuries*. Berkeley: University of California Press, 1979. The definitive study of electricity in the larger context of the development of early-modern physics.

Holmes, Frederic L. *Eighteenth Century Chemistry as an Investigative Enterprise*. Berkeley: Office for History of Science and Technology, 1989. Reflections on the history of chemistry in the 18th century by one of the most authoritative historians of the subject.

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Hufbauer, Karl. *The Formation of the German Chemical Community, 1720–1795*. Berkeley: University of California Press, 1982. A study of the emergence of German chemistry in the 18th century. Particularly strong on the role of German identity in the debates over the new French chemistry of Lavoisier.

Jordanova, L. J. *Lamarck*. Oxford: Oxford University Press, 1984. A short, readable intellectual history of Lamarck's ideas, their impact, and their legacy.

Kuhn, Thomas. *The Structure of Scientific Revolutions*. 3rd ed. Chicago: University of Chicago Press, 1996. The classic work by Thomas Kuhn that introduced the notions of *paradigm* and *paradigm shift* to contemporary culture in 1962.

Lenoir, Timothy. *The Strategy of Life*. Dordrecht: Reidel Publishing Co., 1982. A study of the teleomechanical theme that ran from the time of Kant and the German Romantics through the mid-19th century and beyond.

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Outram, Dorinda. *Georges Cuvier: Vocation, Science, and Authority in Post-Revolutionary France*. Manchester: Manchester University Press, 1984. A helpful analysis of Cuvier's rise to fame and power as France's leading naturalist during the tumultuous years of the Restoration.

Pancaldi, Giuliano. *Volta: Science and Culture in the Age of Enlightenment*. Princeton: Princeton University Press, 2003. A wonderful study of Volta that locates him within the larger context of the pursuit of natural philosophy in Italy in the decades around the turn of the nineteenth century. An important study of the social context of Italian science in the Enlightenment.

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Sepper, Dennis L. *Goethe Contra Newton*. New York: Cambridge University Press, 1988. A careful study by a philosopher of Goethe's evaluation of Newton's ideas on light and color.

Terrall, Mary. "Émilie du Châtelet and the Gendering of Science," *History of Science*, 33(1995), pp. 283–310. Discusses du Châtelet's struggle to broaden the definition of femininity to include a rational mind and mathematical accomplishment. In the process, reveals her role with Voltaire in popularizing Newtonian and Leibnizian philosophy.

Terrall, Mary. *The Man Who Flattened the Earth: Maupertuis and the Sciences in the Enlightenment*. Chicago: University of Chicago Press, 2002. Prize-winning study of Pierre-Louis Moreau de Maupertuis and the French and German intellectual communities during the middle decades of the eighteenth century. More than just an account of the controversy about the shape of the earth, the author sheds light on what went on behind the scenes in the institutions of natural science in Paris and Berlin.

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Whewell, William. *Of the Plurality of Worlds.* Text of Whewell's original anonymously published bombshell with an introduction by the philosopher of science Michael Ruse. Includes Whewell's rebuttal of critics from the second edition and materials omitted from the text before it went to press.

Williams, L. Pierce. *The Origins of Field Theory*. Lanham, MD: University Press of America, 1989. An examination of the philosophical background of field theory as developed by Faraday and of its maturity in the 19th century.

Internet Resources:

An excellent starting point for research in the history of science is the website of the History of Science Society, whose general page is: http://www.hssonline.org/main_pg.html.

Specific resources are given at: http://www.hssonline.org/teach_res/hst/mf_hst.html.

Electronic databases, bibliographies, and Web sites are at: http://www.hssonline.org/teach_res/hst/mf_hst.html.